DETERMINING THE EFFECTIVENESS OF DIFFERENT INDICATORS IN IDENTIFYING INFORMAL SETTLEMENTS USING THE MEMBERSHIP FUNCTION

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Commission IV, WG IV/3

KEY WORDS: Informal Settlements, GIS, Network Analysis, Space Syntax Theory, Membership Function

ABSTRACT:

Informal settlement is one of the most common forms of urbanization, increasing every day all over the world, especially in developing countries. One of the important topics informal settlements studies is the measurement of indicators that can identify these settlements effectively. In many articles, the authors use various indicators to identify these areas. In addition, the literature shows these areas are suffering from several problems including the occurrence of fire due to the use of informal electricity, poor access to urban facilities and services such as fire stations, and dead-end and narrow alleys, isolated from other developed areas. Therefore, low accessibility and morphology of the transport network make fire suppression a very hard task in these areas. As such, in this study, we investigated the effectiveness of spatial and space syntax theory indicators in informal settlement mapping. For this purpose, we used ArcGIS and DepthMap software. The study area is District 19 in the southwestern part of Tehran in Iran, which includes 18 neighborhoods. The results show the connectivity index with 16% error or in other words, 84% correctness can be a good index or map to detect informal settlements, and the most prominent feature of informal settlements is the poor accessibility.

1 INTRODUCTION

1.1 Background

Urbanization is a social process that plays vital role in determining the shape of the urban built environment (UN-Habitat, 2019). In 2018, 55.2% of the world's population lived in urban areas (UN-Habitat, 2020), and this number is increasing. Rapid urbanization has been experienced in most developing countries in the last century. One of the main reasons for the increasing urbanization is the increasing migration from the village to the city (Akirso, 2021). People who live in the village migrate to bigger cities with better working conditions to find a job with a decent income. These cities often have a high cost for buying and renting housing; that is why most immigrants for a lower cost take refuge in informal settlements that are often created on the outskirts of cities. Urban informal settlements are self-built housing with poor-quality services and low-income residents due to poverty, disorganization, and marginalization (Lombard 2014). In the country of Iran, the residential context of these settlements is usually combined with the workshop context, which causes disturbances in the comfort of the residents of the region and the occurrence of air pollution and noise pollution in these settlements. Due to being out of urban planning, they do not have official electricity and due to the presence of many workshops, we often see fires in these areas. The long distance from service centers such as the fire station, and the presence of inappropriate access, slow down the relief operation.

1.2 Literature Review

In studies related to the identification of informal settlements, various indicators are measured to identify these areas, for example, fire can be introduced as one of the characteristics of informal settlements, which is caused by the lack of official electricity (Lefulebe et al., 2014). Other indicators can also be mentioned in other studies; for example, Kim Dovey and colleagues (2020) use the shape of buildings, blocks, streets, and lines to extract informal neighborhoods and believe that these settlements are embodied in morphologies that benefit from informal rules, and morphological characteristics are effective indicators in identifying informal settlements. Rabiei-Dastjerdi and colleagues (2021), and also Namvari and colleagues (2021) show the changes in land use cover in different periods as a suitable method for identifying informal, and in another research, Rabiei-Dastjerdi and colleagues (2020) evaluated the level of air pollution in these areas and examined the effect of the economic and social conditions of the residents on the level of pollution. John Abbott (2003) deeply examines the way settlements are established and concludes that the close relationship of households affects the form of settlement of houses and morphological characteristics, and considers the social relations of households with each other as characteristics of informal settlements, and Inostroza (2017) believes that informal settlements have four common dimensions: the lack of

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formal legal titles, the irregular development of the urban structure, the lack of essential public services, and the occurrence on public lands. Akirso (2021) states that these settlements are dense and unplanned with an irregular pattern, including self-built houses without formal land ownership. Also, the low income of the residents can be considered an indicator of informal settlements (Suditu, Valceanu, 2013) because there is a big gap between the residents' income and the housing price (Rabiei-Dastjerdi, McArdle, 2021). Generally, a wide range of physical, environmental, and morphological variables and census data can be used to identify and classify informal settlements (Feitosa et al., 2021).

1.3 Objective

The effectiveness of spatial information and urban context in identifying informal settlements has always been discussed among researchers, and both are always used separately or simultaneously by researchers. Most researchers consider the value, weight, and effectiveness of each index according to their own beliefs, but the accuracy and usefulness of this information in the detection of informal settlements have never been investigated, knowing which index can identify informal settlements with the least error. This research aims to investigate the impact of various factors in detecting informal settlements and to identify informal settlements as soon as possible so that these areas can be developed with proper planning.

2 MAIN BODY

2.1 Study Area

Informal settlements often occur in developing countries and the third world. In recent years, Iran, as a developing country, and its more developed cities, including Tehran, have faced a significant growth of informal settlements. The increase in inflation and the decrease in the financial capacity of the people have caused the migration of a huge population of rural people to this city. Due to favorable working conditions in this city, even Afghan immigrants live there. Since the low income and large population of households are the characteristics of these people and the price of buying and renting housing in Tehran is increasing day by day, so most of the immigrants settle in the outskirts of this city due to the change in land use. Settlement in these areas is usually done without urban planning, which causes all kinds of social problems.

The area studied in this research is district 19 of Tehran city, which is in the southwest part of this city. According to the potential and characteristics of the region, this area is one of the main cores of immigrants' residence in Tehran city (Figure 1). Among the features of this area, we can mention the presence of Iran's largest park, Iran's largest fruit sales center, various markets, including Tehran's largest fabric market, Tehran's largest second-hand car buying and selling center, and one of the furniture sales areas in Tehran. This area consists of 18 neighborhoods: Abdolabad, Abuzar, Bahmanyar, Dolatkhah, Esfandiary, Kazemi, Khani-Abad-North, Khani-Abad-South, Mortezagerd, Nematabad, Resalat, Shariati-North, Shariati-South, Shokufeh-North, Shokufeh-South, Soheyl, Velayet, and Zamzam. The neighborhoods of Velayat (Park), Kazemi (entirely industrial structure), and Abdolabad (fruit sale center) are uninhabited, so 15 other neighborhoods have been studied in this research.

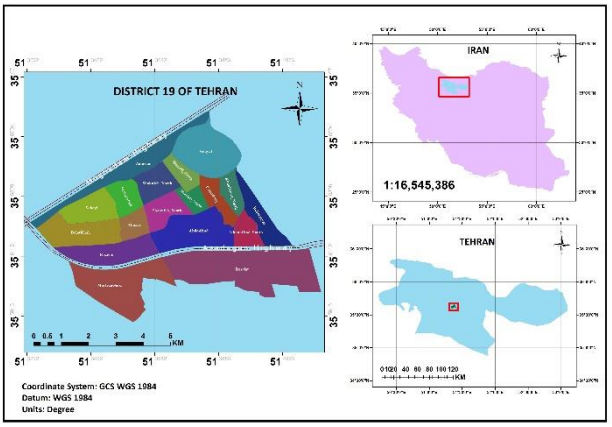


Figure 1. Map of the study area

2.2 Definition

In this research, an attempt has been made to determine the effectiveness of different indicators in identifying informal settlements, so that the results of this research can be used as the first step in future research. Informal settlements can be referred to as the illegal occupation of land and unplanned residential construction that does not comply with a city's current planning and construction regulations (Abebe et. al., 2019) and can observe the index of lack of official ownership in all the definitions of different researchers. Therefore, this index can be considered a common feature in all informal settlements. This indicator is more significant in the case of Iran, in such a way that people need a permit to start work from the municipality to start construction. After the construction, they receive a certificate confirming the "end of construction". After receiving the letter of completion, they can receive an official document for their building. The problem in informal settlements in Iran is that after receiving permission to start work, people do not follow the principles of building or they exceed the limit of their construction (changing the land use), which makes these people fail to receive the letter of completion and, as a result, the official document. In this research, we went to the municipality to get a map of the houses that did not receive the completion of construction. As a result, they do not have an official document and we use it as a validation map.

There are various indicators to identify informal settlements, such as lack of official electricity, distance from service centers, inappropriate access such as narrow alleys, and isolation from developed areas. For the morphological surveys of the region, we use the space syntax theory. The main idea of the space syntax theory is about spatial configuration, in which the relationship of each element with other elements of the whole system becomes important (Hillier et al., 1993). This theory states that the spatial configuration and the way urban spaces are combined is the main factor in the distribution pattern of socio-economic activities, namely the distribution pattern of commercial uses, different ethnicities, urban crimes, and movement in the city (Hillier & Vaughan, 2007). Among the critical indicators of the space syntax theory, we can mention Connectivity, Integration, and Depth. The concept of Connectivity means spatial connection. This means that the greater the value of connection, the greater the number of connections between the desired space and other spaces. Its

practical concept can be expressed as access. The numerical value of the Connectivity expresses the number of accesses leading to the desired space; in other words, the Connectivity specifies the number of nodes directly connected to every single node in the connection graph (Jiang et al., 2000).
The value of the Integration of each line is the average number of intermediate lines that can be used to reach all areas of the city; in other words, it is the average number of changes of directions that can be reached from that space to all the spaces of the city. The Integration of an urban space shows its conjunction with the whole city. Research shows that the distribution of the value of Integration in the city strongly correlates with the movement of pedestrians in that city (Turner, 2007).
Depth: The Depth of space means that to reach that space, you have to pass through several other spaces; in other words, Depth is the smallest space step that is taken to reach from one node to each of the nodes in the graph (Jiang, Claramunt, 2002)

2.3 Data Collection

In this article, the various data mentioned in Table 1 have been used to perform the necessary analyses. The required data for this research include roads and points specifying the location of fire stations, which are obtained from Open-Street-Map (OSM) and Web searches, respectively. To check the accuracy and validation of the research method, the map of undocumented houses obtained from the municipality was used.

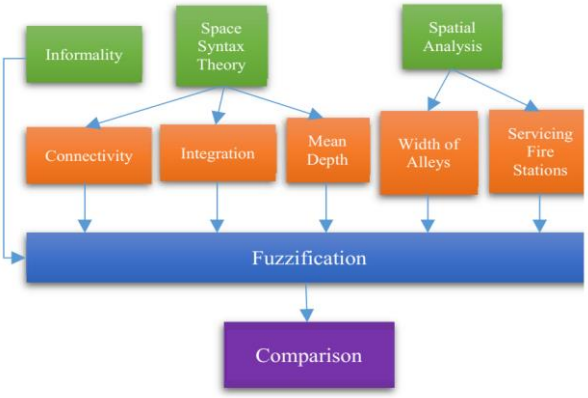
Data	Source	Software	Information
roads	OSM	DepthMap	Connectivity
			Integration
			Mean depth
		ArcGIS	Width of alleys
Points of fire stations	Web searches	ArcGIS	The accessibility of fire stations
Houses without formal legal titles	Municipality	ArcGIS	The percentage of houses without formal legal titles in each neighborhood

Table 1. Data

2.4 Methodology

The method of doing the work is done in three phases (Graph 1), in this way, in the first phase, it is done in several sections, which you will see below:

- Having the points of fire stations in the desired area and performing Network Analyst in ArcGIS software, the distance of each neighborhood from fire stations is calculated (Figure 2).
- Using ArcGIS software, we determine the width of the alleys in each neighborhood (Figure 2).
- By using space syntax theory in DepthMap software, we create maps of Connectivity, Integration, and Mean Depth and get the value of indicators for each of the neighborhoods (Figure 3).



Graph 1. Work steps

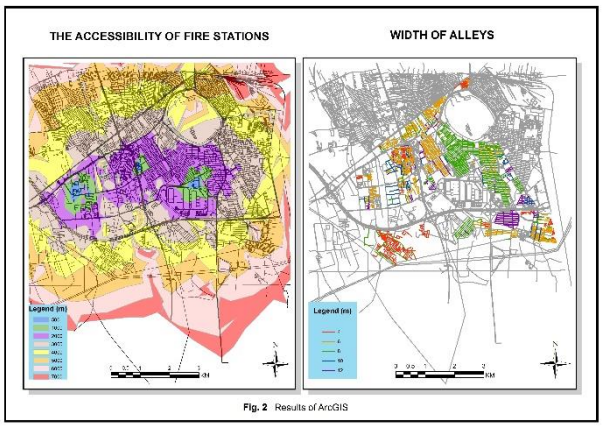


Figure 2. Results of ArcGIS

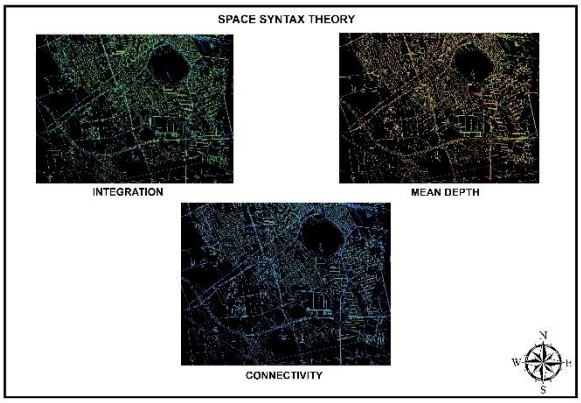


Figure 3. Results of DepthMap

In the second phase, to compare the effect of these indicators, we have to standardize the values of these indicators, for this purpose we use Equation (1) (fuzzy function) to determine the membership level of each of the indicators for each neighborhood (Figure 4). Therefore, according to the range of values for each index, we express these values as membership in the fuzzy function as follows (Zadeh, 1965):

$$A = \{(x, \mu_A(x)) | x \in X\} \quad (1)$$

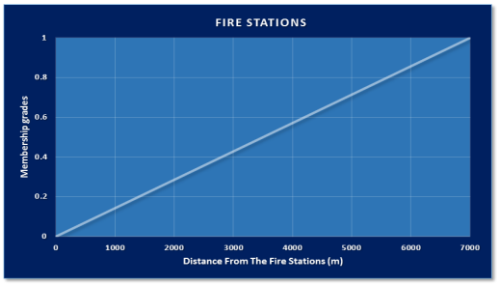
$$\mu_A(x): X \rightarrow [0, 1]$$

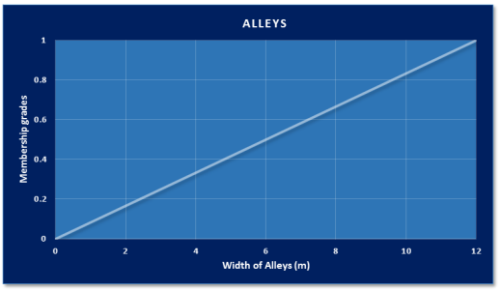
Where $\mu_A(x) = 1$ if x is totally in A
$\mu_A(x) = 0$ if x is not in A
$0 < \mu_A(x) < 1$ if x is partly in A
A = Fuzzy set
$\mu_A(x)$ = Membership function
X = Universe of discourse

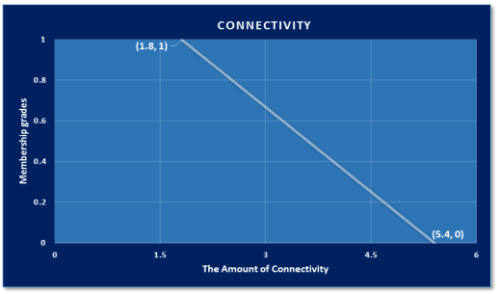
In the final phase, we must compare the values obtained for each index in each neighborhood with the fuzzy membership value in the validation map for each neighborhood, we use Equation (2) for comparison, and after calculating the error rate of each index for each neighborhood, we obtain the overall average of each index between the neighborhoods to determine the error rate of each index in identifying informal settlements.

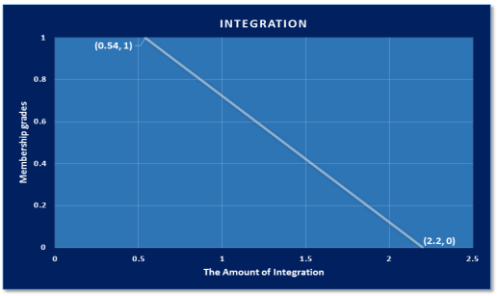
$$\delta = \frac{(\upsilon_A - \upsilon_E)}{\upsilon_E} \times 100 \quad (2)$$

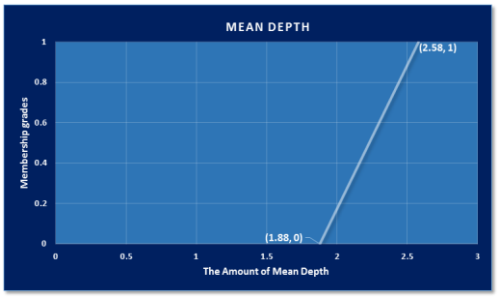
Where δ = Percent error
υ_A = Actual value observed
υ_E = Expected value











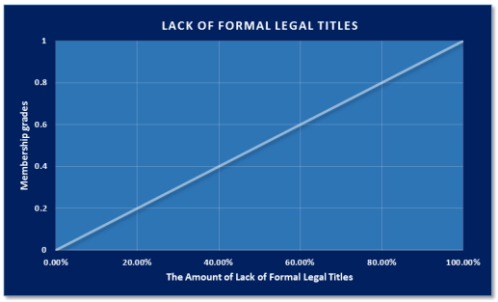


Figure 4. Membership Functions

3 RESULTS

As mentioned, the steps of this research were done in three phases. In the first phase, we obtain the value of each index as an average for each neighborhood in the study area. In this way, the distance from the fire stations and the width of the alleys were calculated in ArcGIS software, and the mean depth, connectivity, and integration were calculated in the space layout software (DepthMap) and then averaged for each neighborhood to obtain these values. Also, based on the validation map, it was determined what percentage of the settlements in each neighborhood are informal (Table 2). Then, in the second phase, we determined the general relationship between informality and each indicators (the direct or indirect relationship of each index with informality). Then, using fuzzy functions specific to each index, we calculated the value of the fuzzy membership degree of each index for each neighborhood. The values of the degree of membership of each index are between zero and one. The value closer to zero indicates formality, and the value closer to one indicates informality (Table 3). In the third and final phase, we calculated the percent error of each index for each neighborhood (Table 4).

Row	Neighborhoods	Int	Con	Width(m)	Mean Depth	Fire Station(m)	Informality
1	Abuzar	1.34	3.03	7.138	2.24	2291.545	70%
2	Bahmanyar	1.37	3.28	9.009	2.2	3190.765	30%
3	DolatKhah	1.31	3.02	7.408	2.22	1885.857	50%
4	Esfandiary	1.44	3.4	7.960	2.27	1809.53	30%
5	KhaniAbad_North	1.59	3.79	7.357	2.33	2053.329	20%
6	KhaniAbad_South	1.3	3	8	2.2	2879.159	25%
7	MortezaGerd	1.3	3	4.342	2.21	4299.976	80%
8	NematAbad	1.45	3.36	6.569	2.26	2133.439	60%
9	Resalat	1.38	3.16	7.469	2.25	4330.477	60%
10	Shariati_North	1.48	3.46	7.935	2.27	2678.895	30%
11	Shariati_South	1.48	3.59	8.03	2.29	1806.241	35%
12	Shokufeh_North	1.45	3.32	6.323	2.23	1918.633	40%
13	Shokufeh_South	1.47	3.5	6.933	2.22	2183.284	40%
14	Soheyl	1.42	3.52	6.686	2.24	2023.447	30%
15	Zamzam	1.51	3.36	6.171	2.28	3015.511	60%

Table 2. Results of Measurements

Row	Neighborhoods	Int	Con	Width	Mean Depth	Fire Station	Informality
1	Abuzar	0.518	0.658	0.405	0.514	0.327	0.7
2	Bahmanyar	0.4	0.388	0.25	0.457	0.456	0.3
3	DolatKhah	0.536	0.661	0.383	0.485	0.269	0.5
4	Esfandiary	0.457	0.455	0.337	0.557	0.258	0.3
5	KhaniAbad_North	0.367	0.247	0.287	0.243	0.253	0.2
6	KhaniAbad_South	0.342	0.267	0.333	0.457	0.311	0.25
7	MortezaGerd	0.642	0.78	0.638	0.471	0.614	0.8
8	NematAbad	0.451	0.567	0.453	0.543	0.305	0.6
9	Resalat	0.494	0.622	0.378	0.528	0.619	0.6
10	Shariati_North	0.233	0.339	0.339	0.557	0.383	0.3
11	Shariati_South	0.367	0.31	0.331	0.585	0.258	0.35
12	Shokufeh_North	0.451	0.578	0.473	0.5	0.274	0.4
13	Shokufeh_South	0.439	0.428	0.422	0.485	0.312	0.4
14	Soheyl	0.47	0.322	0.443	0.514	0.289	0.3
15	Zamzam	0.415	0.567	0.486	0.571	0.431	0.6

Table 3. Results of Fuzzy Functions

Row	Neighborhood	Int	Con	Width	Mean Depth	Fire Station
1	Abuzar	26%	6%	42%	26%	53%
2	Bahmanyar	33%	29%	16%	52%	52%
3	DolatKhah	7%	32%	23%	3%	46%
4	Esfandiary	52%	51%	12%	85%	14%
5	KhaniAbad_North	83%	23%	43%	21%	26%
6	KhaniAbad_South	36%	6%	33%	82%	24%
7	MortezaGerd	19%	2%	20%	41%	23%
8	NematAbad	24%	5%	24%	9%	49%
9	Resalat	17%	3%	37%	12%	3%
10	Shariati_North	22%	13%	13%	85%	27%
11	Shariati_South	4%	11%	5%	67%	26%
12	Shokufeh_North	12%	44%	18%	25%	31%
13	Shokufeh_South	9%	7%	5%	21%	22%
14	Soheyl	56%	7%	47%	71%	3%
15	Zamzam	30%	5%	19%	4%	28%

Table 4. Results of Percent Error

4 CONCLUSION

This research aimed to investigate the effectiveness of different indicators in identifying informal settlements. After examining various indicators at the neighborhood scale, displaying them in fuzzy form, and comparing them with validation map values, it was proved that the indicators of the accessibility of fire stations, Width of alleys, Mean Depth, Integration, and Connectivity have error percentages of 28%, 23%, 38%, 28%, and 16% respectively (Table 5). As a result, we can consider the connectivity index with a correct percentage of 84% as the most important and main index in identifying informal settlements. This index shows the lack of immediate neighborhoods of informal settlements. As a result, these settlements are facing a decrease in the mobility of residents. In other words, when a person stands on the street, he has a less direct view of other parts of the neighborhood, which disrupts movement in informal settlements because vehicles have to constantly change direction to move, which causes severe traffic jams and increasing slowness in movement. Also, when faced with problems resulting from disasters and aid operations, the movement of vehicles namely ambulances or fire trucks faces serious problems, and the possibility of increasing casualties increases due to the slowness of relief operations. In the general definition, the index of connectivity has a direct relationship with integration, therefore, the lack of immediate neighborhoods causes the isolation of these neighborhoods from other neighborhoods (such as an island), which can cause social harm to the residents of these settlements. Therefore, planners and government managers should prioritize the element of connection between neighborhoods and create direct routes in each neighborhood to prevent the emergence of informal settlements.

	Connectivity	Mean Depth	Distance of Fire Station	Width of Alleys	Integration
Average Percent Error	16 %	38 %	28 %	23 %	28 %
Average Percent correctness	84 %	62 %	72 %	77 %	72 %

Table 5. Results of research

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