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Development of a GIS Based Public Transport Composite Social Need Index in Jeddah

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Abstract

Provision of public transport is critical for all social groups with high need. The provision of effective public transport system in Jeddah is at the top priorities of the national, regional and local plans. This paper attempts to develop a public transport composite social need index in Jeddah using GIS. Population density, car ownership, family size and income level indicators were considered for identifying the social need in Jeddah. Results indicate that Jeddah is in high social need for public transport and the provision of an efficient public transport is crucial for the city. The composite social need index has shown both dispersed and clustered patterns of high need for public transport in Jeddah. The results of this study facilitate the identification of the high social need for public transport in Jeddah. Further studies are highly recommended to include other social need indictors in Jeddah city.

1. Introduction

Rapidly growing cities confront with enormous challenges. High population growth rates, increased expansion of urban areas stimulate traffic and high dependence on private vehicle, causing congestion and consequent effects, for instance air pollution, greenhouse gas emissions and economic losses [1] [2].

Saudi cities are not an exception; main cities in Saudi Arabia experience these challenges. Jeddah, the second largest city, has undergone a rapid urban growth, land use changes and spatial expansion during the past 50

years. The population of Jeddah has rapidly grown from about 147,900 in 1964 to more than 3.5 million nowadays. In line with that, the urban area has extended from about 18,315 hectare in 1964 to about 60,000 hectare nowadays [2]. In addition to that, transportation infrastructure has expanded dramatically from about 101 km in 1964 to more than 850 km nowadays.

These changes have catalyzed notable travel pattern effects. Urban sprawl, lack of integrated planning framework and dramatic land use changes have caused a significant impact on the modal split [2]. The share of daily non-car trips has decreased dramatically. Trips with public transportation have decreased from about 19% of all travel modes in 1970 to about 2.3% in 2007 [2]. Moreover, the share of other modes, such as cycling and pedestrian trips, has declined notably from about 31% in 1970 to about 4.6% in 2007 [2]. Conversely, the percentage of daily trips by car has increased dramatically from about 50% in 1970 to about 96% in 2012. This has coincided with poor public transport coverage and service in Jeddah city.

This has stimulated high levels of mobility all over the city wherein congestion is widespread on Jeddah's streets in the morning and evening peak periods and in non-peak hours [3] [4]. The average speed on the highways and the main roads is lessening, and traffic safety is decreasing, while transportation emissions and average trip durations are increasing [2] [4].

To confront theses challenges, encouragement of effective public transport is vital. In fact, public transport is becoming an alternative to the private vehicle and highly used by different socioeconomic groups, given the high costs of individual transport, impact on environment, and continues increase of congestion in cities [5].

The provision of effective public transport is at the top priorities of the national, regional and local plans. It is a major priority in Jeddah city; thus understanding of the social need for public transport has received a little attention.

Geographic Information Systems (GIS) represent powerful tools for urban management and spatial analysis. GIS functionalities support the examination of urban spatial analysis, trends, and urban systems interaction [6]. Developed methods of spatial analysis have shown rich opportunities for urban analysis [7]. This paper attempts to develop a public transport composite social need index in Jeddah using GIS.

2. Methodology

2.1. Study Area

Jeddah is the second largest city in Saudi Arabia. Jeddah located in the western region of Saudi Arabia on the Red Sea eastern coast (**Figure 1**).

The rapid rates of urban growth over the last 5 decades have caused several challenges for Jeddah city. The travel pattern has been affected accordingly and this has catalyzed the car dependency wherein Jeddah people use private vehicle for about 96% of daily trips [8]. This has coincided with deficient public transport system [9]. Accordingly the provision of efficient public transport system is critical. However, to an efficient public transport, understating the social need for public transport is vital. This issue has received a little attention. Thus, this study attempts to develop a composite social need index for Jeddah using GIS. The extent of urban districts boundaries is considered in this study.

2.2. Public Transport Social Need Composite Index

In essence, various factors influence the need for public transport. Murray and Davis [10] developed an index to determine the public transport need based on attribute indicators of spatial units. Three indicators were used, *i.e.*: the family income, unemployment rates, and average family size. A weighting approach that combines these indicators was used to evaluate the public transport needs for each zone within the study area.

Currie [11] [12] proposed a transport needs index at district level. This index encompassed indicators for transport needs, namely: adults without cars, persons aged over 60 years, persons on a disability pension, low income households, adults not in the labour force, students and persons 5 to 9 years.

Yao [13] used a composite need index to measure the relative potential demand for public transport in a spatial unit. Three groups of factors for public transit ridership for commuting trips in Atlanta were identified. The first group was the land use characteristics which include: population density, employment rate (percentage of people who have jobs), job density (total jobs in the TAZ divided by the area of the TAZ), average number of jobholders per household, and percentage of home workers. The second group was the socioeconomic characteristics which encompass: income and car ownership. The third group was the network structure which includes
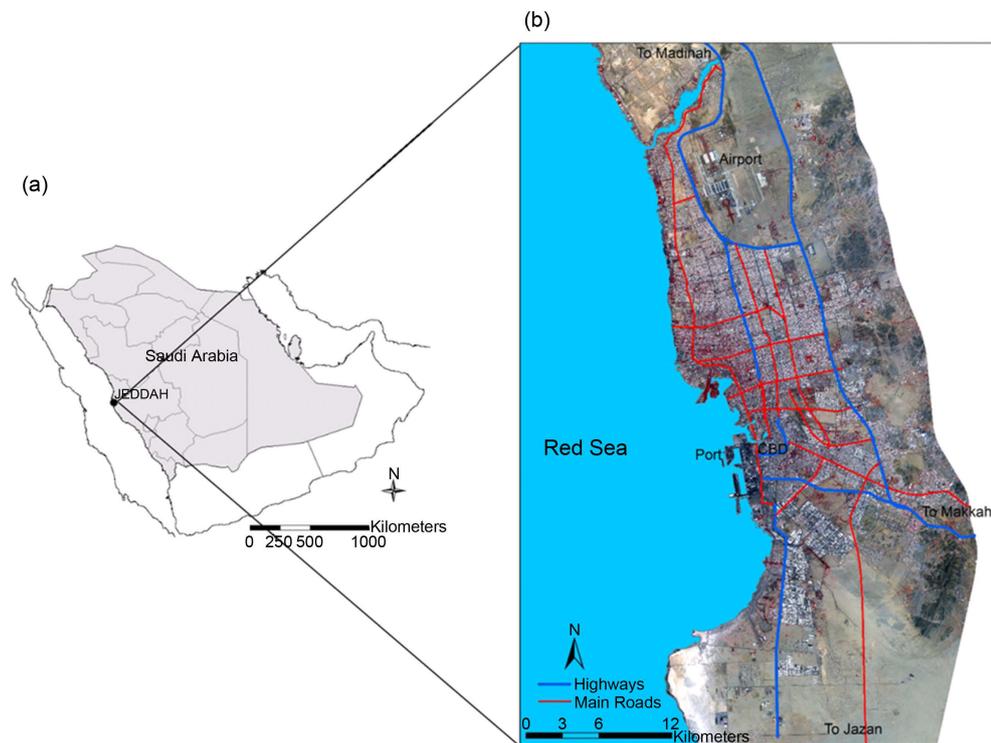
Figure 1. (a) Jeddah city location; (b) Jeddah urban boundaries.

the density of public transit stops in the TAZ.

In view of that four social indicators were considered. **Table 1** depicts the selected indicators which were based on a review of available socioeconomic data and related to public transport need. Population density, car ownership, family size and income level indicators at district level were considered.

A consistent weighting approach that evaluates the public transport social needs for each district within the study area was used. Each indicator was classified into three weights as followings:

- High: high need for public transport,
- Medium: medium (moderate) need for public transport, and
- Low: low need for public transport.

An absolute need scores from 3 to 1 (High = 3, Medium = 2 and Low = 1) were used in the weighting to standardize the value of indicators. Weight 3 represents districts with high social need for public transport while weight 1 represents districts with low social need for public transport. The weightings of each indictor into the three classes were based on the available data and sources [14] [15].

Subsequently, a composite social need index was developed. It was generated by adding the scores for each indicator together as followings:

$$CSNI = \sum PdI + CI + FsI + InI$$

where *CSNI* is the composite social need index, *PdI* is the standardized population density indicator, *CI* is the standardized car ownership indicator, *FsI* is the standardized family size indicator and *InI* is the standardized income indicator.

The composite social need index was standardized between 3 and 12 for all districts in the analysis in order to obtain need scores. Value 3 represents districts with low social need for public transport while value 12 represents districts with low social need for public transport. To quantify the composite social need, the results were then divided into three groups as followings:

- High: from 8 to 12.
- Medium: from 7 to 8.
- Low: from 3 to 6.

Table 1. Selected indicators and weight.

Indicator	Description	Weight
Population density	Person/hectare per district	3) High: >150 person per hectare 2) Medium: 75 - 150 person per hectare 1) Low: <75 person per hectare
Car ownership	Number of car per 100 persons per district	3) High: <20 car/100 persons 2) Medium: 20 - 30 car/100 persons 1) Low: >30 car/100 persons
Family size	Average family size per district	3) High: >5 person 2) Medium: 3 - 5 person 1) Low: ≤3 person
Income level	Average family income per district	3) High: ≤5000 SAR 2) Medium: 5000 - 15,000 SAR 1) Low: >15,000 SAR

2.3. Data Collection and Preparation

Different data sources were used to quantify the public transport social need indicators in order to calculate the composite social need index. **Table 2** indicate the data sources of the considered indicators.

For population density census data of 2007 were used. In conjunction with that, Jeddah urban observatory data of 2009 were considered for car ownership, car ownership, family size and income level indicators. However, the urban observatory data of 2009 were available for 58 districts out of 117 districts (the total of Jeddah urban districts). Thus, a questionnaire designed to collect data o the remaining districts.

The questionnaire has included three questions (closed-ended multiple-choice questions) to define data of car ownership, family size and income level indicators.

The questionnaire was simplified to take about 5 minutes in maximum to be completed. This timing was vital in order to raise the respondent rate. The survey was performed during the period from 10th March 2015 to 10th May 2016. The survey was conducted at the main attractions of each district (has no data) including shopping centres and main commercial arterials. Moreover, the questionnaire was posted online also using different social network sites. The respondent rate was high and the completed questionnaires were considered in the analysis.

3. Results and Discussion

The indicators of public transport social need in Jeddah are determined by district. **Table 3** and **Figures 2-6** show the results of the spatial analysis of the considered public transport social need indicators and the developed composite social need indicators.

Population density indicator depicts high transport need in different districts throughout Jeddah, **Figure 2**. It is noted that low need is dominant with this indicator as compared with high and medium need which reflected by the number of districts as depicted in **Figure 2** and **Table 3**. However, high and medium need districts exhibit majority of the population. It is noted that high and medium need districts concentrate at the city centre and drawn areas. Conversely, low need districts distributed all over Jeddah urban peripheries.

Figure 3 show the spatial distribution of the absolute scores of car ownership indicator. The districts which show high public transport need are concentrated in the city centre. The population with high and medium need are foremost under this indicator as compared with population with low need, as indicated in **Table 3**. However, medium need districts are dominant which reflected by the number of districts as depicted in **Figure 3** and **Table 3**. Medium need districts distributed all over the Jeddah urban peripheries and in some districts drawn to the city centre.

Family size indicator depicts high transport need in different districts throughout Jeddah, **Figure 4**. It is noted that high need is dominant with this indicator as compared with medium and low need which reflected by the number of districts as depicted in **Figure 4** and **Table 3**. It is also noted that high need districts exhibit majority of the population. It is noted that high and medium need districts concentrate at the city centre and drawn areas and disperse at north and south urban peripheries. Conversely, low need districts distributed all over Jeddah urban peripheries in a disperse pattern at the north and the east and concentrate at the south of Jeddah.
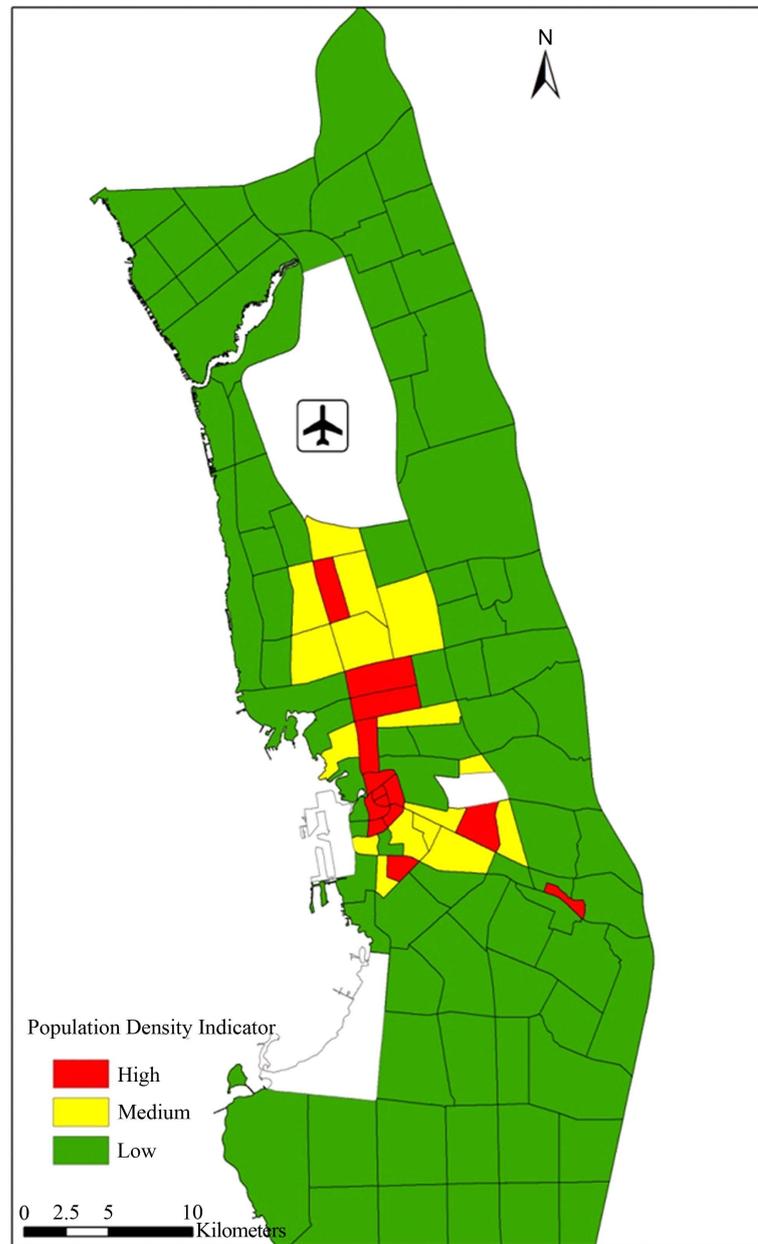
Figure 2. Population density indicator.

Table 2. Selected indicators and weight.

Indicator	Description	Source
Population density	Person/hectare per district	Census 2007
Car ownership	Number of car per 100 persons per district	-Jeddah Urban Observatory 2009[*] -Survey
Family size	Average family size per district	-Jeddah Urban Observatory 2009[*] -Survey
Income level	Average family income per district	-Jeddah Urban Observatory 2009[*] -Survey

[*]Jeddah Urban Observatory (2009). Districts GIS Indicators, Jeddah Urban Observatory, Jeddah Municipality.
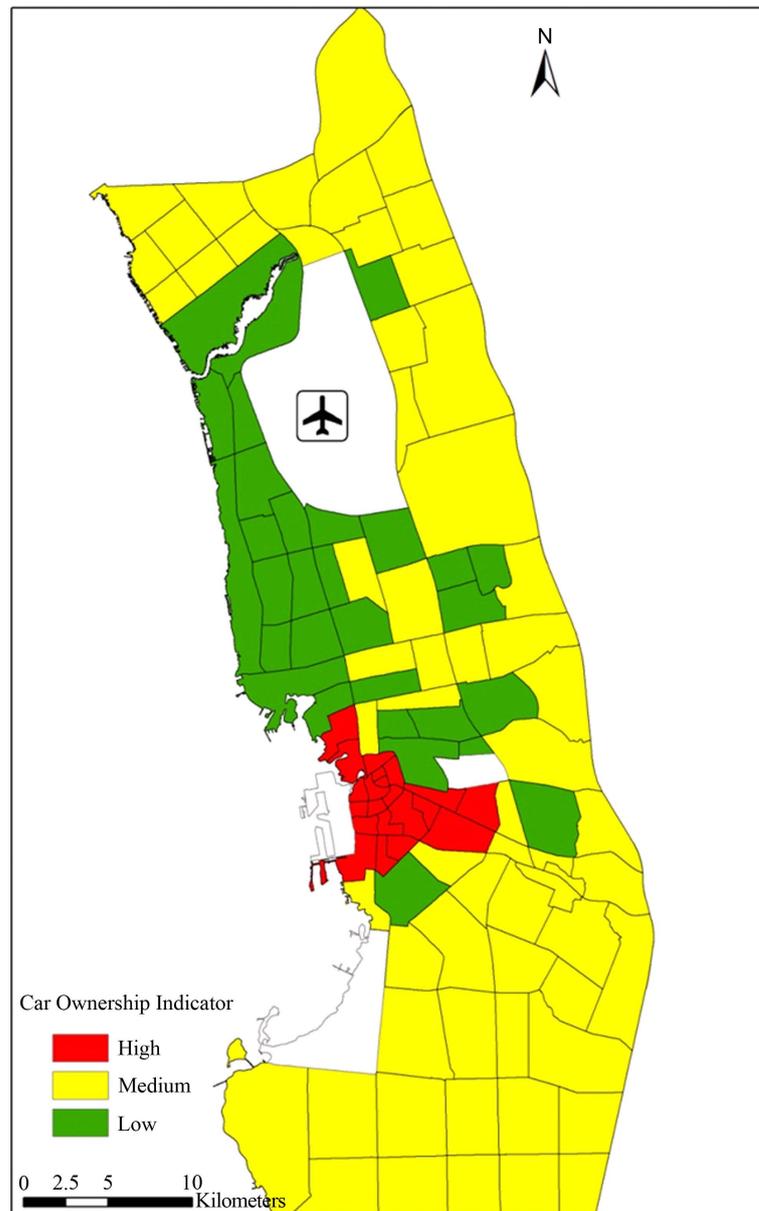
Figure 3. Car ownership indicator.

Table 3. No. of districts and population by transport need for each indicator.

Need	Population density indicators		Car ownership indicator		Family size indicator		Income level indicator		Composite social need index	
	Dist.	Pop.	Dist.	Pop.	Dist.	Pop.	Dist.	Pop.	Dist.	Pop.
High	14	876,831	23	834,142	49	1,598,123	25	615,505	27	1,524,833
Medium	16	1,181,026	62	945,999	25	1,218,341	69	1,779,761	35	892,056
Low	83	781,379	30	1,059,095	39	22,772	19	443,970	51	422,347

Figure 5 show the spatial distribution of the absolute scores of income level indicator. The districts which show the high public transport need are concentrated in the city centre and slightly disperse at the east and the south of Jeddah. The population with high and medium need are foremost under this indicator as compared with
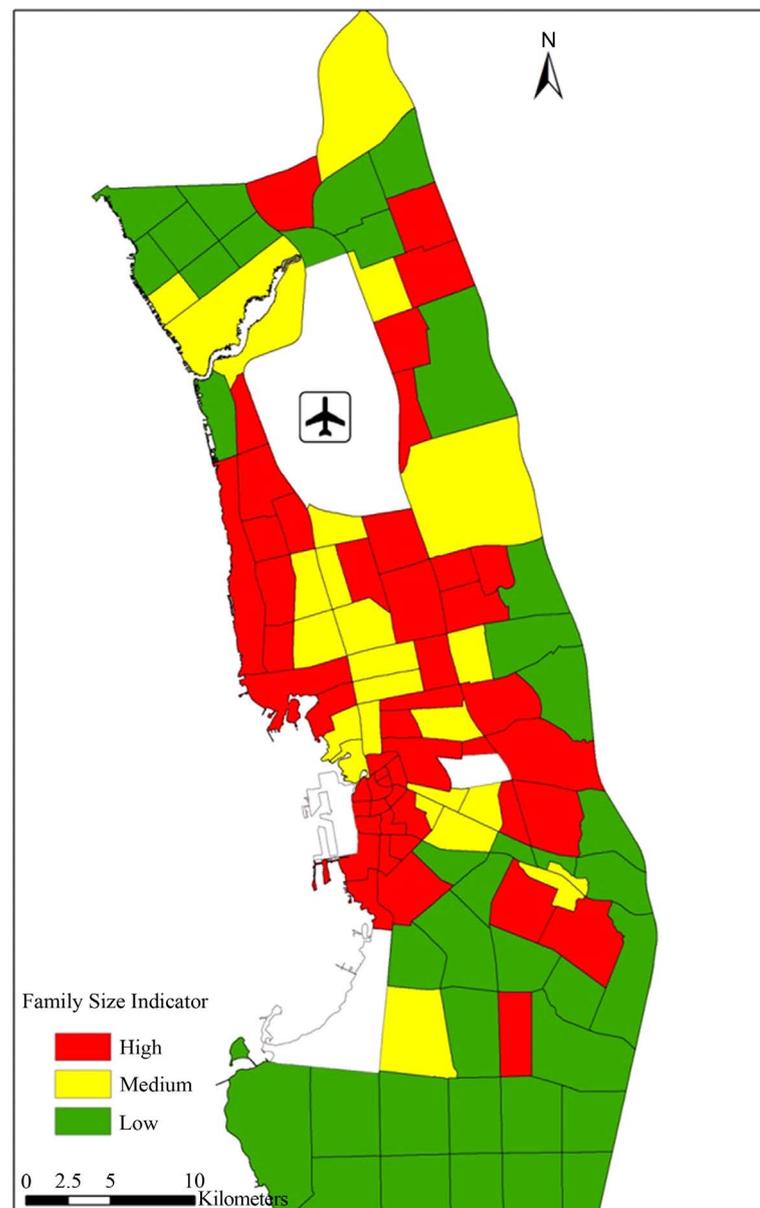
Figure 4. Family size indicator.

population with low need, as indicated in **Table 3**. However, medium need districts are dominant which reflected by the number of districts as depicted in **Figure 5** and **Table 3**. Medium need districts distributed all over the Jeddah urban peripheries and in some districts drawn to the city centre.

It is noted that car ownership indicator and income level indicator exhibit a comparable spatial distribution of public transport need, as shown in **Figure 3** and **Figure 5**. However, the population of these indicators differs. Conversely, population density indicator and family size indicator exhibit a different spatial distribution pattern of public transport need. These indicators also show a different population of high, medium and low needs.

The result of composite social need index, which combines all the considered four indicators, show both dispersed and clustered patterns of high need for public transport in Jeddah. It is found that districts with high social need are concentrated and clustered in the city centre, while some districts are found at the north of the city centre, **Figure 6**. Medium need also exhibit the clustered and a dispersed pattern of districts at area drawn to the city centres and at the north, east and south of Jeddah city. It is noteworthy that high and medium need districts are dominant and spatially connected, **Figure 6**. Notably, about 53% of Jeddah population are in high social
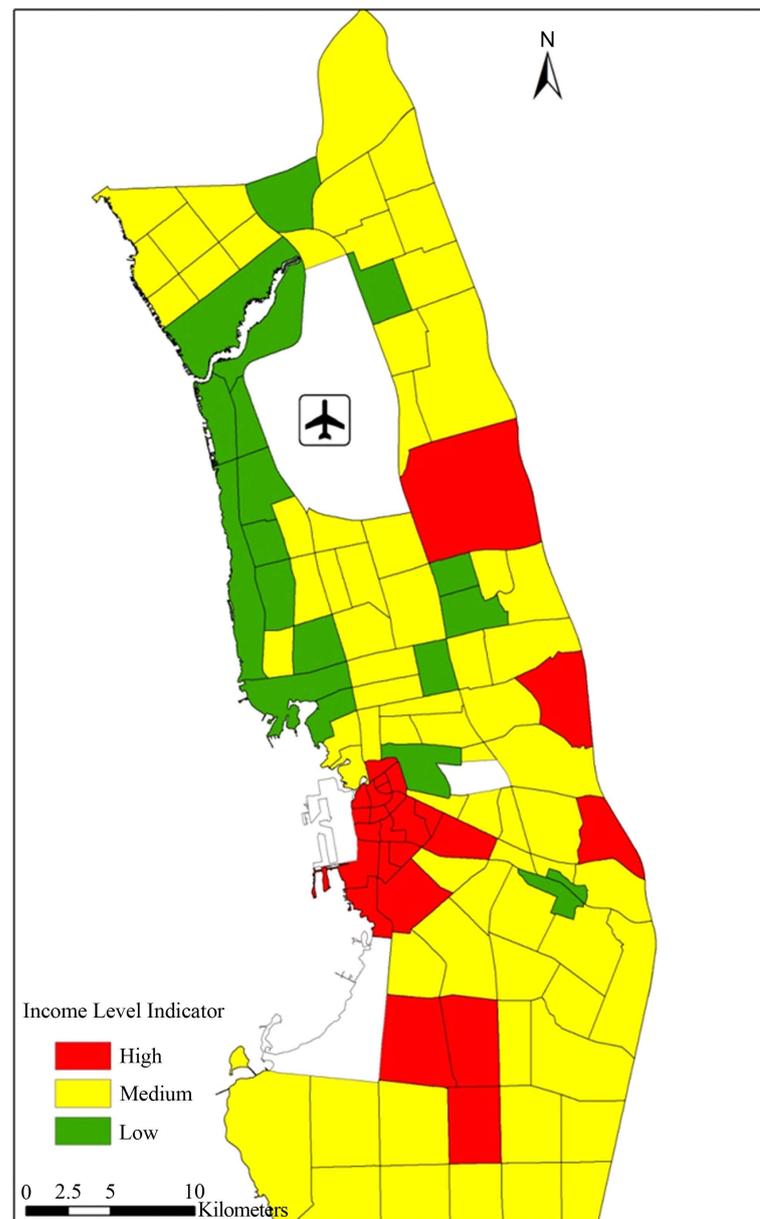
Figure 5. Income level indicator.

need for public transport, about 32% are in medium social need for public transport, and about 15% of Jeddah population are in low social need for public transport, **Table 2**. This indicates that Jeddah is in high social need for public transport and the provision of an efficient public transport is crucial for the city.

Public transport is important for social inclusion, for providing access to reach activities and services such as work, education, health, shopping and social-recreational activities [16]. The provision of public transport depends on demand which is based on the population need. This paper has developed a composite social need index for Jeddah using GIS. GIS has shown the capability of identifying, visualizing and calculating the social need for public transport. This index facilitates the identification of social need for public transport in Jeddah and assists transportation planners for high social inclusion in planning the routes of public transport system.

4. Conclusion

This paper has developed a composite social need index for public transport in Jeddah using GIS. Population
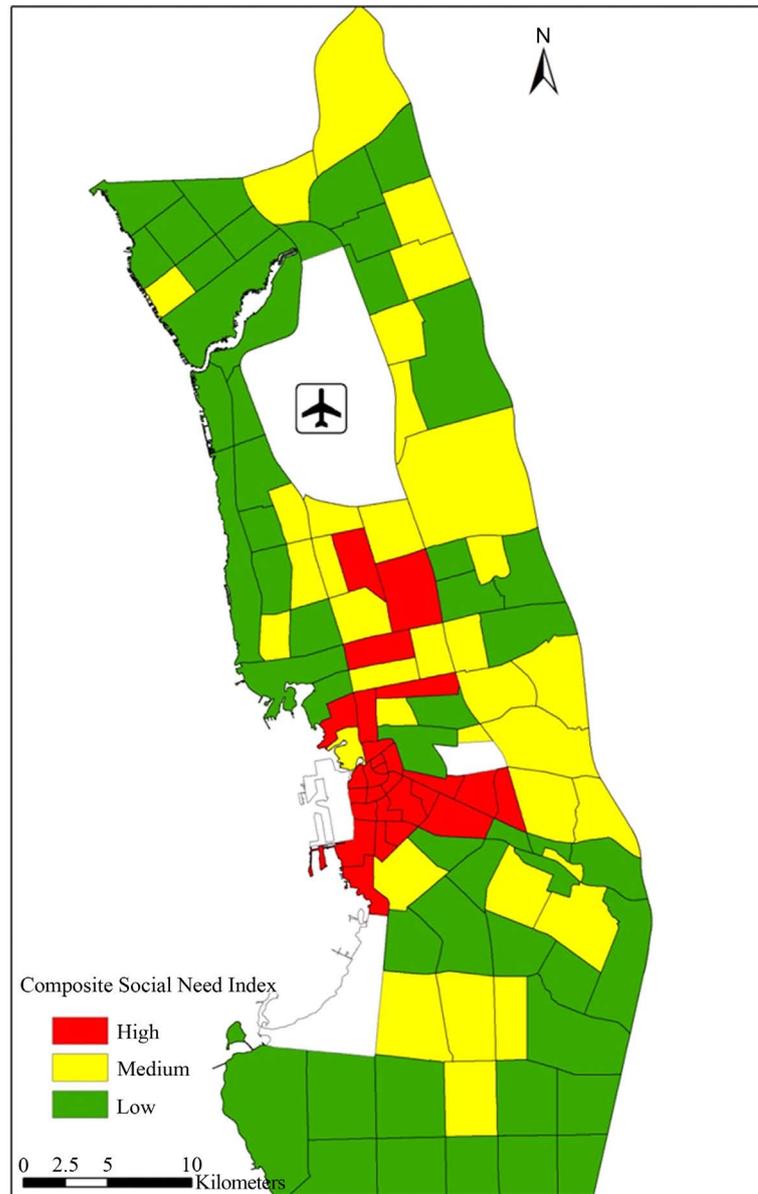
Figure 6. Composite social need index.

density, car ownership, family size and income level indicators were considered for identifying the social need in Jeddah. The composite social need index has shown both dispersed and clustered patterns of high need for public transport in Jeddah. Districts with high need are concentrated and clustered in the city centre, while some districts are dispersed at the north of the city centre. This index reveals that Jeddah is in high social need for public transport and the provision of an efficient public transport is crucial for the city. The results of this study facilitate the identification of potential demand for public transport in Jeddah and assist transportation planners for high social inclusion in planning the routes of public transport system. GIS has shown the capability of identifying, visualizing and calculating the social need for public transport. Although this study has provided valuable information, it must be noted that available data don't depict all the social need in Jeddah. Thus, further studies with the same methodology are highly recommended to include other social need indictors in Jeddah city.

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