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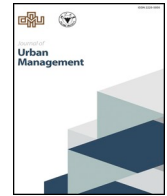
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Analyses and modeling of urban land use and road network interactions using spatial-based disaggregate accessibility to land use

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ABSTRACT

Rapid urbanization in developing countries enforces authorities to assess the sustainability and balanced development of urban cities from multiple perspectives and recommend appropriate solutions for policy and decision-makers. This study proposes spatial-based disaggregate accessibility to land use to figure out the influencing factors and key indicators that enable a comprehensive categorization of cities' subdivisions from the perspectives of urban land use and road transport network. A general GIS and statistical software programs-based methodology is adopted and validated in the case example of Kandahar City, located in Afghanistan. The methodology involves five major steps; 1) limited primary and secondary data collection regarding road network and land uses, 2) calculation of urban land uses weights, 3) identifying critical centers of neighborhood land uses, 4) estimation of origin-destination cost matrix, and; 4) formulating and modeling accessibility measures. The statistical and theoretical significances have been illustrated in the result. The final accessibility measures have divided the subdivisions of Kandahar City (case study) into three different categories, namely, a) high-level municipal districts (CBD), b) medium-level municipal districts (semi-urban), and; c) peripheral municipal districts. The research has incorporated qualitative and quantitative approaches for sustainable and balanced urban development.

1. Introduction

Professionals of urban land use and transport have been working separately for many years due to inadequate channels of communication and misdirected collaboration between them, the challenge of integration of urban land use and transport planning still exists and is yet to be fully solved to a large extent (Xie, Jiang, & Wang, 2013). It is a well-known fact that land use and transport are interrelated. The utilization of different land uses in different locations generates the demand for transport, where system and supply of transport enable the distribution of different land uses in different locations. Therefore, one can simply argue that urban and spatial planners, transport planners, highway engineers, public transport and logistics operators, retailers and developers should all come together to create new strategies and policies on the logic of land use management, transport geography, accessibility, and implied division of labors and other commuters involved (Marshall & Banister, 2007). Transport directly influences urban development and spatial distribution of opportunities in different forms, such as services, households, employment, etc. Thus, the plan for

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the development of a new area should simultaneously be prepared with integrated kind of transport planning strategies.

The integrations of land use and transportation in developing countries are of greater concern in comparison with the developed countries. Ordinarily, developing countries have short term policy plans for regional and urban road network planning. It is usually assumed that the future demand is understood or estimated based on the current mobility patterns, not considering, for instance, the change in the economics and demographic dynamics caused by the improvement of the road system, the unexpected rapid urban growth. Besides, due to a lack of sufficient socio-economic and demographic data, commuting flows, employment data results in poor urban land use, road network, and transport infrastructure planning, which is often the case in developing countries.

Accessibility is one of the important concepts that allows the integration of land use with various transport networks. In this work, we have proposed an entirely new approach (especially for the cities of developing countries) through which the interaction, sustainability, intensity and relationships of urban land use and road transport network components across the various subdivisions of the city will be explored.

This approach enables measuring spatial-based disaggregate accessibility to land use and aims to establish a general-based methodology so that it can provide a scientific contribution to the people of interest. Given attention to the challenge of limited data in developing countries, the study may require some limited secondary data regarding urban land use from relevant local government bodies or other authorities. Whereas, road network data can be obtained or established from several available online sources.

The main objectives of this study are listed below:

1. To assess the interactions, intensity, and sustainability of various urban land use and road networks (subdivision and city level) using an entirely different type of accessibility, named; “spatial-based disaggregate accessibility to land use”.
2. To model and investigate the linear relationships, theoretical and statistical significances of land use, travel time, travel distance, housing, and population and their influences and contributions to spatial-based disaggregate accessibility.

The paper is arranged in six parts, the next part discusses the relevant literature about the concept, followed by, methodology, case study, results and analysis, conclusion and further research. Each part is explained in detail.

2. Literature review

2.1. Measuring urban land use and urban road transport networks

Prior to studying the interactions between urban land use and road transport, it is important to measure the extent of *mixed land use* and *road transport networks* within the case study neighborhoods particularly needed for the research. Various dynamic and static approaches have been conducted with regards to the modeling of transportation networks and urban land use (Feng, Bai, & Xu, 2019; Simwanda, Murayama, & Ranagalage, 2020).

In a research article by (Dempsey et al., 2010), the method of measuring land use is explained, in which a number of appropriate land uses were selected, excluding land uses which are not relevant for the purposes of the research. A ‘buffer zone’ of approximately 400 m (equivalent to approx. 5 min walking distance) was applied around each case study area to account for any ‘edge effect’ during this study. By doing this, there was a higher possibility of capturing and investigating the usage of particular services and facilities of the research components. This land use information was then mapped using a GIS-based platform.

In a research paper by (Qi, Wang, & Lu, 2011), the IKONOS satellite imageries were used to measure the land use in a disaggregated manner in two major steps. In the first step, land use classification was performed based on the Object-Oriented (OO) Classification scheme, whereas, in the second step building density, building volume and gross floor area were calculated by land-use intensity indexes. Furthermore, generating the layouts of road transport networks and their quantification is also one of the mandatory steps to be carried out prior to interacting them with land use. The accurate modeling of layouts and their quantification is a time-consuming process. A plethora of studies have used different approaches, for instance, a research article by Liu & Yang (2010) shows that a hierarchical method based on dual approach for assessing and measuring the road transport network was used, whereas, in a research article by (Porta, Strano, Iacoviello, & Messori, 2009), MCA (Multiple Centrality Assessment) was employed to the layout of road network. In this study, however, a GIS-based approach is employed that not only provides spatial structure but also all the necessary quantitative indicators to interact land use with road transport networks. Therefore, for road network component, the approach used in this research describes topological and spatial structure of road transport networks; along with all the spatial and statistical data of road networks that can ultimately be used for official roads within the city.

2.2. Urban land use and road transport interactions

Quite a few approaches have been employed in the past to study the interactions of land use with road networks from different perspectives. However, there are still gaps to effectively analyze the realistic variations with all dynamic interventions. In fact, road transport interacts with land-use in the presence of several other factors. For instance, an increase in households and population lead to a change in land use weights and employment opportunities. As a result, the accessibility scores increase, and one place, one zone or one subdivision become more important than the other.

In a study by (Zeng, Song, Zheng, & Li, 2019), the effects of a traffic network on urban transformation in terms of road network density, road network connectivity, and traffic service capability were illustrated. The study mostly focused on traffic network data and indirectly assessed its interaction with urban morphology.

In a research article by (Szeto, Jiang, Wang, & Sumalee, 2013), the interaction of transportation with land use was explained over time. The drawback of the study is that the research needs micro-level data pertaining to employment within different zones which can be the hardest task in the regions from developing countries. Similarly, a study by (Alqhatania, Bajwaa, & Setungea, 2012) attempted to explore land use and transport interactions using the journey to work trips (commuting flows) and origin-destination matrix. In recent years, the application area of Spatial Interaction Modelling (SIM) has extensively increased especially in urban transport and land use planning related issues (Roy, 2004; Nakaya, 2001). In SIM, the interactions between individuals or firms in space and choices in physical space are predicted and measured. The choices include, but not limited to; total employment, exports, contacts, schools, retail sector, population (Roy & Thill, 2003).

2.3. Accessibility

Accessibility from the perspective of urban planning may have one meaning in general but is defined in different forms. It can be defined as the ease with which one reaches opportunities (Jianghao, Yu, Ci, & Dajiang, 2016), or the intensity of the opportunities that ultimately increase the convenience of the commuters. The opportunities include population, households, employment, land use, etc. The first simple concept of accessibility was introduced by Harris (1954), and later on (Hansen, 1959) described more comprehensive equation of accessibility as follows:

$$A_i = \sum_{j=1}^n S_j \times T_{ij}^{-x} \tag{1}$$

Where, A_i is the accessibility score of Zone i to an opportunity located within Zone j for $j = 1, 2, 3 \dots, n$. S_j is the size of the activity (opportunity) at Zone j ; e.g., employment, population, income, etc. T_{ij} is the travel time or distance between zones i and j , x is decay factor indicating the effect of travel time or distance between zones i and j . Moreover, likely to the concept of accessibility, a research article by Pooler (1987) focused more on population potentials as a means of basic index of spatial accessibility.

In contrast, this technical research paper focuses on spatial-based accessibility to land use, which means, land use weight is considered as a proxy of opportunities within different subdivisions. Besides, the study also assesses the effects of households, population, travel time, and travel distance on the intensity of accessibility. Keeping the concept of this research in mind, according to Geurs & Wee (2004) there are four types of components through which accessibility can be identified;

1. Land Use
2. Transportation
3. Individual, and;
4. Temporal

Land use component contains; (1) a proxy of opportunities exists in destinations, including commercial facilities, administrative and management, recreational, institutional, health, religious, etc. (2) the demand for the opportunities of destination in origin, (3) the interest of clash between supply and demand for opportunities.

The transportation component includes the system, the travel distance and time between an origin and destination, the available transport modes, the functional (classification of road) and operational (level of service) hierarchical characteristics of the roads. The Individual component describes the relevant attributes of individuals, such as income, lifestyle, educational level, age, physical condition, etc. The temporal component considers the time of the day in which the opportunities are available. As stated earlier, this research emphasizes land use weights in destinations, however, the influences of the travel time and distance (transport component), population and households are also explored.

Furthermore, one of the most important concepts to be particularly considered is the effect of travel time and travel distance sensitivities in accessibility. Another way of putting it is the attractiveness of opportunities at a certain destination increases when travel time or distance between origin and destination decreases, and vice versa. The formula that reflects this phenomenon is given by O’Kelly & Horner (2003); Stepniak & Rosik (2018) is as follows:

$$A_i = \sum_{j=1}^n O_j \times f(t_{ij}) \tag{2}$$

$$A_i = \sum_{j=1}^n O_j \times f(d_{ij}) \tag{3}$$

Where, A_i is the accessibility score of Zone i to an opportunity located within Zone j for $j = 1, 2, 3 \dots, n$. O_j is an opportunity at Zone j , $f(t_{ij})$ and $f(d_{ij})$ is time and distance impedance functions, respectively, in which t_{ij} is travel time between origin i and destination j , and d_{ij} is travel distance between origin i and destination j . In literature (Hooper, 2015; Reggiani, Bucci, & Russo, 2011; Taylor, 1971), impedance function is formulated and described in various ways, however, considering the availability of data into consideration; the most important ones needed for our study are as follows:

Negative exponential decay function:

$$f(t_{ij}) = e^{-\beta_1 t_{ij}} \tag{4}$$

$$f(d_{ij}) = e^{-\beta_1 d_{ij}} \tag{5}$$

The power decay function:

$$f(t_{ij}) = t_{ij}^{-\gamma} \tag{6}$$

$$f(d_{ij}) = d_{ij}^{-\gamma} \tag{7}$$

In the aforementioned impedance functions, the coefficients of β and γ represent time or distance sensitivity parameters. The β value is calculated using the following approach made by (Östh, Reggiani, & Galiazzo, 2014):

$$-\beta = \frac{\ln(0.5)}{\text{Median trip (length or time)}} \tag{8}$$

From equation (8) it can be inferred that median travel length or time within the origin-destination matrix should be obtained at the point at which the intensity of the opportunities in the destination is decreased by half.

The aforementioned literature has revealed that accessibility can be identified in several ways from different perspectives; both in aggregate and disaggregate manners. It is important to note that due to the availability of comprehensive, essential and detail data systems in developed countries. Especially in reference to employment and commuting flows from one place to another has made the task quite simpler for researchers and policymakers. In contrast, in developing countries unavailability of sufficient data and strong database systems have limited the options for research. In spite of this, this study attempts to use land use data as a proxy of opportunities with the effects of travel time, travel distance, population, and households.

3. Methodology

3.1. Database (data collection, capture, and preparation)

The methodology proposed for this study basically requires existing update urban road transport networks and urban land use data in a disaggregated manner. One of the main problems in developing countries however still is to get the updated data from available competing sources, e.g. OpenStreetMap (OSM), Google, DIVA-GIS, etc. In short, the images, features, and their details are 7–8 years old. Given the importance to the type of study, it becomes mandatory to capture the data based on the most recent satellite imageries (Ahmadzai, Rao, & Ulfat, 2018). In the meanwhile, relevant municipalities can also be approached in case they are willing to share their data.

The methodology, on a general basis, may require both primary and secondary data. However, the data necessary for this research may vary depending upon the characteristics of the study area (case study). The primary data used here include; transportation network files (urban road network topological and spatial structure), functional classification of the roads based on supervised classification due to having sufficient ground reference information, justified speed limits as per (ECMT, 2006). The secondary data include, city subdivisions (municipal boundaries), GPS field survey data on existing land use and public facilities (hand-held GPS field survey conducted for ground-truthing), existing urban land use database, population, and housing data subdivision-based.

3.2. Calculation of weights for urban land uses significant within the city

Principally, to significantly study the interactions of urban land use and road network from the perspective of accessibility, a surplus of data is a must. In this study, the author attempts to use land use data as a proxy of opportunities while measuring accessibility. It is neither impractical nor necessary to consider all land uses of the city. Therefore, we need to consider the types of land uses significance within the city. For determining land use weights, the research employs an equation that was initially introduced by Schaffer (1999), and later modified for land use by Liu & Zhou (2015). The formulation of the equation from the perspective of land use proxy is as follows:

$$L_{ki} = \frac{S_{ki}}{\sum_{i=1}^n S_{ki}} / \frac{S_i}{\sum_{i=1}^m S_i} \tag{9}$$

Where, L_{ki} is land use weight of type k in municipal district i (subdivision), S_{ki} is land use size of type k in municipal district i (keeping in mind that n represents number of land uses significant within the study area), S_i represents total land size of municipal district (keeping in mind that m represents number of municipal districts or subdivisions within the entire study area). The value of L_{ki} obtained from equation (9) for a particular land use indicates how important it really is with respect to the area associated by the respective subdivision, and it also indicates how influential a particular land use when compared to the city area. As a result, the greater the corresponding value, the more important it would be. Furthermore, based on L_{ki} , the decision can be made whether the urban sprawl in a particular subdivision has taken place consistently in comparison with other subdivisions, higher deviations in values lead to the unevenness of the urban sprawl within the city.

3.3. Critical center points of neighborhood land use and their coding

Prior to creating an origin-destination cost matrix, it is quite crucial to find the effective centers of the neighborhood. There are

several ways that can be carried out for finding these centers see (Benenson, Martens, Rofé, & Kwartler, 2011; Saberi, Mahmassani, Brockmann, & Hosseini, 2017). However, the method proposed for this research focuses more on land use component, hence, the locations that are most central (not geometrical central) and interactive with respect to the corresponding land use and subdivision are considered as “critical center point of the neighborhood”. The analysis was performed according to the following GIS-based steps:

1. Locating the spatial geography of land uses significant for study from land use geodatabase as discussed in the data collection methodology.
2. Adding database tables of land use mapping that contains GPS coordinates of public facilities.
3. Spatially displaying XY coordinates of all public facilities (collected with handheld GPS receiver) in data view using ArcGIS.
4. Selecting the most interactive and central points (one point per land use) and exporting them all by saving them as a single shapefile.

The file obtained from the aforementioned steps would be used for origin and destination purposes. Moreover, to make analysis easy in the next steps, it is suggested to code the locations in a way that is easily understood and make use of them consistently in all analyses. For instance, a critical central point for residential use in municipal district 1 is denoted as “MD1R”, in which, the first two letters indicate (Municipal District), the number indicates number of the district, the letter(s) after the number, indicates type of the land use, means, “R” for Residential, “C” for Commercial, “I” for Institutional, “E” for Education, “A” for Administrative and Management, “H” for Health, and “RL” for Religious, thus, the code “MD1R” is; residential land use at municipal district one. However, the coding cases may vary depending upon the constitution of a particular city, region, or country.

3.4. Origin-destination cost matrix

After identifying origins and destinations, the next key stage is to estimate the OD (Origin-Destination) cost matrix which relates to the transport component of accessibility. In contrast to the available literature on this subject, as per the main goal of the study, the author has estimated the OD cost matrix without restricting them to a particular service or access areas. That means the OD cost matrix is estimated both in terms of time and distance by considering the entire length/time between all pairs. The estimation follows the following steps:

1. Creating two road network datasets: 1) road network dataset of city official roads where length in meters is to be taken into account as cost attributes, 2) road network dataset of city official roads where travel time is to be considered as cost attributes.
2. By loading the shapefile of origins and destination created in earlier steps, calculate shortest paths based on a) time, and; b) distance. The shortest paths are computed by ArcGIS Network Analyst Extension.
3. Exporting the newly created OD cost matrix database tables to Microsoft Excel or IBM SPSS for further analysis.

3.5. Accessibility measures and modeling: (components, decay function, and sensitivity parameters)

This study has adopted the spatial-based accessibility to land use where disaggregate land uses are taken into account as a proxy to opportunities. The process starts with the collection of comprehensive data relating to land use, performing a GIS-based approach for justifying origins and destination, and estimating the OD cost matrix based on both time and distance. In this stage of research, it is necessary to model and measure accessibility form various perspectives in two different forms.

3.5.1. Form 1

Firstly, accessibility is measured without the weights and effects of population and household dynamics using the following formulation:

$$A_{1ik} = \sum_{j=1}^{m \times n} L_{kj} \times f(t_{ij}) \tag{10}$$

$$A_{2ik} = \sum_{j=1}^{m \times n} L_{kj} \times f(d_{ij}) \tag{11}$$

$$A_{ik} = \frac{A_{1ik} + A_{2ik}}{2} \tag{12}$$

Where, A_{1ik} is the accessibility of type k land use in zone i to an opportunity located within Zone j , while considering time-based sensitivity with time impedance function as explained through equation (4). L_{kj} is land use weight as a proxy of opportunity considering equation (9). Given the importance to one of the main objectives of this study; the author uses $m \times n$ access for each origin representing the central critical point of type k land use in zone i , in which, n represents number of land uses significant within each subdivision (municipal district), m represents number of municipal districts or subdivisions within the entire study area. Similarly, A_{2ik} is the accessibility of type k land use in zone i to an opportunity located within Zone j , while considering distance-based sensitivity with time impedance function as explained in equation (5). A_{ik} is the average of A_{1ik} and A_{2ik} .

The sensitivity parameters β_1 and β_2 in equation (4) and equation (5), respectively, are explained with the following equations:

$$-\beta_1 = \frac{\ln(0.5)}{\text{Median of travel times}} \tag{13}$$

$$-\beta_2 = \frac{\ln(0.5)}{\text{Median of travel distances}} \tag{14}$$

3.5.2. Form 2

If accessibility is to be called as the intensity of opportunities that possibly increase interactions (Hansen, 1959), one can simply argue that population and housing positively impact on accessibility; especially in the cities of mixed-land use. This means a substantial increase in accessibilities may be noticed with an increase in population and housing. Many studies are available pertaining to the impacts of accessibility on housing and population, however, there is a dearth of research to compare the impacts of population and housing on accessibility. The method proposed for this study can explain the effects of population and household on accessibility with the following formulation:

$$A_{1wik} = \sum_{j=1}^{m \times n} L_{kj} \times \log(P) \times \log(h) \times f(t_{ij}) \tag{15}$$

$$A_{2wik} = \sum_{j=1}^{m \times n} L_{kj} \times \log(P) \times \log(h) \times f(d_{ij}) \tag{16}$$

$$A_{wik} = \frac{A_{1wik} + A_{2wik}}{2} \tag{17}$$

Where, *P* indicates population and *h* indicates households. The reason for using logarithm is to express the large numbers of the population and household weights in short form. The notations used in accessibility measurements; *A* denotes Accessibility, *i* denotes subdivision (municipal district), *k* denotes land use type, and *w* denotes weights of population and household.

4. Case study

4.1. Urban land uses and their corresponding weights

The case example for this study is Kandahar City, located in the southern region of Afghanistan as shown in Fig. 2. Kandahar is the second largest city of Afghanistan consisting of urban and semi-urban areas. The net land size (excluding mountainous and barren land sizes) of the case study is about 225.6 km² which has a population of 845,680 and housing of 76,880. The local Municipality Corporation has divided the city into 15 municipal districts zones. Due to the historical development, the city traditionally has a mixed-land use, including– residential, commercial, institutional, educational, administrative and management, health, religious, cemetery, cultural and communal, green areas, industrial, and water. However, only seven land uses being most significant in terms of size, interaction and operation have been selected for the proposed research.

The details of seven land uses significant within the city (as illustrated in Fig. 3) are: 1) Residential 2) Commercial, 3) Institutional, 4) Education, 5) Administrative and management, 6) Health, and; 7) Religious.

The land use database file has been obtained from Kandahar Municipality Corporation and the author has spatially and statistically illustrated the land uses using ArcGIS. The central business district contains municipal district 1, municipal district 2, municipal district 3, municipal district 4, and municipal district 13. Apart from municipal districts located in the central part, the more urbanized districts are municipal district 9, municipal district 10, municipal district 11, municipal district 12, and municipal district 14. Whereas, the semi-urbanized districts are municipal district 5, municipal district 6, municipal district 7, municipal district 8 and municipal district 15.

As stated earlier, the land use weights; also termed as land use quotients, have to be determined as per equation (9) for seven particular land uses (see Table 1). Hence to do so, an integrated method based on GIS software program (ArcGIS) and statistical software programs (Microsoft Excel and IBM SPSS) is employed to measure: 1) land size of every significant land use within each municipal district, 2) total land size of all seven land uses within each municipal districts (subdivision), 3) total area of municipal district, and; 4) Total area of all 15 municipal districts (excluding mountainous and barren land) within the city. The land use weights (municipal district based) are calculated accordingly and are shown in Table 2.

The next important step to be carried out is to identify the critical center points for neighborhood land uses according to the methodology addressed in the previous section. Thus, one location point per each land use, lead to becoming seven location points for each municipal district. As there are 15 municipal districts, in total 105 critical location points (15 × 7 = 105) are identified as shown in Fig. 4.

4.2. Measuring OD cost matrix and accessibility

Understanding the magnitude of disaggregation of land use interactions for this study, the OD cost matrix both in terms of time and distance is determined without identifying the service areas or restricting the interactions to a particular predefined interval coverage. Apart from this, especially in developed countries, mostly the time-based OD cost matrix is preferred as the speed limits are

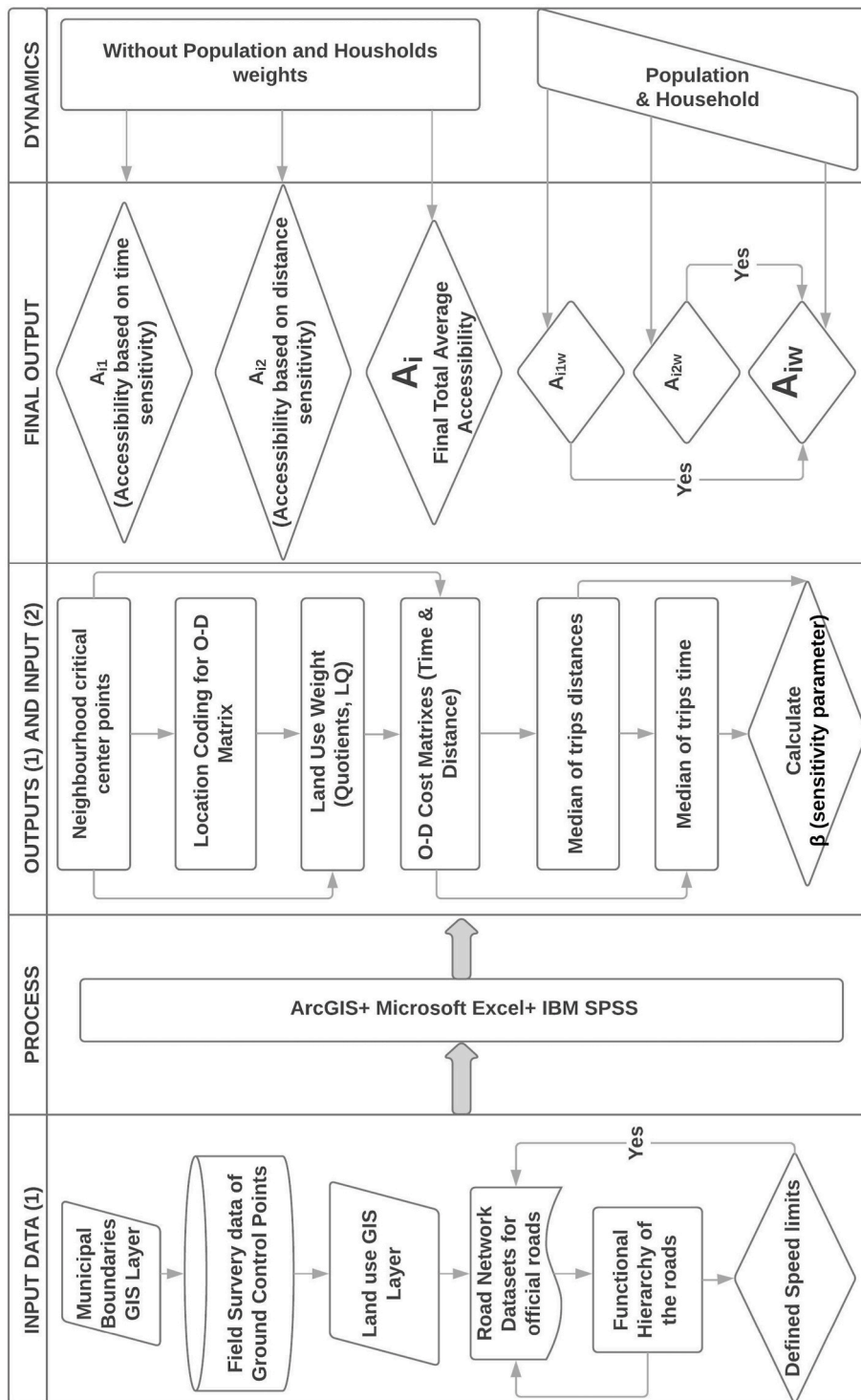


Fig. 1. Flowchart for data processing and model building for interacting land use and road transport network hereinafter measuring spatial-based disaggregate accessibility.

taken seriously and real-time traffic information is accurate too. However, in developing countries due to the mixed-mode of traffic flows and unavailability of real-time traffic information, it is important to assess the accessibility with both time-based and distance-based impedances. Furthermore, the OD cost matrix is obtained based on the shortest path according to the methodology stated earlier using ArcGIS Network Analyst Extension.

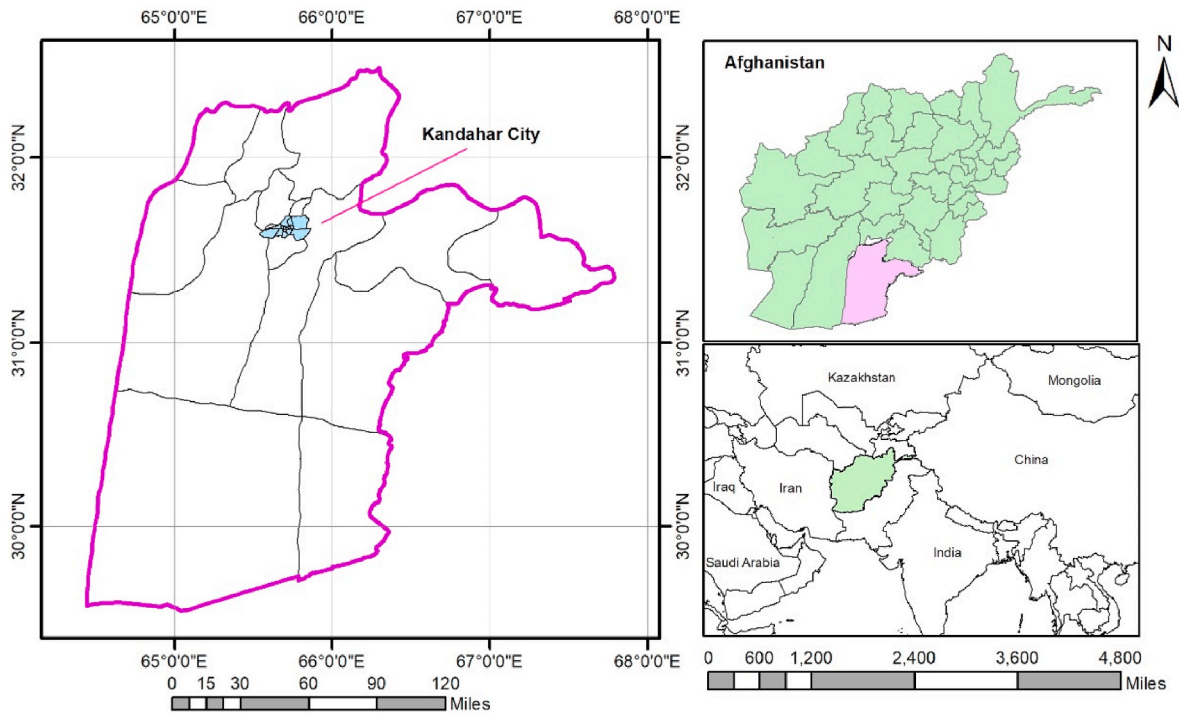


Fig. 2. Study area.

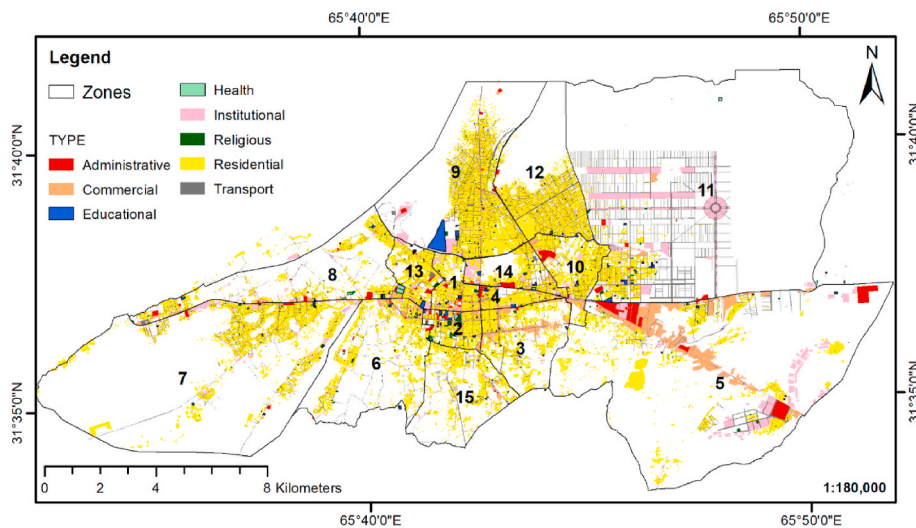


Fig. 3. Spatial illustration of seven land uses significant within the Kandahar City.

As a result, the cost of 11,025 shortest path links in terms of time and distance is estimated, in other words, figures of travel time and travel distance from each origin to each destination are estimated. Taking formulated and modeled sensitivity parameters, impedance functions, and accessibility equations into account; spatial-based disaggregate accessibility measures to land use in two forms (A_{ik} and A_{wik}) are shown in Table 3 and Table 4.

5. Results and analysis

From the above computation, formulations and modeling some interesting facts regarding the utilization of land use, urban sprawl, and road network development in terms of origin-destination cost matrix within each municipal district (subdivision) have been revealed. The details from the various perspectives are as follows:

Table 1
Size of land uses within different municipal districts of Kandahar City.

District #	Land use Sizes (m ²)						
	Residential	Commercial	Institutional	Educational	Administrative & Management	Health	Religious
District 1	1,297,907	228,856	185,728	36,929	67,534	536	65,956
District 2	1,138,102	280,214	29,319	80,522	97,462	34,276	161,588
District 3	2,335,764	805,723	46,792	11,952	20,206	1749	57,903
District 4	813,855	216,137	32,149	33,372	63,810	7931	40,135
District 5	4,142,717	2,932,813	1,622,957	20,341	1,084,587	4023	86,417
District 6	2,659,965	190,906	127,861	24,194	37,254	7287	57,238
District 7	5,013,164	144,171	416,421	40,623	78,545	4390	72,524
District 8	1,647,305	240,566	197,125	42,015	143,247	1342	63,976
District 9	4,717,876	129,846	256,858	425,520	9799	3344	89,431
District 10	2,269,149	93,744	145,395	48,570	225,920	709	67,275
District 11	1,623,438	225,759	2,624,466	87,243	85,613	19,602	47,037
District 12	4,720,955	113,475	91,320	13,431	74,214	9099	63,596
District 13	2,268,070	120,511	455,716	67,062	126,113	79,228	51,213
District 14	1,303,668	172,176	343,211	47,151	118,573	29,117	20,530
District 15	2,072,803	121,574	53,139	6329	4494	3535	28,961

Table 2
Land use weights (Land use quotients) obtained based on spatial and statistical disaggregation.

District #	Residential	Commercial	Institutional	Educational	Administrative & Management	Health	Religious
District 1	57.433	10.127	8.219	1.634	2.988	0.024	2.919
District 2	55.177	13.585	1.421	3.904	4.725	1.662	7.834
District 3	20.344	7.018	0.408	0.104	0.176	0.015	0.504
District 4	91.651	24.340	3.620	3.758	7.186	0.893	4.520
District 5	1.953	1.383	0.765	0.010	0.511	0.002	0.041
District 6	14.941	1.072	0.718	0.136	0.209	0.041	0.322
District 7	6.400	0.184	0.532	0.052	0.100	0.006	0.093
District 8	12.274	1.792	1.469	0.313	1.067	0.010	0.477
District 9	13.731	0.378	0.748	1.238	0.029	0.010	0.260
District 10	38.017	1.571	2.436	0.814	3.785	0.012	1.127
District 11	1.216	0.169	1.966	0.065	0.064	0.015	0.035
District 12	28.786	0.692	0.557	0.082	0.453	0.055	0.388
District 13	53.081	2.820	10.665	1.569	2.951	1.854	1.199
District 14	37.071	4.896	9.760	1.341	3.372	0.828	0.584
District 15	21.998	1.290	0.564	0.067	0.048	0.038	0.307

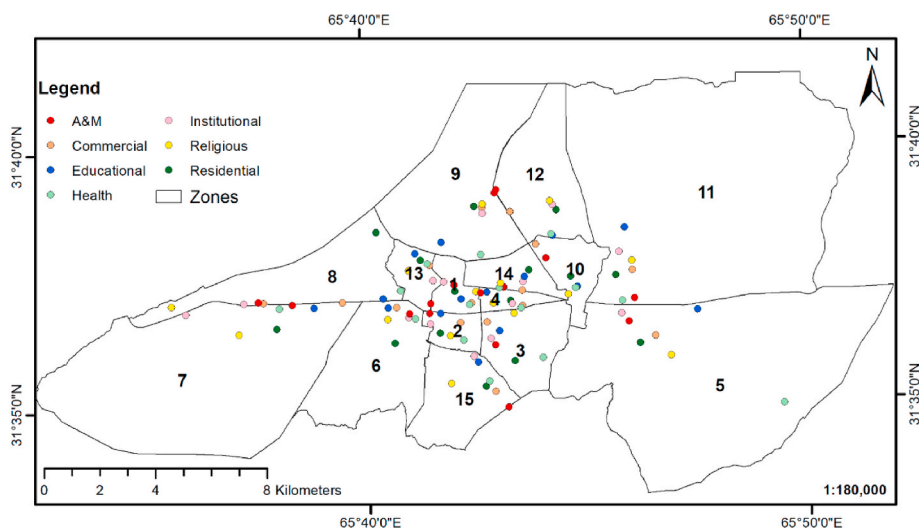


Fig. 4. Critical center points of neighborhood land uses for the origin-destination purpose.

Table 3
Accessibility measures (A_{ik}) without population and housing dynamic weights.

District #	Residential	Commercial	Institutional	Educational	Administrative and Management	Health	Religious
1	439.237	443.950	433.655	445.094	443.294	443.672	439.740
2	404.547	434.430	400.371	424.218	408.319	412.188	409.793
3	355.111	434.343	395.683	425.580	395.442	290.937	430.729
4	447.343	431.157	445.258	444.680	438.980	432.982	449.847
5	256.182	258.743	305.310	221.546	292.913	142.334	225.287
6	14.941	362.058	377.436	348.149	373.326	385.718	332.446
7	204.360	294.897	152.077	254.683	241.795	224.458	162.152
8	323.425	215.754	196.177	348.196	210.234	374.570	136.527
9	327.243	338.644	343.128	367.172	302.534	403.802	333.584
10	356.538	366.538	369.150	362.388	369.150	365.904	380.151
11	248.158	266.650	229.143	244.218	288.612	283.474	265.983
12	305.950	317.894	296.220	345.475	299.127	344.800	289.449
13	397.984	409.677	387.071	386.402	415.466	406.905	352.764
14	401.368	434.777	423.065	407.419	448.142	449.600	432.363
15	338.786	330.031	360.416	377.662	307.664	346.552	298.683

Table 4
Accessibility measures to land use (A_{wik}) weighed with population and housing dynamic.

District #	Residential	Commercial	Institutional	Educational	Administrative and Management	Health	Religious
1	7299	7354	7217	7388	7368	7351	7290
2	6708	7201	6647	7037	6781	6835	6795
3	5882	7182	6548	7033	6543	4808	7093
4	7362	7098	7328	7360	7274	7129	7431
5	4231	4273	5041	3660	4838	2351	3721
6	265	6024	6271	5798	6205	6406	5532
7	3415	4916	2539	4248	4035	3748	2709
8	5405	3601	3275	5801	3509	6244	2279
9	5478	5662	5733	6136	5059	6721	5578
10	5893	6088	6105	5984	6105	6042	6274
11	4109	4418	3796	4059	4769	4684	4413
12	5116	5304	4955	5751	5002	5741	4843
13	6652	6839	6445	6459	6906	6794	5897
14	6634	7177	6984	6726	7406	7432	7153
15	5617	5470	5970	6256	5100	5744	4945

5.1. Analysis, interpretations, and modeling of interactions using multiple regression

The study has employed four mathematical models (equations (10), (11), (15) and (16)) for the formulation of spatial-based disaggregate accessibility to land use. Based on the same, the analysis, interpretations, significance, and linear relationships of all four equations considering their variables are discussed in this section:

5.1.1. Unweighted accessibility measures with travel time impedance function, A_{1ik} , equation (10)

The author performed regression analysis, in which, accessibility, A_{1ik} , is selected as an independent variable and travel time distance, t_{ij} , and land use quotients, L_{kj} , as dependent variables. The regression analysis is performed using SPSS, and the necessary results are shown in Table 5.

Essentially, the number of observations required for regression analysis to answer scientific relationships depends on the number of parameters or variables, as per (Frank E. Harrell, 2001). It is recommended to have at least 10–20 observations per predictor. The more observations there are, the better the accuracy would be. Consequently, there are 11,000 observations for this study which are

Table 5
Regression output results for enquiring A_{1ik} (model represented by equation (10)) significance level.

Predictor	Unstandardized Coefficients		Standardized Coefficients	t-value	Sig.	Multicollinearity		R Square
	B	Std. Error	Beta			VIF	Pearson Correlation	
Constant	1.433	0.051		28.100	0.000			0.916
L_{kj} (LQ)	0.572	0.002	0.941	335.883	0.000	1.013	-0.114	
t_{ij}	-0.0044	0.000	-0.099	-35.451	0.000	1.013		

Dependent Variable: A_{1ik}

Table 6
Regression output results for enquiring A_{2ik} (model represented by equation (11)) significance level.

Predictor	Unstandardized Coefficients		Standardized Coefficients	t-value	Sig.	Multicollinearity		R Square
	B	Std. Error	Beta			VIF	Pearson Correlation	
Constant	1.399	0.052		27.118	0.000			0.908
$L_{kj}(LQ)$	0.572	0.002	0.935	317.979	0.000	1.014	-0.117	
d_{ij}	-0.0002	0.000	-0.102	-34.763	0.000	1.014		

Dependent Variable: A_{2ik}

well above the required criteria. From the statistical figures shown in Table 5, it can be concluded that there is a significant linear relationship between independent and dependent variables, following by p-values (denoted as Sig. in SPSS) less than 0.05 along with $t > 1.96$ (associated with 95% confidence level) indicates that coefficients of predictors are significantly different from zero (Leech, Barrett, & Morgan, 2005), VIF (Variance Inflation Factor) = 1.013 (less than 5) and Pearson Correlation (r) = -0.114 < 0.7 (absolute value) indicates no multicollinearity problem. The R square = 0.916 > 0.5 represents that 91.6% variations of dependent variable can be explained by independent variables. Collectively, the output figures indicate a higher significant level of the proposed model.

5.1.2. Unweighted accessibility measures with travel distance impedance function, A_{2ik} (equation (11))

As stated earlier, the research methodology employs the formulation of unweighted accessibility considering both travel time and travel distance frictions. Based on the employed formulation, it becomes imperative to interpret the significance level of equation (11) too from the perspective of regression analysis. Similarly, as it is seen in Table 6 all regression figures meet the criteria to be called high significant level; such as, p-value = 0.000 ≤ 0.05, t-statistics > 1.96, $r = -0.117$, VIF = 1.014 < 5, R square = 0.908 > 0.5. Furthermore, the statistics illustrate that there is a positive correlation between accessibility and land use quotients, and negative correlation and linear relations between accessibility and travel cost (travel time or travel length) which used to be one of the accessibility fundamentals.

5.1.3. Weighted accessibility measures, A_{1wik} and A_{2wik} (Equation (15) and Equation (16))

In weighted accessibility, in addition to land use weights and travel cost impedance functions, the population and housing dynamics are also taken in to account. Thus, the author attempts to figure out the linear relationships, interactions, and interpretations of their significance level through multiple regression analysis. To do so, initially, the estimation of Pearson's correlation is carried out, given the focus on the existence of multicollinearity. It is found that a high quotient of multicollinearity exists between population and housing (see Table 7), besides, if considered individually (population and housing) the significance level noted is very low.

Thus, to avoid this error, after several attempts, it was established that the logarithmic production of population and housing provides substantive significance results. Therefore, $\text{Log}(P) \times \text{Log}(H) = X_3$ was considered as third significant independent variable after land use weights (L_{kj}) and travel costs (t_{ij} and d_{ij}).

The author has illustrated the statistical significance of the proposed equations (15) and (16) through applied multiple regression modeling where accessibilities (A_{1wik} and A_{2wik}) are selected as independent variables, and land use weights (corresponding to the quotients of seven significant land uses), t_{ij} (associated to A_{1wik}), d_{ij} (associated to A_{2wik}), $\text{Log}(P) \times \text{Log}(H)$ are selected as independent variables, keeping in mind that population and household are transformed into a single independent variable indicating logarithmic production of them.

Regression output results from Table 8 and Table 9 reveal that coefficients of independent variables are statistically and theoretically significant from all perspectives (p-value, F-value, t-values, VIF, and R square).

However, coefficients of the constants of the relevant models are statistically insignificant which have p-values = 0.634, 0.438 and t-values = -0.477, -0.775 corresponding to A_{1wik} and A_{2wik} independent variables, respectively. The data has been checked in

Table 7
Pearson's single Correlation coefficients matrix for initial assessment of weighted accessibility measures.

Variables	t_{ij}	d_{ij}	$L_{kj}(LQ)$	$\text{Log}(H)$	$\text{Log}(P)$	$\text{Log}(H) \times \text{Log}(P)$	A_{1wik}	A_{2wik}
t_{ij}	1.000							
d_{ij}	0.987	1.000						
$L_{kj}(LQ)$	-0.114	-0.117	1.000					
$\text{Log}(H)$	0.133	0.099	-0.180	1.000				
$\text{Log}(P)$	0.133	0.099	-0.180		1.000			
$\text{Log}(P) \times \text{Log}(H)$	0.133	0.099	-0.179	1.000	1.000	1.000		
A_{1wik}	-0.207	-0.208	0.952	-0.166	-0.166	-0.165	1.000	
A_{2wik}	-0.210	-0.214	0.947	-0.161	-0.161	-0.160	0.999	1.000

P: Population, H: Housing.

Table 8
Regression output results for enquiring A_{1wik} (equation (15)) significance level.

Predictor	Unstandardized Coefficients		Standardized Coefficients	t-value	Sig.	VIF	R Square
	B	Std. Error	Beta				
(Constant)	-2.097	4.397		-0.477	0.634		0.917
L_{kj} (LQ)	9.255	0.028	0.944	333.350	0.000	1.047	
t_{ij}	-0.072	0.002	-0.102	-36.469	0.000	1.027	
$\text{Log(P)} \times \text{Log (H)}$	1.579	0.252	0.018	6.255	0.000	1.042	

Dependent Variable: A_{1wik}

Table 9
Regression output results for enquiring A_{2wik} (equation (16)) significance level.

Predictor	Unstandardized Coefficients		Standardized Coefficients	t-value	Sig.	VIF	R Square
	B	Std. Error	Beta				
(Constant)	-3.625	4.676		-0.775	0.438		0.908
L_{kj} (LQ)	9.267	0.030	0.938	314.115	0.000	1.040	
d_{ij}	-0.004	0.000	-0.106	-35.950	0.000	1.044	
$\text{Log(P)} \times \text{Log (H)}$	1.645	0.267	0.018	6.159	0.000	1.020	

Dependent Variable: A_{2wik}

various forms, and it is uncovered that the insignificance caused by the nonlinear relationship of housing and population with land use and accessibility. There is no strong theoretical reason for the omission of the insignificant constants. In contrast, it is more reasonable to include constant even though the terms are statistically not significant, as constant represents the background level of the independent variable. If the predictors are found insignificant should not be retained but a constant if found insignificant should be retained (Samprit Chatterjee, 2006).

5.2. Average accessibility measures of different urban land uses at city-level

Given importance to the land use characteristics of the study area, hence, seven land uses types significant within the city are selected for the proposed research, the results obtained from the figures are explored below:

5.2.1. Residential land use

Residential land use is the most dominant one within the Kandahar city in terms of the land size (area) where most of them include single-family housing. Taking only the seven particular land use sizes in consideration (not all land use types of the city); 68.51% land use area amongst them is residential (see Fig. 3) with an average travel time of 359 s (equivalent 6097 m travel distance) from each residential critical centers of municipal districts (origin) to each critical center of other land uses within all 15 municipal districts (destination). The average accessibility score of residential land use city-based $A_{ik} = 321$ and $A_{wik} = 5,338$, which means that the land use significance in terms of accessibility (both weighted and unweighted) is ranked 7th (last amongst all seven land uses).

5.2.2. Commercial land use

Commercial land use is the best-suited proxy of opportunities especially within this case study as the more is the commercial land use the more would be opportunities availability. Amongst seven land uses 11.29% is commercial. Travel time and travel distance from commercial critical centers to the critical central points of all other land uses are 331 s and 5785 m, respectively. It is important to note that the commercial land uses are not evenly distributed as most of them are existed in Central business district, where huge urban sprawl has taken place, it is therefore, on average bases the accessibility scores with friction of travel costs are $A_{ik} = 356$ (unweighted) and $A_{wik} = 5,907$ (weighted) and is ranked second in terms of accessibility scores.

5.2.3. Institutional land use

This land use includes government and non-government institutes, private places, some green areas and open spaces for residents, etc. According to figures; 11.94% of land use is institutional with having an average travel time of 361 s and a travel distance of 6231 m to the critical central points of all other land uses within the city. Despite being the second largest land use size amongst the seven land uses, the accessibility score ($A_{ik} = 341$ and $A_{wik} = 5,657$) is ranked fifth due to the two reasons: 1) Institutional land uses are not in central areas, 2) the second highest travel cost which has acted as an impedance to the opportunities in destinations.

5.2.4. Educational land use

In spite of the fact that only 1.8% of the land use is consumed for educational land use, the result of the research revealed that Educational land use is the most accessible and sustainable in comparison to other types of land uses. Bearing in mind the significance

of the higher values of land use weights (as per equation (9)), and the least travel cost impedance and decay (328 s or 5682 m), the resultant accessibility scores both weighted and unweighted are obtained the highest amongst all other land uses. The accessibility scores are $A_{ik} = 360$ and $A_{wik} = 5,980$ and are ranked first.

5.2.5. Administrative and management land use

In the land use database of Kandahar Municipality, administrative and management land use includes government directorates, district administrative offices, police stations, etc. This can in some ways be called as a proxy of retail sector employment. The land use covered by administrative and management purpose is 4.28% with respect to the total land size of all other land uses. The average travel time or travel distance to the centers of other land uses is 341 s or 5895 m, respectively, being the second least travel cost after educational land use, as most of these areas are located in the central part of the city. Moreover, the average accessibility score ($A_{ik} = 349$ and $A_{wik} = 5793$) is ranked fourth.

5.2.6. Health land use

The study revealed that health-related land uses are well placed across the city. Health land use contains 48 small and large health centers (district-based clinics, basic health centers, and city-based hospitals). The area covered by health land use is 0.38% (212,873 m²) where the sum of all seven land uses is 100%. The average travel cost between health centers and other land uses is 341 s or equivalent 5998 m. The accessibility scores on average ($A_{ik} = 354$ and $A_{wik} = 5869$) are ranked third highest accessibility after educational and commercial land uses.

5.2.7. Religious land use

Religious land use is one of the most important land uses within Kandahar city. Hence, there are 1285 religious places in the forms of large mosques, small mosques, Madrasas (schools for religious studies), and shrines. Approximately 1.79% land use is occupied by religious purposes and are uniformly distributed at each municipal district. Average travel time and travel distance between religious land uses and all other land uses is 385 s 6516 m, respectively. The unweighted accessibility score is $A_{ik} = 329$, whereas, the weighted accessibility score is $A_{wik} = 5464$. The religious centers are more connected and nearly placed to residential land uses; hence, accessibility is ranked 6th, means, second lowest accessibility score after residential land use.

All in all, in this section; the average based land use interactions, their importance, and sustainability from the perspective of spatial-based disaggregate accessibility to land use are explored with respect to the entire city. The aforementioned average based results of the same are spatially illustrated in Fig. 5.

5.3. Accessibility measures of different urban land uses and their sustainability at municipal district-level

In the previous section the results of average accessibility of different land uses with respect to the whole city were discussed. However, it is important to note that there are 15 municipal districts (subdivisions) in Kandahar City, and the results obtained from the proposed study indicate high differences amongst them in terms of urban development, sustainability of land uses, and road networks interactions. In addition, in the previous section the authors could conclude that there is zero significance from population and housing dynamics in average accessibility scores. However, in municipal district-based accessibility scores, some noteworthy differences will be noticed.

This section would explore on how are the significance, intensity, and importance levels of different municipal districts from the perspective of spatial-based accessibility (weighted and unweighted) in a disaggregated manner. The following findings are noticed:

5.3.1. High-level municipal districts (subdivisions)

As expected, without having employment and commuting flows data, the research could categorize and determine the intensity of the land uses and road network interactions based on the proposed spatial-based disaggregate accessibility to land uses. As a result of stepwise methodology, it has been revealed that Municipal District 1, Municipal District 4, Municipal District 14, Municipal District 2 and Municipal district 13 are the top five highly developed subdivisions within the city by getting highest absolute scores of accessibilities. Nonetheless, there are some differences between Municipal District 1 and Municipal District 4. For instance, based on weighted accessibility considering population and housing weights Municipal District 1 has received the highest accessibility absolute value, whereas, Municipal District 4 has received the second highest accessibility absolute score. On the other hand, based on unweighted accessibility without considering population and housing weights; Municipal District 4 is ranked first, and Municipal district 1 has been concluded as second. Whatsoever, all the aforementioned five municipal districts are categorized as high-level subdivisions in the Kandahar City and all together can be called as Central Business District (CBD). The results are also spatially reflected in Fig. 6 and Fig. 7.

5.3.2. Medium-level municipal districts

The results have shown that Municipal District 3, Municipal District 10, Municipal District 9, Municipal District 15 and Municipal District 12 are medium-level municipal districts within the city from the perspectives of spatial-based disaggregate accessibility, while taking urban land use sprawl, land use weights, population, housing and OD cost matrix (as impedance) in consideration. The medium-level subdivisions (municipal districts) actually covered larger areas in comparison with high-level municipal districts, however, given focus to the smaller sizes and quotients of seven significant urban land uses surrounding them, thus, leading to medium values of accessibilities (see Figs. 6 and 7).

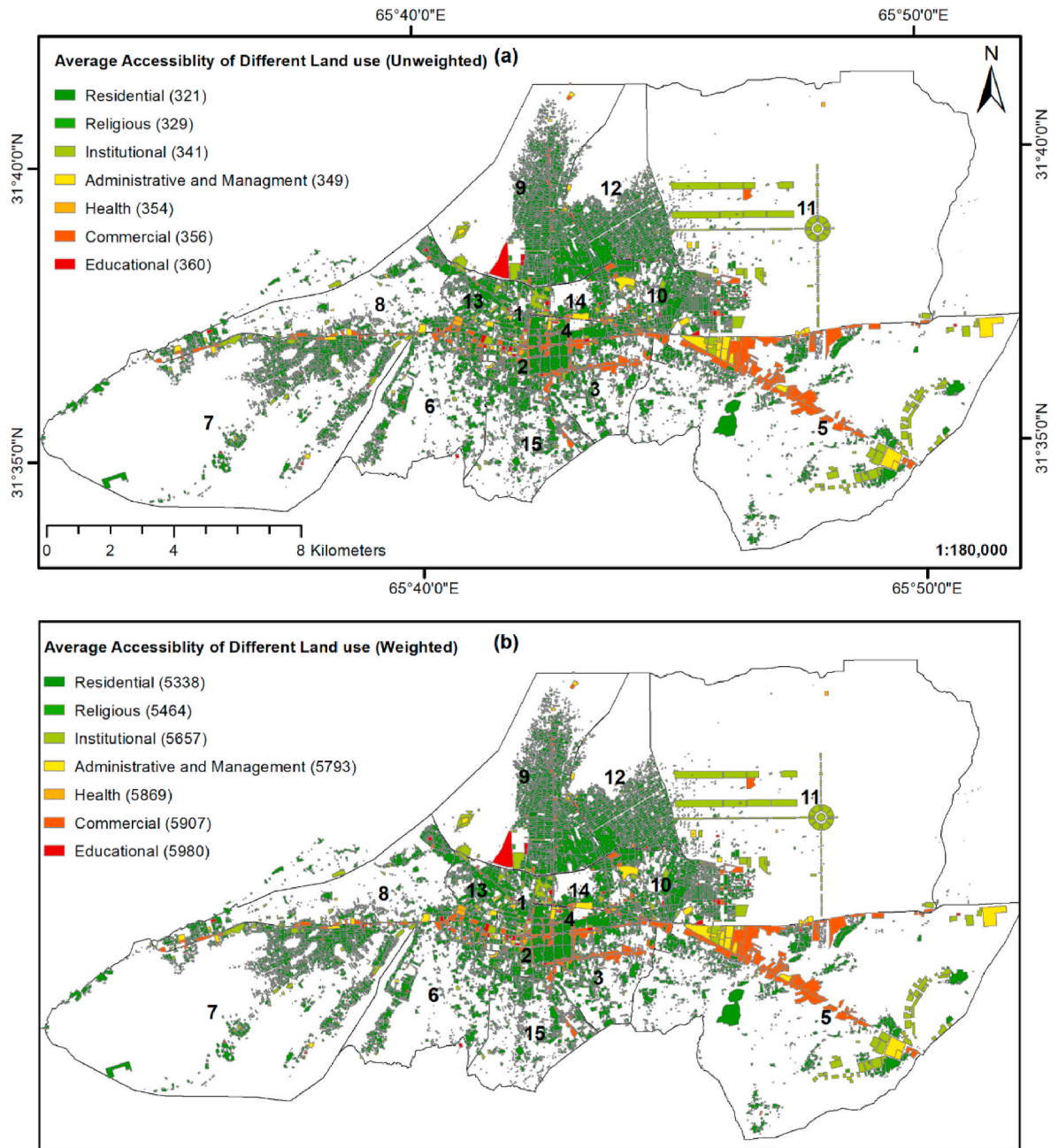


Fig. 5. Illustration of average accessibility of different land uses where indication starts from highest values, red, towards lowest values, green, (a) Accessibility score without population and housing weights b) Accessibility score with population and housing weights, see equations (10) and (15). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

5.3.3. Low-level municipal districts

These subdivisions are located at the periphery of the city where most of them have residential land uses except some notable commercial areas in Municipal District 5. The low-level municipal districts include; Municipal District 6, Municipal District 11, Municipal District 8, Municipal District 5 and Municipal District 7, also termed as peripheral areas. The study reveals that most of the land use quotients' values nearby them are less than one, whereas, urban land uses having high weights are located at the farther side to them, thus leading to having lower accessibility scores.

It is worth mentioning that, in fact, the Municipal District 11 is the most developed district in terms of having high road density along with modern residential land uses. Moreover, 54% of paved roads of the city are within Municipal District 11 connecting high quality single-family residential land uses with each other. However, the reason of being one of the low-level districts is that the main

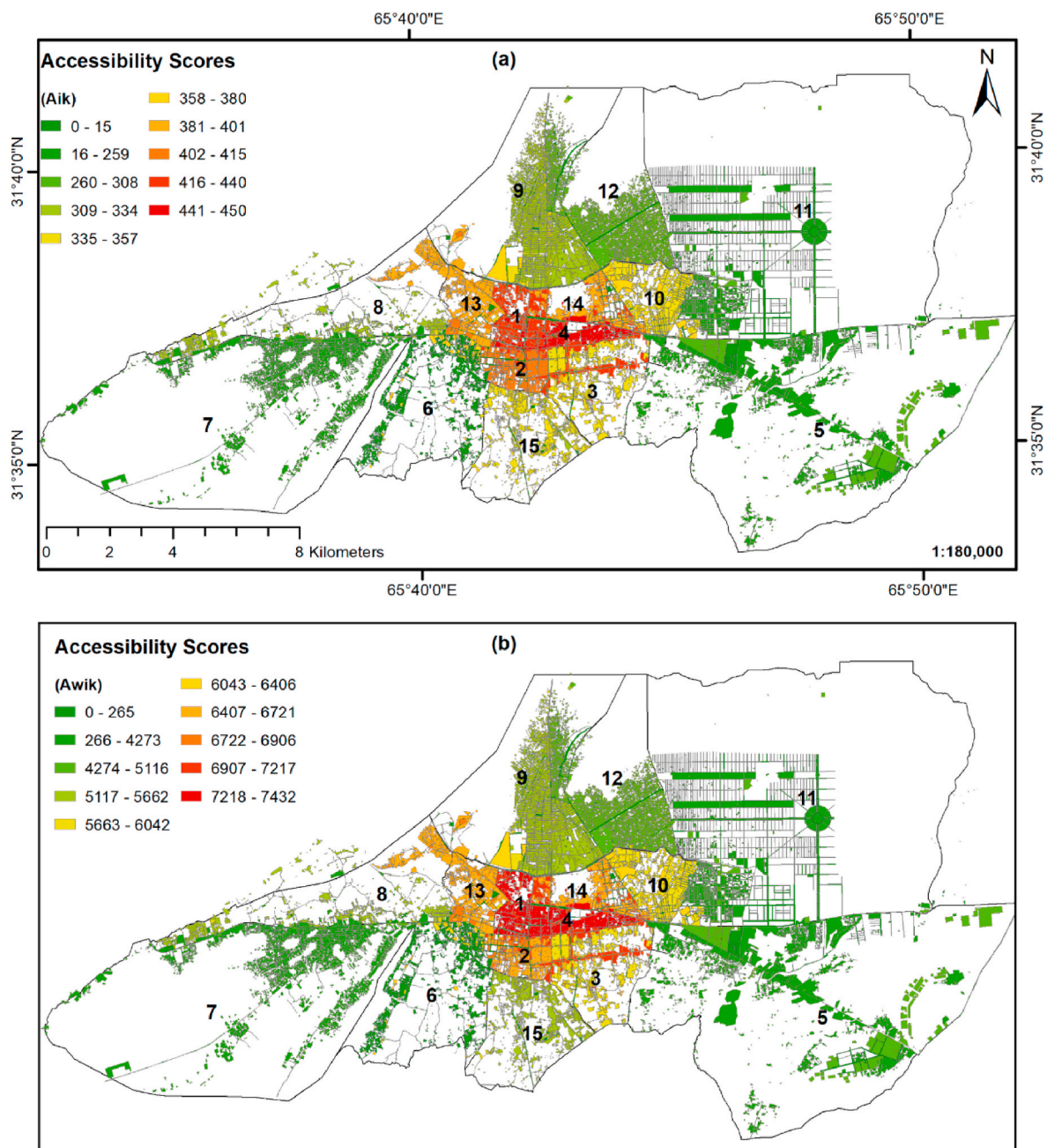


Fig. 6. Municipal district-based accessibility intensity (a) unweighted accessibility, A_{ik} (b) Weighted, A_{wik}

proxy of opportunities here is mixed land use weights estimated with equation (9), whereas, only 7% of land size within the Municipal District 11 is built up, the remaining 93% land is barren land and yet to be developed. Therefore, if the subdivision is not sufficiently developed with respect to its land size and lacks appropriate built-up or mixed urban land use, the formulated results as per the proposed methodology would be at the lower side as it is shown in Figs. 6 and 7.

6. Discussion and conclusion

The methodology of the research can be used as a helpful tool in the classification of the urban sprawl to figure out the deficiencies and obstacles towards balanced urban development. The study manipulates various influencing factors such as land uses, households, population, road transport network, travel time, and travel distance.

This study has employed a user-friendly methodology to assess and model the interactions of urban land uses with each other

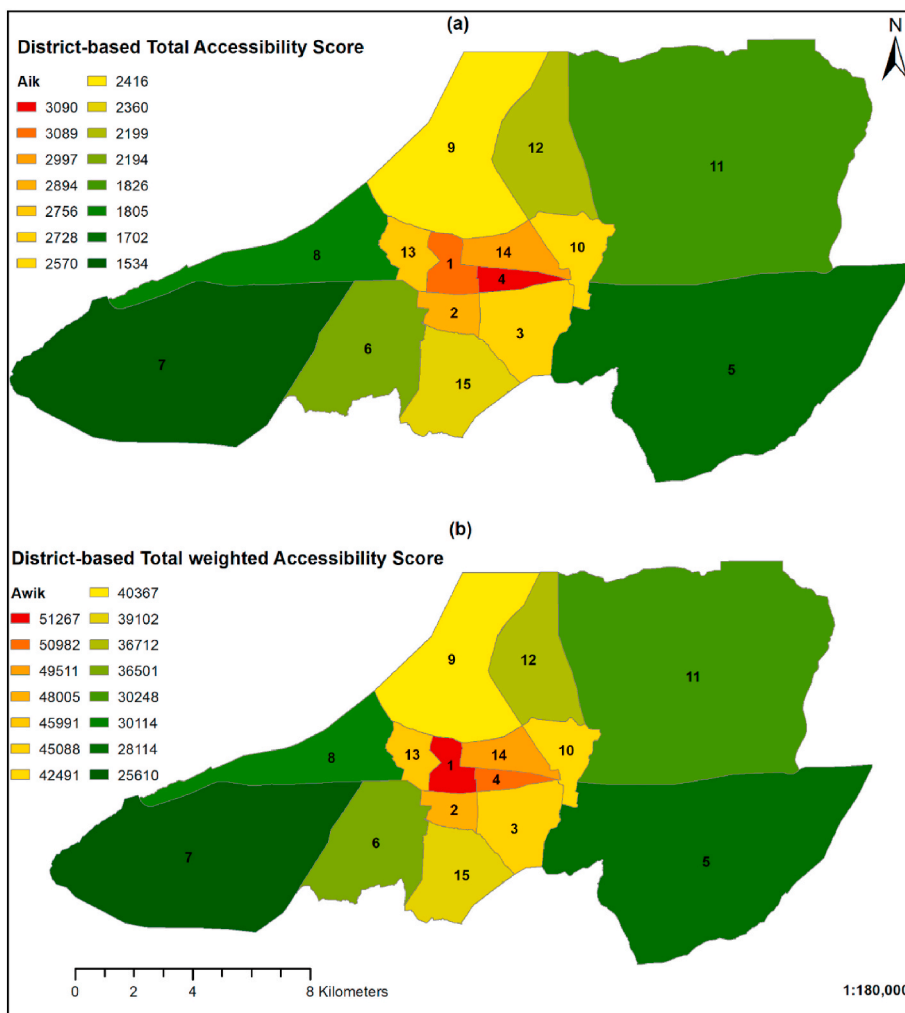


Fig. 7. Cumulative district-based accessibility scores illustrations (a) Cumulative unweighted accessibility, A_{ik} (b) Cumulative weighted accessibility, A_{wik}

connected through the road transport network. The results obtained from this research can be used to check the sustainability and development of urban sprawl from the perspectives of urban transportation and urban land uses within the subdivisions of the City. In actuality, the method proposed in this study would be more suitable to be used for the assessment of the cities in developing countries where finding reliable disaggregate data with regards to commuting flows between origins and destinations, and employment within the different destinations is many times a challenge for the researchers, planners, and decision makers.

The study has determined city level and municipal district level (subdivision-based) land uses and road network interactions using limited data, and presented a general scientific platform for the case studies of having the same characteristics. The following conclusions are drawn from the case study:

1. Urban land uses are the main contributor to this type of accessibility. Thus, the land sizes both in city and municipal district level play an important role as long as the land sizes represent urban built-up (seven influential and significant urban land uses). In other words, if the sizes of seven justified significant urban land uses in a particular subdivision are quantitatively not adequate with respect to the total area of subdivision the resultant land use quotients would be below than average, means, the larger is subdivision the larger should be the urban built-up to getting high value of land use quotients. As a result, it was found that all urban land uses associated with subdivisions having larger total area obtained low land use weights. For instance, most of the residential land uses have taken place in the largest subdivisions leading to be the second lowest contributor of accessibility.
2. Accessibility is the ease of reaching to opportunities or the intensity of the opportunities. In this case, in many pieces literatures, the emphasize is more on the opportunities at destinations and do not consider the origin's own opportunities in accessibility score, however, in this study the equations (10), (11), (15) and (16) are formulated such that an origin's i own land uses (proxy of opportunities) and nearby surrounding land uses are counted alongside all other destinations within the city without restricting them to a particular service or access areas. Means, service areas are not assigned to the origins, hence the interaction between all

105 origins and 105 destinations are taken into consideration.

3. The OD cost matrix is estimated for both travel time (in seconds) and travel length (in meters). The travel cost impedance functions $f(t_{ij})$ and $f(d_{ij})$ are formulated based on β_1 and β_2 sensitivity parameters, respectively.
4. Unweighted accessibility is determined with land use quotients and travel cost impedance functions, whereas, weighted accessibility is calculated by adding two more additional dynamics, namely, population and housing. The theoretical and statistical significances of all variables in both forms of accessibilities are explained through multiple regression analysis. The results have shown a high significance level meeting the required criteria to be termed as best fit models.
5. All in all, the results of the case example have shown that the 15 municipal districts of Kandahar City can be divided in three categories: a) High-level subdivisions: which can also be termed as Central Business District include; Municipal District 1, Municipal District 4, Municipal District 14, Municipal District 2 and Municipal district 13, b) Medium-level subdivisions: which can also termed as semi-urban areas include; Municipal District 3, Municipal District 10, Municipal District 9, Municipal District 15 and Municipal District 12. Lastly, c) Low-level subdivisions: which can also be termed as peripheral areas of the city with least development include; Municipal District 6, Municipal District 11, Municipal District 8, Municipal District 5 and Municipal District 7.
6. Although Municipal District 11 is considered in the low-level category, in fact, from the perspectives of road transport and residential land uses the district is the most developed district containing 54% of paved roads of the whole city connecting high quality single-family residential land uses with each other. The reason of being one of the low-level subdivisions is that only 7% of the subdivision area is built-up.
7. The study focuses on spatial-based accessibility to land use, by assuming that all significant seven land uses equally contribute as a proxy of opportunities in accessibility score. However, for further research, it is recommended to assign weights to various land uses depending upon the characteristics and intensity of land uses, and check it out with the interactions of public transport networks, e.g., BRT (Bus Rapid Transit), MRT (Mass Rapid Transit), etc.

Declaration of competing interest

The author declares that there is no conflict of interest.

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Not Applicable.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jum.2020.06.003>.

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