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Informal Settlement Characterization and Socio-Economic Vulnerability Assessment in Kolkata Metropolitan City, India

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Abstract

The study investigates the physical, social, and economic environment of the Kolkata Metropolitan Area (KMA) to elucidate the living conditions of informal settlements and its influence on the local environment using geoinformatics and multi-criteria decision making-analytical hierarchical process (MCDM-AHP). The informal settlements were delineated using high-resolution Google Earth imagery and generic ontology informal settlements. knowledge considering building characteristics, building density, locations of the dwelling units, and their characteristics. The study exhibits that most informal settlements were concentrated in the wards located in the eastern and central parts of the city. The neighborhood land-use functions of the major informal settlements indicated that the informal settlements were highly influenced by green space (R2=0.97), followed by water bodies (R2=0.74), unplanned settlement (R2=0.68) and planned settlement (R2=0.67) in KMA. In addition, the informal settlements were closely associated with very low relief zones (3m to 13m) followed by moderate relief zones (13-23m). The municipal ward-level analysis of the physical-socio-economic health conditions exhibited that most of the areas located in the low vulnerable zones (53.71 km^2; primarily in southern, and eastern periphery), followed by very highly vulnerable zones (43.09 km^2; primarily in central and northern parts). The study provides an insight into urban areas with special reference to informal settlements and necessitates the implication of effective policy for poverty alleviation. This study encourages the availability of real-time data that can improve mitigation activities in the event of a health disaster, such as SARS COVID-19 through methods for qualitative investigation of disadvantaged locations in Kolkata.

1. Introduction

The proliferation of informal settlements is a complex derivative of the organic development of growing cities (Marques & Saraiva, 2017). As per UN Habitat (2022), 20% of the global population resides in inadequate, crowded, and unsafe housing, out of which 1 billion live in slums and informal settlements and is expected to grow to 2 billion in the next 30 years, which represents roughly 183,000 people each day (Hughes et al., 2021). The factors that contribute to the formation and growth of informal settlements in urban areas include but are not limited to unprecedented population growth, an influx of rural migrants, uneven industrial development lack of employment opportunities, poverty, and inequalities, lack of building space, and concentration of land in few hands (Mahabir et al., 2016; Ministry of Housing & Urban Poverty Alleviation Government of India, 2013; Ooi & Phua, 2007; Tripathi, 2015; UN Habitat, 2003). In India, informal settlements in urban areas are amalgams of different linguistics, religions, and caste groups due to the inclusion of populations from diverse socio-economic backgrounds and regions (Schenk, 2010). These unplanned and unauthorized dwellings fail to provide adequate livable conditions due to various reasons such as dilapidation, overcrowding, the faulty arrangement of buildings and streets; lack of ventilation, light, sanitation facilities, safety and health, or a combination of these factors (Martínez et al., 2008; Ministry of Housing & Urban Poverty Alleviation Government of India, 2013).

The concept of informal settlements and its definition varies from country to region, its characteristics, the socio-economic conditions, dilapidated housing conditions; irrespective of location, be it the core or outskirts (Richter et al., 2011). Even within the same country slum definitions can vary among various degrees of administration (Patel et al., 2014). UN-Habitat defines informal settlements as areas that lack at least one of the amenities viz., a durable housing structure, access to clean water, sanitation with ample living space, and secure tenure (UN Habitat, 2003). The temporary roof structure- roof, walls, and floor, non-compliance with building codes, the dwelling near the toxic waste, flood plain, unstable slopes, and vulnerable sites are also other determining variables (UN Habitat, 2003). Metropolitan areas almost everywhere and especially in the cities of the 'Third World' are occupied by squatters near the city center (Mahabir et al., 2016). Slums have both positive and negative impacts on the physical, social as well as the economic health of urban environments. The dwellers are prone to health problems (Awadall, 2013; Riley et al., 2007) in many cities in developing countries, especially adolescents and young adults due to overcrowding (Satterthwaite, 1993).

The prevailing physical threat of dwellers from various disasters (United Nations Development Programme, 2012) and improper housing (Napier, 2007) is mainly due to the low enduring capacity of slum dwellers to revive and combat disasters, such as floods and earthquakes, compared with more formal communities (Ajibade & McBean, 2014; Braun & Aßheuer, 2011; Ebert et al., 2009). They create an unhealthy milieu (Dana, 2011; Kjellstrom et al., 2007) due to a lack of basic services, which results in contaminated soil, air, and water bodies as well as the overall urban environment at regional and national levels (Richter et al., 2011). This results in a perpetuated cycle of deterioration for both slum inhabitants as well as for the environment, with the plausibility of impacts extending to communities beyond the informal settlements (Ali & Sulaiman, 2006). Consequently, the growth and expansion of informal settlements deteriorate the sustainability of urban development at the local, and global level (Patel et al., 2012). The low literacy level of the slum people negatively affects the robustness of the urban environment socially as well as economically (Mahabir et al., 2016; Zaman et al., 2018). As they are deprived of proper education, there is a lack of awareness among the dwellers which later affects the economy of the urban area (Mahabir et al., 2016). Poor sanitation facilities act as the breeding grounds for pathogenic bacteria which causes serious health illness (Zaman et al., 2018). The high population density and complex social interactions in slum areas, with overcrowding, may result in health cataclysm (Patel & Burke, 2009) as evident in the case of COVID-19 in Dharavi Slum, Mumbai in April-May 2020. Consequently, this nature of housing and living conditions strongly affects all aspects of life in the squatter community. Due to the aggregation of census data at administrative units, the characteristics of individual slums become opaque (Kuffer et al., 2017).

Many scholars adopted various approaches and collected information on slums in order to characterize informal settlements such as participatory method (Hasan, 2006; Joshi et al., 2002; Lemma et al., 2006), integrating census data with GIS as well as analysis of very high-resolution satellite images for slum detection (Duque et al., 2018; Sliuzas et al., 2008), simulation models to understand the emergence and expansion of slums (Roy et al., 2014). The informal settlements can be differentiated in terms of their surface characteristics and texture variations, in the satellite images (Duque et al., 2015). The satellite images area then used to identify, classify, and monitor slums in both space and time, providing a deeper understanding of their physical manifestations in growing urban surfaces. Very high-resolution images can also be very appropriate to study the different characteristics of slum units at different scales more precisely (Hofmann, 2001; Kohli et al., 2012). Many methods such as cellular automata and agent-based models have been used to develop dynamic models to simulate and project the growth of urban areas (Tripathy & Kumar, 2019) and the evolution of slums (Roy et al., 2014). The usage of SAR images for urban mapping especially for slum area characterization has proliferated recently (Gamba et al., 2011; Kuffer et al., 2016). The nature of housing structure, other neighboring land surface features, neighborhood environment characteristics, and topography are vital components of ontology

(Hofmann, 2001; Kohli et al., 2012; Shekhar, 2013). The ontology reduces the semantic gap created in image interpretation (Durand et al., 2007) and contributes to the identification of features more precisely (Durand et al., 2007; Frank, 1997; Tomai et al., 2009). Generic slum ontology has been utilized using very high-resolution imagery such as Quick Bird, IKONOS Imagery, etc. to identify slum-dwelling units based on the structural compositions of the dwelling units (Kohli et al., 2012; UN Habitat, 2003).

The generic slum ontology (GSO) consists of characteristics at three spatial levels including object level, settlement level, and slum environment. However, remote sensing images have enhanced capacity to identify the physical and structural heterogeneity in such environments, which is not captured in census information (Weeks et al., 2007). However, satellite images cannot independently capture the socio-economic properties of dwellings and slums. Therefore, the amalgamation of the satellite image-based physical properties with census-based socio-economic properties is crucial in understanding the slum characteristics. Kolkata is one of the largest metropolitan cities in India, located in the eastern part of the country, which is an inchoate metropolis, where 32.9% of families are devoid of basic amenities. There are 0.2% of households in the slum areas of Kolkata, who suffer from extreme housing deprivation, i.e., lacking all of the five basic elements of housing including water, air, earth, light, and greenery (Patel et al., 2014). In 2011, 44,96,694 people were living in the city of Kolkata. Of those, 14,57,273 lived in informal settlements, which were distributed throughout 144 wards of the KMC (Kolkata Municipal Corporation), which accounts for 32.4% of the city's urban population (Ray, 2017). The city's informal settlements are most concentrated in the east along the Eastern Metropolitan bypass, in the north in the Cossipore area, and the west around the dock area. The rise in the informal population with a severe lack of basic services has an adverse impact on India's overall target to attain the water and sanitation sector (Ali & Islam, 2015).

Being a coastal city, together with its vast hinterland attracted multiple industries, which enhanced the scope of employment (Bhattacharya & Chatterjee, 1973; Ghosh, 2013). The informal settlements grew in central parts of Kolkata during the early urbanization of the British Raj with jute and other cotton factories in the suburbs (Kundu, 2003). The living condition in urban areas is profoundly influenced by the type of shanty towns and living conditions (Das et al., 2012). The growth of informal settlements in the city cannot be prevented as a result of excessive urbanization and rural poverty (Roy et al., 2014). Therefore, the physical and socio-economic characteristics are needed to analyze the informal settlements more accurately to devise a suitable urban development policy pertaining to poverty alleviation and healthier living conditions (Wekesa et al., 2011).

Thus, this study emphasizes the characterization of slums and analyzes the impact of urban functions on slum units in Kolkata. Further, the study focuses on the effect of relief on the slum locations and explains the impact of slum areas on the physio-socio-economic health of the urban environment. While much of the previous research focuses on the general causes of slum growth and lack of basic services (Das et al., 2012; Patel et al., 2014), this study offers a more nuanced approach by specifically characterizing slums in Kolkata through a combined analysis of their spatial distribution, relief patterns, and socio-economic impacts. Unlike other studies, which primarily concentrate on infrastructural deprivation, our research uniquely integrates an understanding of urban functions and how they intersect with slum distribution. By examining the role of relief (topography) in the formation and persistence of slums, this study fills a critical gap in the literature. Additionally, we explore the bidirectional relationship between slum areas and the physio-socio-economic health of the urban environment, contributing to the development of targeted policies for urban sustainability and poverty alleviation.

2. Data and Methods

2.1. Study Area

Kolkata is the capital of the state of West Bengal and one of the largest metropolitan cities in eastern India (Figure 1). It comprises the Kolkata Municipal Corporation (KMC) region and is located between 22⁰ 25' N to 23⁰39' N latitude and 88⁰15'E to 88⁰28'E longitude. It has a jurisdictional area of 187.33 km^2 and comprises 141 electoral wards, as shown in Figure 1. Kolkata has multiple active business centers including the Benoy-Badal-

Dinesh Bagh area, Burrabazar Area, Shobhabazar, Shyambazar, Chitpur, Esplanade, Park Street, Sudder Street, etc. Because the business centers are well spread across the city, residential areas including informal settlements are associated and spatially distributed in and around these economic centers.

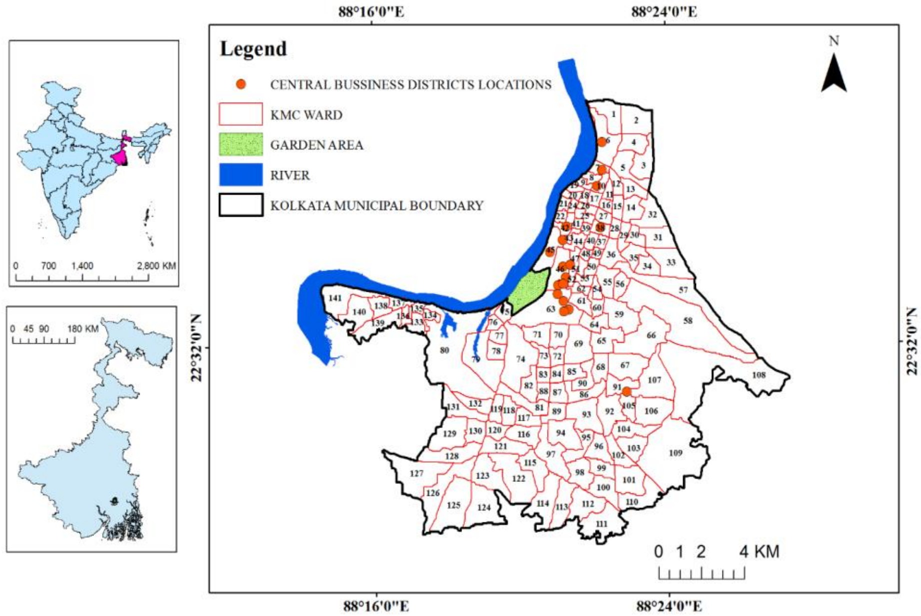

Figure 1. Location Map of Study Area Representing Kolkata Metropolitan Area in West Bengal, India (Dark blue color represents Ganga River)

2.2. Data

The study adopted the survey report of the Bustee (habitation) Department, KMA for the year 2001 was used. The survey report includes the house structure, sanitary condition, and various socio-economic variables including income, number of workers, etc. Remotely sensed data including Google Earth, Sentinel-2A, and ASTER Digital Elevation Model (DEM) were used. In addition, the ward-level census variables were also used (see Table 1). The data flow diagram and methods of this research are described in Figure 2.

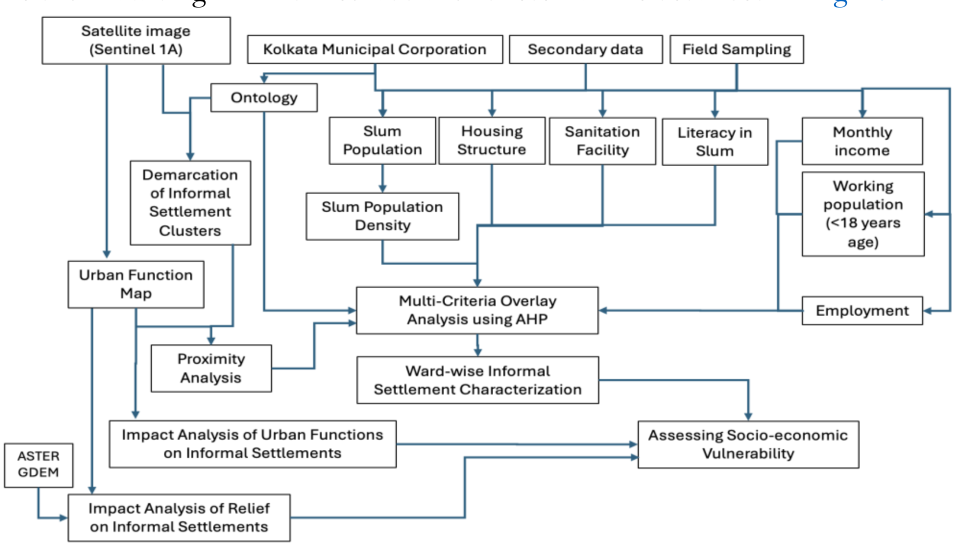

Figure 2. Methodology Flow Chart

2.2.1. Ontology-based Identification of Informal Settlements

Sentinel-2 satellite data and 2017 Google Earth imagery were used to identify and delineate informal settlement clusters across the KMA. A total of 127 slum pockets were delineated based on their image

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characteristics on the satellite image and then they were verified using Google Earth. The specification of the built form in the satellite imagery was carefully interpreted visually at three different levels, as mentioned in Table 2 as adopted from Kohli et al. (2012),

Table 1. Data Used in the Present Study

Data	Resolution	Source	Significance
Survey (2001)	Ward level	Kolkata Municipal Corporation	Demographic, physio-socio-economic aspects of informal settlements in each ward
Sentinel-2A (2017)	10m	European Space Agency[1]	Delineating informal settlements and monitoring spatio-temporal changes in land cover features
ASTER DEM	30m	United States Geological Survey[2]	Topography and relief profile of the landscape
Google Earth (2017)	5m	Google Earth desktop application	Cross-checking delineated polygons from Sentinel-2A and adding the left-out patches

Note: [1] https://scihub.copernicus.eu/dhus/ [2] http://earthexplorer.usgs.in/

Table 2. Observed Elements in the Satellite Images Related to Informal Settlement

Level	Observation
Environs	Surroundings of the settlement, i.e., its location with respect to neighboring land uses prominent land cover features
Settlement	Overall form/shape/density of the settlements
Object	Components of the settlement, such as characteristics of buildings and roads

Source: Kohli et al., 2012

2.2.2. Identifying Major Zones of Informal Settlements

To identify major clusters of informal settlements and analyze different land use functions in the vicinity, we conducted proximity analysis using the buffer tool with a 500 m radius. The resulting polygons were dissolved to generate larger polygons and a total of eight new polygons were generated. These polygons were treated as zones of major informal settlements and were labeled as A, B, C, D, E, F, G, and H for analysis in the present study (see Figure 5).

2.2.3. Analytical Hierarchical Process (AHP) for Urban Physio-Social-Economic Vulnerability Analysis

All the eight ward-level factors were assigned relative weights based on the respective number of classes such that a higher weight complements unfavorable health conditions with reference to physical, social, and economic characteristics of the informal settlements and vice-versa (Table 3). The weights were assigned based on an informed assumption, local field experience, as well as expertise based on the relative contribution of each class to the suitability of informal settlements within each ward. The individual weights were normalized using Satty's AHP technique (Saaty, 1980). The normalization process reduces the subjectivity associated with the assigned weights of the thematic maps and their features as recommended by Saaty (1980) to maintain consistency. The Consistency Ratio (CR) for each theme and unit, initially, principal Eigenvalue (λ) was computed by the Eigenvector technique followed by the Consistency Index (CI) (Equation 1) was calculated from the following Multi-Criteria equation (MCE) (Saaty, 1980):

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$$CI = (\lambda\_max - n) / (n - 1) \ldots\ldots\ldots\ldots\ldots \text{(Equation. 1)}$$

where n is the number of criteria. Using the above equation, the CR (Equation 2) was computed using (Saaty, 1980):

$$CR = CI / RCI \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Equation. 2)}$$

where RCI is an acronym for Random Consistency Index. CR value of less than 0.1 indicates good consistency (Saaty, 1980). If CR=0.1, the comparison is inconsistent and requires reconsideration of weights.

2.2.4. Ward level factors

The following information was compiled at the ward level and examined in order to describe the wards according to the state of the informal settlements and to comprehend how the latter interact with the environment (see Table 3).

Table 3. Description for the Ward Level Factors

Variables	Description
Number of informal settlements	The number of delineated informal settlements in each ward
Number of dwellers in the informal settlements	Population of informal residents was based on the survey report, KMA
Population density of the informal settlements	This was computed by dividing the total population of the informal settlements' clusters with the area covered by the informal settlement's clusters in that ward
Percentage of the kutcha and pucca houses	There are various types of housing structures in the informal settlements in Kolkata metropolitan area, which were primarily broadly classified into Kutcha houses and Pucca houses based on the dominance of the housing material used for house construction. The kutcha structure comprises roof materials and wall materials that vary from tile, tin to khapra (mud tiles) and thatched roof and 'mud' etc., respectively. Whereas, the Pucca structure consisted of hutments with a brick wall, cemented wall and RCC roof. The percentage of kutcha/ pucca houses is based on the total number of kutcha/ pucca houses with respect to total houses in KMA
Per capita sanitation facility	This is the sanitation facility per person in the informal settlements with respect to the total population of informal settlements in KMA
Percentage of literates	This is the number of literate persons expressed in percentage with respect to the total number of people in the informal household
Workers aged below 18	The number of workers below the age of 18 years
Land use function	This comprises various land use functions in the KMA obtained from Sentinel 2A. Google Earth and field-based information
Relief	The average elevation (in meters) of informal settlement patches within each ward. The elevation is from the mean sea level as obtained from the ASTER data

Note: All the parameters were normalized between zero to one such that the most significant zones get the highest value and vice-versa

2.2.5. Contributing Factors to Physio-Socio-Economic Health Vulnerability

Number of informal settlement patches: The number of informal settlements within a municipal ward represents the discreteness of the informal settlements and the influence of either geographic or socio-economic or both. The wards with a higher number of informal settlements will have a relatively higher population density and are less suitable with reference to the health of urban environments and vice-versa. Therefore, the wards with informal settlements clustered in the range >49 and 37-48 were assigned higher weightage with reference to the proliferation of poor and unhealthy environments (Table 3, Figure 8a). *Percentage of Kutcha Houses in clusters of informal settlements:* The presence of different types of kutcha houses in the urban areas poses obstruction with reference to the development of the urban areas, thus hampering the overall setting of the urban environment. Therefore, the wards with more percentage of kutcha houses i.e., 72-96 and more than 96 in the slum clusters result in poor urban health (Agarwal, 2011; Awadall, 2013; Gambo et al., 2012), thus are more vulnerable and have been given a higher weightage (Table 3, Figure 8g).

No. of persons per household in informal settlements: Overcrowding contributes to the growing psycho-social health problems of many urban dwellers in developing countries, especially adolescents and young adults (Satterthwaite, 1993). As the number of persons in a dwelling increase, the availability of necessary resources is compromised which leads to an unhealthy environment. Therefore, an informal settlement with a higher number of persons per household was given higher weightage and vice-versa (Table 3, Figure 8c).*Percentage of literate in informal settlements population:* The literacy of the people living in the informal settlements clusters is important for determining the social health condition of the urban environment in many ways such as better accomplishment of health and nutritional status, economic growth, and empowerment of the community (Lahon, 2017; Mahabir et al., 2016; Pawar & Mane, 2013). Thus, the wards with more than 50% of the literate in informal settlements' population will tend to provide a healthier environment, thus are more suitable and given lower weightage (Table 3, Figure 8d).

Per capita sanitation facility in informal settlements: Lack of access to sanitation leads to the presence of pathogenic microorganisms, which in turn affects health but also affects social and economic development (Awadall, 2013; Hanchett et al., 2003). Thus, the wards with poor sanitation facilities (i.e., per capita sanitation 0.04-0.08 and less than 0.04) were considered more vulnerable and unsuitable in terms of urban health (Agarwal, 2011) and have been given higher weightage (Table 3, Figure 8e). *Engagement of children of informal settlements for earning:* The poverty, lack of good schools, and growth of the informal economy were considered as the vital causes for engaging the children for earning. Thus, the wards with a higher number of children labor (workers below the age of 18 i.e., 70-100 and greater than 100) were more vulnerable and were given a higher weightage (Table 3, Figure 8f).

Relief of informal settlements: The informal settlements lying in low-lying areas are highly susceptible to waterlogging/ flood inundation (Braun & Aßheuer, 2011). Thus, the low-elevation zones are more vulnerable and have been given higher weightage and vice-versa (Table 3, Figure 8h). *LU Functions in the proximity of informal settlements:* Based on previous knowledge and examples from existing literature (Kundu, 2003; Shekhar & others, 2013; Uddin, 2018), places close to land-use functions including green space, waterbody, open-land, and institutions; are prone to the formation of informal settlements, were assigned a higher weightage. On the contrary, land use functions, which negatively influence the proliferation of informal settlements, were assigned lower weightage (Table 3, Figure 8i).

These ward-level factors were converted to raster layers of 30m cell size for high spatial accuracy. Each sub-class of each feature was assigned the respective Eigenvectors in their attribute table. Finally, the AHP-based normalized weighted maps were spatially accumulated in a GIS environment. The resulting map was reclassified into five classes, namely, 'very high', 'high', 'moderate', 'low', and 'very low' vulnerable zones with reference to the health of urban environments

Table 4. Normalized Weight based on AHP with Reference to the Health of Urban Environment Assigned to Various Classes of Input Parameters

Theme	Rank	Normalized Weight	Sub Class	Rank	Normalized Weight
Number of Slum units	1	0.17	<12	1	0.16
			13-24	3	0.29
			25-36	5	0.64
			37-48	7	1.23
			>49	9	2.68
Percentage of Kutcha Houses	7	1.5	<24	1	0.18
			24-48	3	0.3
			48-72	5	0.54
			72-96	7	1.26
			>96	9	2.72
Population Density	3	0.34	<0.066	1	0.18
			0.06-0.13	3	0.32
			0.13-0.19	5	0.56
			0.19-0.24	7	1.2
			>0.24	9	2.75
Percentage of literate in slum population	4	0.49	>80	1	0.16
			60-80	3	0.29
			40-60	5	0.53
			20-40	8	1.36
			<20	9	2.65
Per Capita Sanitation	5	0.71	>0.16	1	0.16
			0.12-0.16	3	0.3
			0.08-0.12	5	0.56
			0.04-0.08	7	1.26
			<0.04	9	2.72

Theme	Rank	Normalized Weight	Sub Class	Rank	Normalized Weight
Number of workers (under 18 years age)	6	1.04	<10	1	0.16
			10-40	3	0.3
			40 - 70	5	0.55
			70 - 100	7	1.29
			>100	9	2.7
Relief	8	2.13	>43	1	0.17
			33-43	3	0.3
			23-33	5	0.6
			13-23	7	1.31
			<13	9	2.62
Land use Functions	9	2.98	Others	1	0.16
			Green Space	1	0.18
			Water Bodies	2	0.19
			Institutional	3	0.26
			Cantonment	4	0.36
			Industrial	5	0.42
			Administrative	5	0.61
			Historical	5	0.66
			Service Sector	6	0.97
			Mixed	7	1.21
			Planned Residential	8	1.48
			Commercial	8	1.86
			Unplanned Residential	9	2.4
			Slum Areas	9	2.84

3. Results

The study describes the ward-level characterization of informal settlements, the distribution and interaction of different land-use functions with informal settlements, and the analysis of vulnerability zones.

3.1. Characterization of Wards based on Informal Settlements

3.1.1. Number of Informal Settlements Clusters

The study indicated that the informal settlements were distributed unevenly in the different wards of KMA (Figure 3a and b). A very high number of informal settlement clusters (i.e., number of informal settlements >49) was observed in the ward located at the eastern part of KMA (ward no. (WN) 66). Followed by wards located in the western parts (WN 58 and 73), comprising a high number of informal settlement clusters (37-48). The moderate occurrence of informal settlement clusters was explicitly located in the central (WN 65) and southwestern parts (WN 82). The remaining wards of the city had low (13-24) and very low (<12) occurrence of informal settlement clusters.

3.1.2. Population Distribution

The spatial distribution of population in informal settlements (Figure 3b) exhibited a high population density (population density > 0.24) throughout the city and there are only three wards without any clusters of informal settlements (WN 42, 45, 87). The high (> 0.24) to very high population density (0.19-0.24) of informal dwellers was observed in the wards located in north-west directions. Whereas the moderate population density (0.13-0.19) of informal dwellers was found in the wards located in the northern and central parts (WN 40, 28, 69, 90) of KMA. The remaining wards consisted of the lowest population density (<0.06) of informal dwellers.

3.1.3. Physical Conditions of the Informal Dwellers

The wards were categorized based on the percentage of kutcha houses into five major classes, viz., very high (>96), high (72-96), moderate (48-72), low (24-48), and very low (<24) (Figure 3c). Most wards were found to have a higher percentage of kutcha houses (72-96 and >96). The low percentage of kutcha houses (<24) were found in four wards (42,45,67,87), located at the western, eastern, and central parts of the KMA. The moderate concentration of Kutcha houses (48-72) was observed in a few wards located in the southern and southeastern periphery. It was observed that the wards comprising active business centers have a high concentration (72-96) of kutcha houses mainly in the Central parts of KMA. In a few remaining wards, the concentration of kutcha houses was observed very high. On the contrary, the availability of sanitation facilities for informal dwellers in all the wards is poor (less than 1.2) (Figure 3d). There is only one ward, in which the condition is good (greater than 1.6 in ward number 101). The poor defecation facility leads to the poorer environment of the informal settlements' areas and the nearby areas, which give rise to various health problems.

3.1.4. Economic Condition of Dwellers of the Informal Settlements

The study indicates the dominance of the wards in medium (42.89 to 64.33 USD i.e., Rs. 3200 to Rs.4800) and low-income (Rs.1600-3200) groups. Very low- (Rs. <1600) and low-income groups were mainly located in the southern, eastern, and northern parts, respectively (Figure 3e). While the medium groups are mostly centered in the central, and western peripheral parts of Kolkata. So, the informal settlement dwellers of the extreme peripheral wards of the city belong to a low-income group and are below the poverty line, whereas informal settlement dwellers located in the wards of the central part of the city were in a better condition (Rs. >4800).

3.1.5. Literacy Rate in Informal Settlements

In informal settlements, the literacy rate is much affected by poverty. (Figure 3f). The study revealed that a very low and low (20%-40%) literacy rate was found in only 9.9% of the wards (14 out of 141 wards). In the remaining wards, a medium to very high literacy rate (>80%) was observed. It is evident that moderate (40%-60%) to high (60%-80%) literacy rate was found in 112 wards out of 141.

3.1.6. Social Condition of Informal Settlements (based on the Engagement of Children in Earning)

There were only 7.09% (10 wards out of 141) wards in KMA that have moderate to very high numbers of children (age <18 years) engaged in earning in the slum clusters. The very high (100) to high numbers (70-100) of child workers (aged below 18 years) were found in the wards located in upper central, central, and southern parts followed by moderate numbers of child workers in the central and western parts of KMA. (Figure 3g). It is revealed from the map of the percentage of total earning members in informal settlements (Figure 3h) that the highest concentration of earning or employed informal settlement dwellers (>44%) are situated in the upper central part of the city. The concentration of earning members was observed primarily in low to very low in central, western, and northern parts.

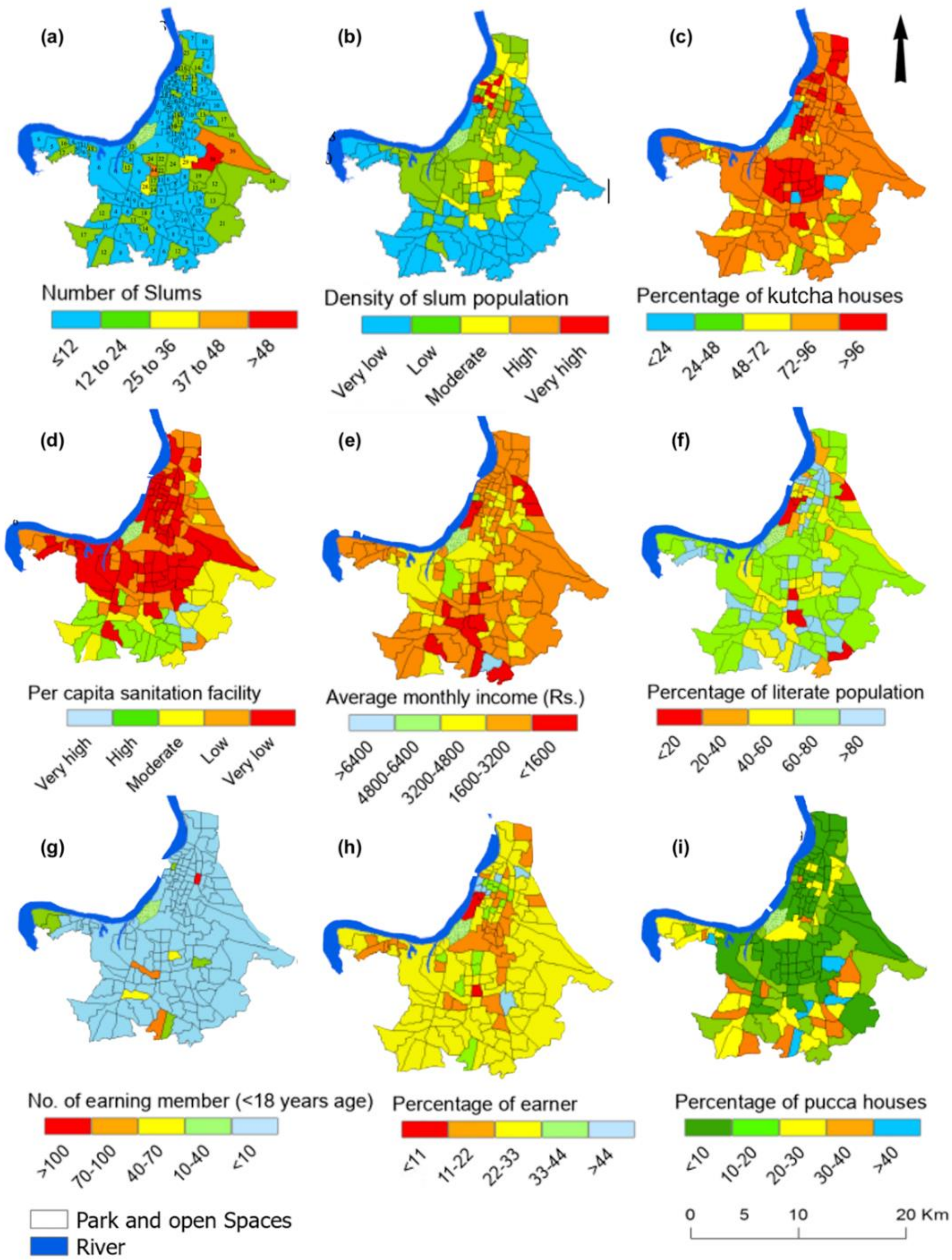

Figure 3. Ward-wise distribution map representing (a) number of slum clusters, (b) population density, (c) percentage of kutcha houses, (d) per capita sanitation facility, (e) average monthly income, (f) total literates, (g) number of below 18 age workers, (h) percentage of total earning members, (i) percentage of pucca houses, in the slums of Kolkata municipal corporation

3.2. Land-Use Functions

To study the characteristics of the informal settlement discreetly, the major informal settlement areas and urban land-use (LU) function were delineated. The study exhibits that a major part of the city is occupied with unplanned residential areas (52.5% of KMA), followed by green spaces (27.3%) comprising vegetation and agricultural lands, with the intrusion of unplanned settlements in between (Figure 4). The central part of the city consists of the commercial areas and the administrative units covering 4.06% of KMA (6.91 km^2) (Table 4). The industrial areas (4.53%) are mainly located in the western part, along the periphery of the Hugli River and the eastern part of the city. The service sector (0.70%), which comprises the dock areas and other transportation services, is near the Hugli River as well as yards of railways and trams (Table 4). The water bodies and wetlands are primarily located in the eastern part of the city along with green spaces. Kolkata is well distributed with small water bodies within the city except for the CBD patches. Ponds and lakes occupy ~4.85% of KMA (8.77 km^2) (Table 4). The mixed land used functions (2.25%) comprising both commercials along with residential areas, banks, institutes, hospitals, etc. cover mostly the central and western part of the city. The rest of the region is classified as others (1.89%) including the major open spaces, vacant and arable lands of the city which mainly occupy the areas along the canal and the wetlands of the eastern fringe.

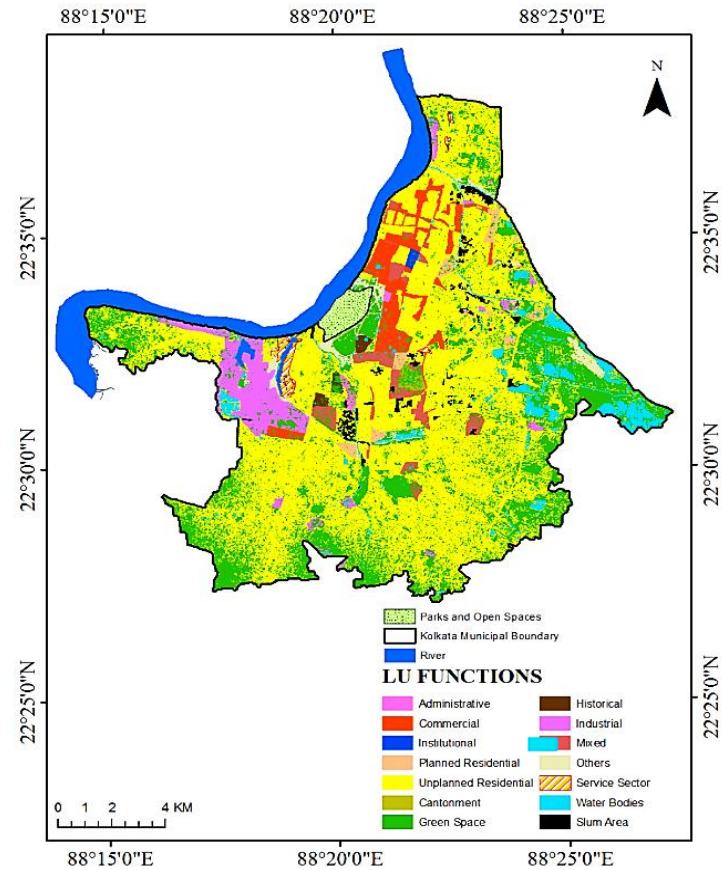

Figure 4. Major Land Use Functions in Kolkata

Table 5. Area Statistics of the Land Use Functions in KMC

LULC Functions	Area (km^2)
Administrative	0.42
Commercial	6.92
Planned Residential	2.05
Unplanned Residential	94.98
Institutional	0.24
Mixed	4.06
Cantonment	0.41
Historical	0.66
Green space	49.41
Industrial	8.19
Service sector	1.26
Water bodies	8.77
Others	3.42
Total	**180.78**

3.3. Geospatial Analysis of Land Use Functions within the Proximity of Informal Settlements

The buffer zones of major clusters of informal settlements (A, B, C, D, E, F, G, and H) were examined with their associated land-use functions, both, spatially and statistically to deduce the level of control of various urban functions on formation and propagation of informal settlements (Figure 5). Pearson's correlation coefficient (r) was computed for different land-use functions and informal settlement dwellers based on the data tabulated in Table 6.

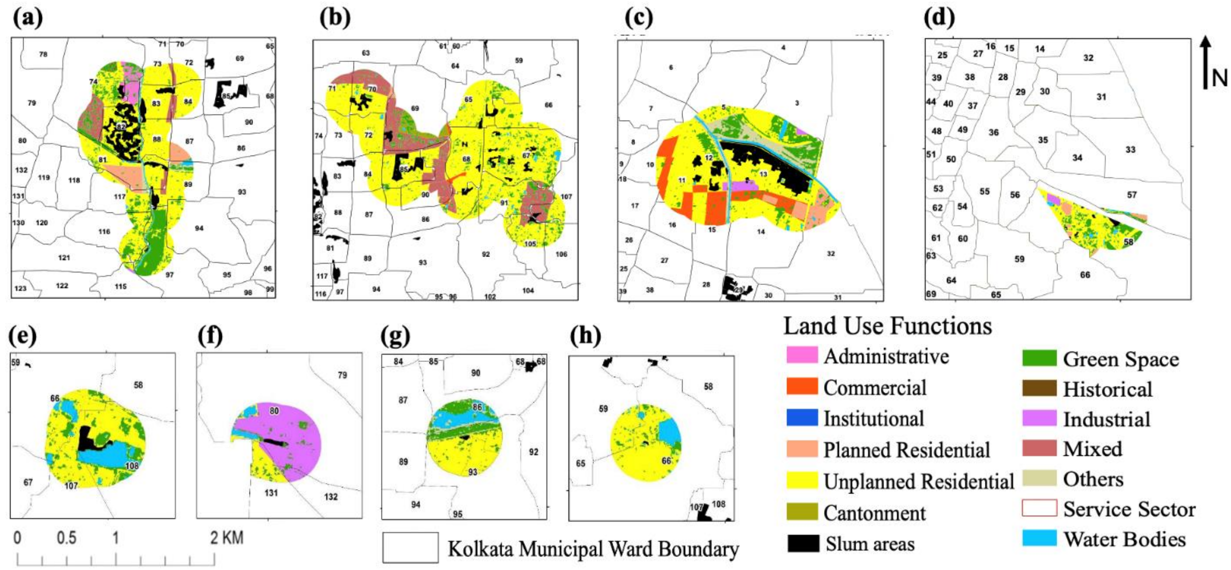

Figure 5. Major Land Use Functions in the Proximity of the Slum Areas of (a) Zone A, (b) Zone B, (c) Zone C, (d) Zone D, (e) Zone E, (f) Zone F, (g) Zone G, and (h) Zone H

Table 6. Quantitative Analysis of the Control of Different Land Use Functions on Geographical Distribution of Informal Settlement (Slum)

LULC Functions	R Value	Control Level w.r.t Slum Formation
Planned Settlement	0.67	Moderate
Unplanned Settlement	0.68	Moderate
Water Bodies	0.74	Major
Green Space	0.97	Major
Industries	0.003	Very Less
Mixed	0.002	Very Less
Service	0.00	Very Less
Educational	0.00	Very Less
Historical	0.0004	Very Less
Cantonment	0.00	Very Less
Others	0.22	Less

The very high correlation of informal settlements was observed with green spaces (R=0.97), followed by water bodies (R = 0.74) exhibiting the major control level of these land-use functions on slum formation and proliferation. Also, a high correlation of informal settlements was observed with unplanned settlements (R= 0.68) and planned settlements (R=0.67) (Figure 6). The commercial zones and informal settlement dwellers are also related to a good correlation value of R =0.60. In contrast, the association of informal settlements with the industrial areas was very poor (R=0.003).

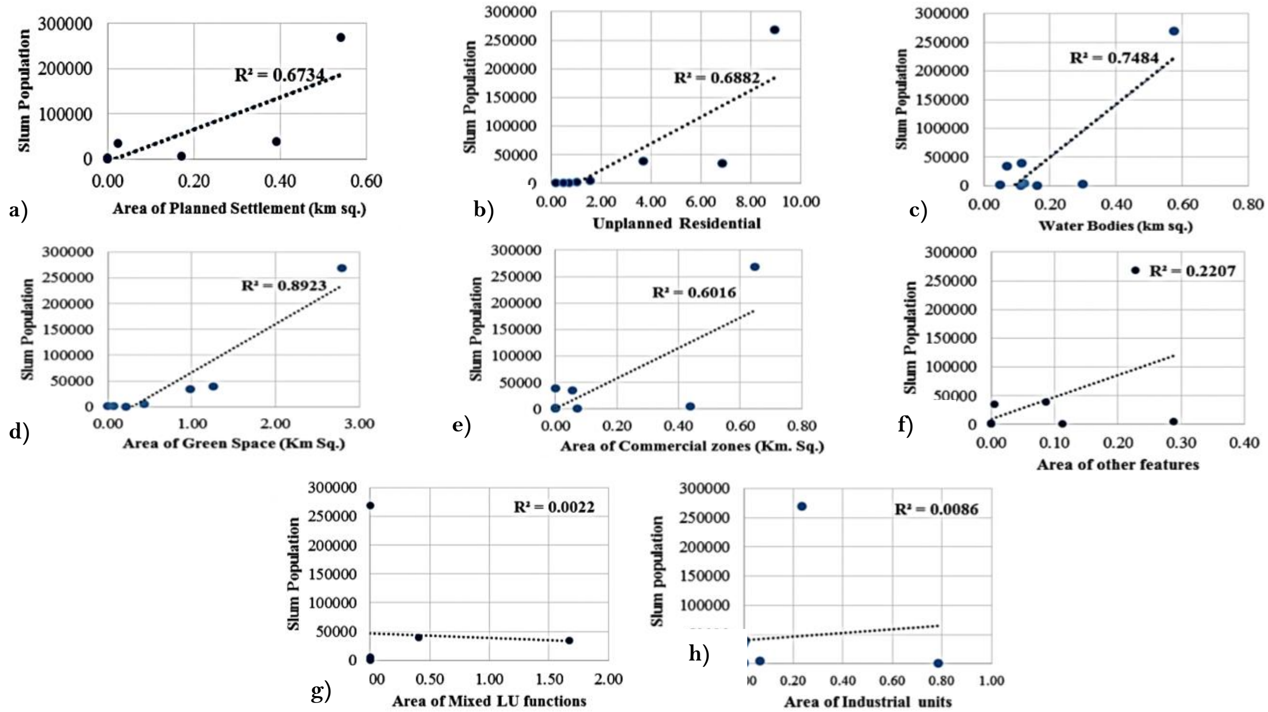

Figure 6. Graph showing Correlation between slum population and (a) planned settlement, (b) unplanned residential, (c) water bodies, (d) green space, (e) commercial area, (f) other features, (g) mixed land use, (h) industrial Area

3.4. Topographical Influence Over Informal Settlements

The relief of buffer zones of major informal settlement clusters was analyzed to study the influence of relief over the proliferation of informal settlements (Figure 7). Although the overall relief of the Kolkata metropolitan area was low (3-51 meters above MSL) due to its proximity to the Bay of Bengal, the informal settlement clusters are confined to the relief zones ranging between 3m to 23m. Most of the informal settlement units are confined to the lowest relief (<13m).

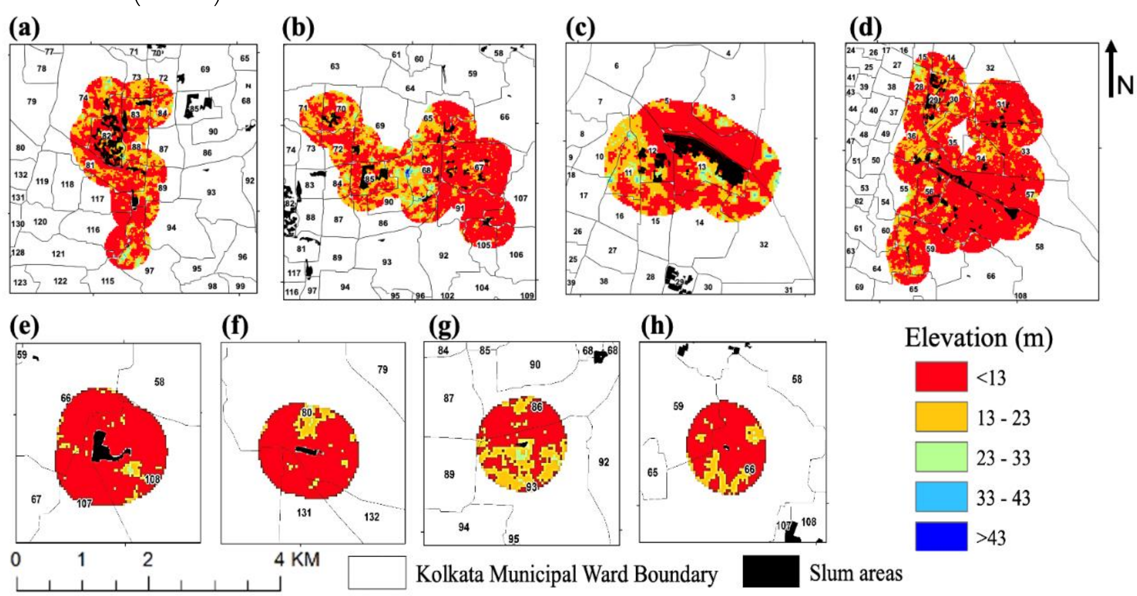

Figure 7. Relief variation in the proximity of the slum areas of (a) Zone A, (b) Zone B, (c) Zone C, (d) Zone D, (e) Zone E, (f) Zone F, (g) Zone G, and (h) Zone H.

3.5. Urban Physio-Socio-Economic Vulnerability Modelling

Various parameters related to informal settlement characteristics, LU function, and topographical variability were employed to deduce the physio-socio-economic vulnerable zones in KMA using AHP and GIS (Figure 8). The resultant zones exhibit that the major parts have moderate (37.80 km^2) to low vulnerability (53.71 km^2), primarily comprising western, southern to eastern parts of KMA (Figure 9). Contrary the high and very highly vulnerable (70.26 km^2) zones were located in the central, northern, and northeastern parts of the city. While the southern and eastern peripheral areas were the least (20.35 km^2) vulnerable in terms of the physical, social, and economic deprivation and health of the urban environment.

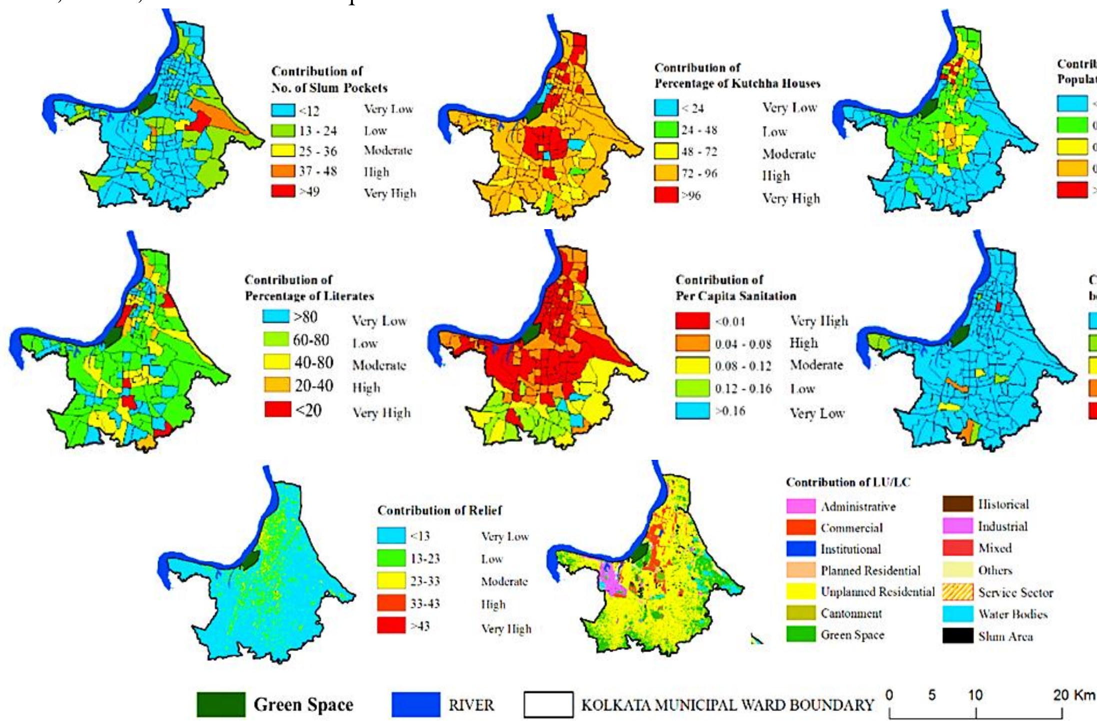

Figure 8. Contribution of (a) No. of slum clusters, (b) Percentage of kutcha houses, (c) Population Density, (d) Percentage of Literates, (e) Per capita sanitation, (f) Workers below 18 years of age, (g) Relief, (h) Land Use Functions to Urban Health Condition within the Municipal Wards of Kolkata Municipal Boundary

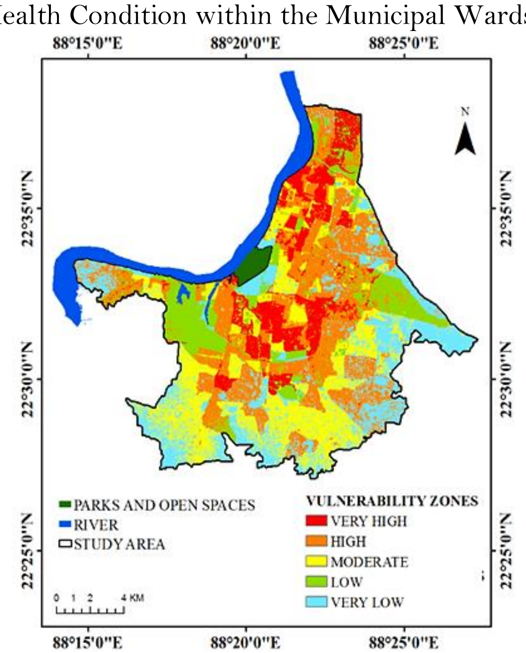

Figure 9. Urban Physical-Socio-Economic Vulnerability in the Kolkata Metropolitan Area

4. Discussion

The high concentration of informal settlements and high density of slum dwellers in eastern and central parts may be attributed to the availability of required vacant space in proximity to the workplace of dwellers. The nature of the distribution of the informal settlement population implies that the density of the informal settlements' population varies inversely with the distance from the city's geographical center, barring very few exceptions (Mahabir et al., 2016). This can be attributed to a large number of CBDs or economic centers (multiple nuclei) in and around the Kolkata Metropolitan Area. The very high proportion of kutcha houses in most of the informal settlements (primarily in the central and the northern parts) of KMA represents lower socio-economic conditions of the informal settlements. Despite a higher literacy rate in all the informal settlement clusters, the lack of proper sanitation facilities is evident, which complements poor health and morbidity due to infections in urban areas in many ways (Kundu, 2003). The central part of the KMA, with intense commercial activities, affords higher informal occupations to slum dwellers as compared to the periphery. Although the poor economic conditions compel the majority of family members to work, the number of children (age <18 years) engaged in earning was very less, and the latter were mostly associated with industrial activities.

In Kolkata, the very high association of informal settlements with green spaces and water bodies corroborated the higher suitability of such dwelling units under tree shades and water bodies, which provide a natural roof to solar insulation and rain, and base for constructing houses (Gopal & Nagendra, 2014; Kohli, 2015). The blue-green zones are vacant land, primarily owned by the government, and are the least interference sites for informal dwellers. These zones are often vulnerable and overlooked sites; as evident in KMA, most of them are the low-lying relief zones (<13m) that are prone to flooding caused by frequent cyclones and heavy rainfall (Bose & Ghosh, 2015; Braun & Aßheuer, 2011; Jha & Bairagya, 2013). On the other hand, the proximity of the blue-green zones to the water bodies, increases the risk of hygiene, triggering water-borne diseases like malaria, cholera etc. The high correlation of informal settlements with unplanned and planned settlements indicates the high plausibility of informal job and service opportunities, whereas the dwellers in proximity to commercial zones probably could not afford to bear daily transport charges to reach residential areas for job opportunities.

The high physio-socio-economic vulnerability in central and northern parts of KMA indicated the poor socio-economic condition of slum dwellers thereby affecting the local urban environment. It is crucial to understand the vulnerability of informal settlements, with complex informal social intersections, to any typical disaster or pandemic due to poor infrastructure and economic conditions. An example is evident during the outbreak of COVID-19, which has disrupted the economy human health, and livelihood at local to global scales (Lal et al., 2020). The cataclysm affected the dwellers of Dharavi slum of Mumbai during April-May 2020 with the meteoric upheaval of the number of positive cases in a very short period (PTI, 2020). Similarly, a few densely populated slums in north Kolkata observed a rapid turn into COVID-19 hotspots during April-May 2020, complemented by the lack of space (Basu, 2020). The findings of the present study about the socio-economic health vulnerability of informal dwellers are crucial to understanding and mitigating COVID-19 hotspots.

The integration of high-resolution Google Earth imagery with the generic ontology of informal settlements in the present study based on geoinformatics and multi-criteria decision-making-analytical hierarchical process (MCDM-AHP), allows for a better understanding of the environment of informal settlements within the Kolkata Metropolitan Area (KMA). Moreover, the study establishes a strong correlation between informal settlements and their proximity to environmental features, which highlights how land use and the natural environment impact the distribution and conditions of informal settlements. The study also highlights the influence of geography on settlement patterns and suggested a differentiated risk profile across the municipal wards. These findings offer valuable insights for urban planning and policymaking, especially in addressing the challenges of informal settlements and improving living conditions in vulnerable areas.

5. Conclusion

The present study aimed at analyzing the physio-socio-economic settings of the Kolkata Metropolitan Area (KMA) through a geoinformatics approach and applying a multi-criteria decision-making-analytical hierarchical process (MCDM-AHP) to further explain the living conditions of informal settlements (slum dwellers) and its influence on the local environment. In the present study, informal settlement clusters were delineated using ontological properties and were used to characterize the urban area (municipal wards) based on its physio-socio-economic condition using geoinformation. While the informal settlement concentration was observed mostly in the peripheral areas, the population density of informal settlement dwellers was concentrated in the central part of the city. The city core witnesses the lowest percentage of pucca houses in informal settlements and low per capita sanitation facilities, primarily in the wards lying along the Hugli River in southern parts of the city. Although the per capita income of informal settlement inhabitants was low, the level of literacy is moderately higher, and the percentage of children engaged in work is very low in many of the informal settlement clusters located in northern, eastern, and southern parts of KMA.

The present study asserts a high correlation of informal settlement clusters with the water bodies and green space. The finding was corroborated by the geographical locations of most of the informal settlements in the low-lying areas (<4 m). The study exhibited that the highly vulnerable zones in KMA are in the central parts and northern parts, whereas the southern, eastern, and western peripheral areas were mostly low vulnerable zones. However, the study had some limitations, the use of a generic ontology for informal settlements, considering factors such as building density and characteristics, may overlook unique, location-specific factors that vary spatially. These generalized assumptions might not fully reflect the diversity of informal settlements across the Kolkata Metropolitan Area (KMA). The study also has not considered other significant parameters such as social networks, local governance, or environmental hazards like flooding, which can also impact living conditions.

Future studies may incorporate such factors and can also investigate the vulnerability of informal settlements to climate change, particularly considering flood risk, heatwaves, and sea-level rise, given that many of these settlements are in low-lying areas of Kolkata. Following the COVID-19 pandemic, future research could assess how informal settlements have adapted to the challenges posed by health crises and what strategies have emerged to improve resilience against future pandemics or similar disruptions. This may also include studying the role of government and non-governmental organizations in crisis mitigation. Future research needs to explore the integration of informal settlements in sustainable urban planning for more comprehensive policies, although improvements have been made. The study necessitates site-specific informal settlement redevelopment strategies to improve the conditions of informal settlement dwellers and the urban environment. It is recommended that measures to improve the status of slums should include raising awareness and increasing community participation wherever possible. In addition, the study encourages the timely availability of data, which can ameliorate mitigation activities in the event of cataclysms, such as COVID-19.

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7. References

Agarwal, S. (2011). The state of urban health in India; comparing the poorest quartile to the rest of the urban population in selected states and cities. *Environment and Urbanization*, *23*(1), 13–28. [Crossref]

Ajibade, I., & McBean, G. (2014). Climate extremes and housing rights: A political ecology of impacts, early warning and adaptation constraints in Lagos slum communities. *Geoforum*, *55*, 76–86. [Crossref]

Ali, J., & Islam, J. (2015). Slums as a barrier to urban development in Kolkata a case study of urban planning. *Indian Journal of Spatial Science*, *6*(2), 1–9.

Ali, M. H., & Sulaiman, M. S. (2006). The causes and consequences of the informal settlements in Zanzibar. *XXIII Congress of the International Federation of Surveyors, Munich, Germany*. *https://www. fig. net/resources/proceedings/fig_proceedings/fig2006/papers/ts35/ts35_01_ali_sulaiman_0320. pdf*

Awadall, H. I. (2013). Health effect of slums: A consequence of urbanization. *Scholarly Journal of Medicine*, *3*(1), 7–14.

Basu, J. (2020). *COVID-19: Does Kolkata face community transmission*. Down To Earth. https://www.downtoearth.org.in/health/covid-19-does-kolkata-face-community-transmission-70586

Bhattacharya, N., & Chatterjee, A. K. (1973). Some characteristics of jute industry workers in Greater Calcutta. *Economic and Political Weekly*, 297–308. [Crossref]

Bose, R., & Ghosh, S. (2015). Slums in Kolkata: A socio-economic analysis. *The Empirical Econometrics and Quantitative Economics Letters*, *3*(3), 134–148.

Braun, B., & Aßheuer, T. (2011). Floods in megacity environments: vulnerability and coping strategies of slum dwellers in Dhaka/Bangladesh. *Natural Hazards*, *58*(2), 771–787. [Crossref]

Dana, T. (2011). Unhygienic living conditions and health problems: a study in selected slums of Dhaka city. *OIDA International Journal of Sustainable Development*, *2*(11), 27–34.

Das, B., Khara, U., Giri, P., & Bandyopadhyay, A. (2012). The Challenge of Slum Development in India: A Case Study of Meltala-Dasnagar Slum Area of Howrah Municipal Corporation. *Int. J. Adv. Syst. Soc. Eng. Res*, *2*, 22–27.

Duque, Juan C, Patino, J. E., Ruiz, L. A., & Pardo-Pascual, J. E. (2015). Measuring intra-urban poverty using land cover and texture metrics derived from remote sensing data. *Landscape and Urban Planning*, *135*(1), 11–21. [Crossref]

Duque, Juan Carlos, Vélez-Gallego, M. C., & Echeverri, L. C. (2018). On the Performance of the Subtour Elimination Constraints Approach for the p -Regions Problem: A Computational Study. *Geographical Analysis*, *50*(1), 32–52. [Crossref]

Durand, N., Derivaux, S., Forestier, G., Wemmert, C., Gancarski, P., Boussaid, O., & Puissant, A. (2007). Ontology-Based Object Recognition for Remote Sensing Image Interpretation. *19th IEEE International Conference on Tools with Artificial Intelligence(ICTAI 2007)*, *1*, 472–479. [Crossref]

Ebert, A., Kerle, N., & Stein, A. (2009). Urban social vulnerability assessment with physical proxies and spatial metrics derived from air- and spaceborne imagery and GIS data. *Natural Hazards*, *48*(2), 275–294. [Crossref]

Frank, A. U. (1997). Spatial ontology: A geographical information point of view. In *Spatial and temporal reasoning* (pp. 135–153). Dordrecht: Springer Netherlands.

Gamba, P., Du, P., Juergens, C., & Maktav, D. (2011). Foreword to the Special Issue on "Human Settlements: A Global Remote Sensing Challenge." *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *4*(1), 5–7. [Crossref]

Gambo, Y. L., Idowu, O. B., & Anyakora, I. M. (2012). Impact of poor housing condition on the economy of the urban poor: Makoko, Lagos State in view. *Journal of Emerging Trends in Economics and Management Sciences*, *3*(4), 302–307.

Ghosh, S. (2013). Regional disparities of slums, 2013—An overview with special emphasis to Kolkata. *International Journal of Humanities and Social Science Invention*, *2*(3), 48–54.

Gopal, D., & Nagendra, H. (2014). Vegetation in Bangalore's Slums: Boosting Livelihoods, Well-Being and Social Capital. *Sustainability*, *6*(5), 2459–2473. [Crossref]

Hanchett, S., Akhter, S., Khan, M. H., Mezulianik, S., & Blagbrough, V. (2003). Water, sanitation and hygiene in Bangladeshi slums: an evaluation of the WaterAid– Bangladesh urban programme. *Environment and Urbanization*, *15*(2), 43–56. [Crossref]

Hasan, A. (2006). Orangi Pilot Project: the expansion of work beyond Orangi and the mapping of informal settlements and infrastructure. *Environment and Urbanization*, *18*(2), 451–480. [Crossref]

Hofmann, P. (2001). Detecting informal settlements from IKONOS image data using methods of object oriented image analysis-an example from Cape Town (South Africa). *Jürgens, C.(Ed.): Remote Sensing of Urban Areas/Fernerkundung in Urbanen Räumen*, 41–42.

Hughes, B. B., Hanna, T., McNeil, K., Bohl, D. K., & Moyer, J. D. (2021). Pursuing the sustainable development goals in a world reshaped by COVID-19. *New York, NY and Denver, CO: United Nations Development Programme and Frederick S. Pardee Center for International Futures*. [Crossref]

Jha, C. V, & Bairagya, H. (2013). Flood and flood plains of West Bengal, India: A comparative analysis. *Revista Geoaraguaia*, *3*(1), 1–10.

Joshi, P., Sen, S., & Hobson, J. (2002). Experiences with surveying and mapping Pune and Sangli slums on a geographical information system (GIS). *Environment and Urbanization*, *14*(2), 225–240. [Crossref]

Kjellstrom, T., Friel, S., Dixon, J., Corvalan, C., Rehfuess, E., Campbell-Lendrum, D., Gore, F., & Bartram, J. (2007). Urban Environmental Health Hazards and Health Equity. *Journal of Urban Health*, *84*(S1), 86–97. [Crossref]

Kohli, D. (2015). *Identifying and classifying slum areas using remote sensing* [University of Twente]. [Crossref]

Kohli, D., Sliuzas, R., Kerle, N., & Stein, A. (2012). An ontology of slums for image-based classification. *Computers, Environment and Urban Systems*, *36*(2), 154–163. [Crossref]

Kuffer, M., Pfeffer, K., & Sliuzas, R. (2016). Slums from Space—15 Years of Slum Mapping Using Remote Sensing. *Remote Sensing*, *8*(6), 455. [Crossref]

Kuffer, M., Pfeffer, K., Sliuzas, R., Baud, I., & Maarseveen, M. (2017). Capturing the Diversity of Deprived Areas with Image-Based Features: The Case of Mumbai. *Remote Sensing*, *9*(4), 384. [Crossref]

Kundu, N. (2003). The Case of Kolkata, India. *Understanding Slums: Case Studies for the Global Report on Human Settlements*.

Lahon, S. (2017). Educational status and level of health awareness of the children of urban slums with special reference to Guwahati city-A study. *International Journal of Applied Research*, *3*(3), 680–686.

Lal, P., Kumar, A., Kumar, S., Kumari, S., Saikia, P., Dayanandan, A., Adhikari, D., & Khan, M. L. (2020). The dark cloud with a silver lining: Assessing the impact of the SARS COVID-19 pandemic on the global environment. *Science of The Total Environment*, *732*, 139297. [Crossref]

Lemma, T., Sliuzas, R., & Kuffer, M. (2006). A participatory approach to monitoring slum conditions: an example from Ethiopia. *Participatory Learning and Action*, *54*(1), 58–66.

Mahabir, R., Crooks, A., Croitoru, A., & Agouris, P. (2016). The study of slums as social and physical constructs: challenges and emerging research opportunities. *Regional Studies, Regional Science*, *3*(1), 399–419. [Crossref]

Marques, E., & Saraiva, C. (2017). Urban integration or reconfigured inequalities? Analyzing housing precarity in São Paulo, Brazil. *Habitat International*, *69*, 18–26. [Crossref]

Martínez, J., Mboup, G., Sliuzas, R., & Stein, A. (2008). Trends in urban and slum indicators across developing world cities, 1990–2003. *Habitat International*, *32*(1), 86–108. [Crossref]

Ministry of Housing & Urban Poverty Alleviation Government of India. (2013). *State of slums in India: A statistical Compendium 2013*. [Crossref]

Napier, M. (2007). Informal settlement integration, the environment and sustainable livelihoods in sub-Saharan Africa. *Council for Scientific & Industrial Research in South Africa*.

Ooi, G. L., & Phua, K. H. (2007). Urbanization and Slum Formation. *Journal of Urban Health*, *84*(S1), 27–34. [Crossref]

Patel, A., Crooks, A., & Koizumi, N. (2012). Slumulation: An Agent-Based Modeling Approach to Slum Formations. *Journal of Artificial Societies and Social Simulation*, *15*(4), 2. [Crossref]

Patel, A., Koizumi, N., & Crooks, A. (2014). Measuring slum severity in Mumbai and Kolkata: A household-based approach. *Habitat International*, *41*, 300–306. [Crossref]

Patel, R. B., & Burke, T. F. (2009). Urbanization — An Emerging Humanitarian Disaster. *New England Journal of Medicine*, *361*(8), 741–743. [Crossref]

Pawar, D. H., & Mane, V. D. (2013). Socio-economic status of slum dwellers with special reference to women: Geographical investigation of Kolhapur Slum. *Research Front*, *1*(1), 69–72.

PTI. (2020). *Tally of Dharavi's COVID-19 patients up by 50 to 783*. The Week. https://www.theweek.in/wire-updates/national/2020/05/07/bom28-mh-virus-dharavi.html

Ray, B. (2017). Quality of life in selected slums of Kolkata: a step forward in the era of pseudo-urbanisation. *Local Environment*, *22*(3), 365–387. [Crossref]

Richter, C., Miscione, G., De', R., & Pfeffer, K. (2011). Enlisting SDI for urban planning in India: Local practices in the case of slum declaration. In *Spatial data infrastructures in context*.

Riley, L. W., Ko, A. I., Unger, A., & Reis, M. G. (2007). Slum health: Diseases of neglected populations. *BMC International Health and Human Rights*, *7*(1), 2. [Crossref]

Roy, D., Lees, M. H., Palavalli, B., Pfeffer, K., & Sloot, M. A. P. (2014). The emergence of slums: A contemporary view on simulation models. *Environmental Modelling & Software*, *59*, 76–90. [Crossref]

Saaty, T. L. (1980). The analytic hierarchy process (AHP). *The Journal of the Operational Research Society*, *41*(11), 1073–1076.

Satterthwaite, D. (1993). The impact on health urban environments. *Environment and Urbanization*, *5*(2), 87–111. [Crossref]

Schenk, W. C. (2010). Slum diversity in Kolkata. *Columbia Undergraduate Journal of South Asian Studies*, *1*(2), 91–108.

Shekhar, S. (2013). Slum modelling by using ontology and geoinformatics: Case study of Gulbarga. *International Journal of Geoinformatics*.

Sliuzas, R. V, Kerle, N., & Kuffer, M. (2008). Object-oriented mapping of urban poverty and deprivation. *4th EARSeL Workshop on Imaging Spectroscopy 2005: New Quality in Environmental Studies*.

Tomai, E., Herlin, I., Berroir, J.-P., & Prastacos, P. (2009). Ontology-based documentation of land degradation assessment from satellite images. *International Journal of Remote Sensing*, *30*(13), 3315–3330. [Crossref]

Tripathi, S. (2015). Determinants of Large City Slum Incidence in India: A Cross-Sectional Study. *Poverty & Public Policy*, *7*(1), 22–43. [Crossref]

Tripathy, P., & Kumar, A. (2019). Monitoring and modelling spatio-temporal urban growth of Delhi using Cellular Automata and geoinformatics. *Cities*, *90*(January), 52–63. [Crossref]

Uddin, N. (2018). Assessing urban sustainability of slum settlements in Bangladesh: Evidence from Chittagong city. *Journal of Urban Management*, *7*(1), 32–42.

UN Habitat. (2003). *The Challenge of Slums - Global Report on Human Settlements 2003*. https://www.un.org/ruleoflaw/files/Challenge%20of%20Slums.pdf.

UN Habitat. (2022). *World Cities Report 2022: Envisaging the Future of Cities*. https://unhabitat.org/sites/default/files/2022/06/wcr_2022.pdf.

United Nations Development Programme. (2012). *Fighting Climate Change: Human Solidarity in a Divided World* (pp. 166–168). https://www.rrojasdatabank.info/hdr_20072008_en_overview.pdf

Weeks, J. R., Hill, A., Stow, D., Getis, A., & Fugate, D. (2007). Can we spot a neighborhood from the air? Defining neighborhood structure in Accra, Ghana. *GeoJournal*, *69*(1–2), 9–22. [Crossref]

Wekesa, B. W., Steyn, G. S., & Otieno, F. A. O. (Fred). (2011). A review of physical and socio-economic characteristics and intervention approaches of informal settlements. *Habitat International*, *35*(2), 238–245. [Crossref]

Zaman, T. U., Goswami, H. D., & Hassan, Y. (2018). The impact of growth and development of slums on the health status and health awareness of slum dwellers. *International Journal of Medical Research & Health Sciences*, *7*(3), 55–65.