Measuring Walkability with Street Connectivity and Physical Activity: A Case Study in Iran

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Abstract: The walkability of urban areas is an important criterion related to the level of physical activity and public health of citizens. This research aims to measure this parameter in Golsar town located in Rasht, Iran. Two methods were used in this research: Street connectivity and International Physical Activity Questionnaire (IPAQ). The principal variables of street connectivity were measured in four districts of Golsar by Geographic Information System (GIS) to rank each one. Then, the acquired results were compared by the average walking time of the respondents of the questionnaire. The comparison explicitly indicated that there is a strong positive correlation between the measures of street connectivity and people’s tendency to walk. As well, District 1 had the highest value of connectivity and the highest average time for walking amongst the four districts. This supports the contention that walkability and the level of outdoor physical activities of people in each district are undoubtedly under the influence of the variables of street connectivity. Nevertheless, the evaluation of other indexes such as proximity, land use mix, safety, and density in Golsar, in future research, can expand our perception of the walkability of this region.

Keywords: walkability; street connectivity; physical activity; healthy city; IPAQ

1. Introduction

Walking is one of the affordable, major, and most elementary types of physical activity [1], that provides a sustainable means of transport and leisure [2]. Walking can be done alone at any time and can be embedded in our routine plans without special equipment or clothes, or consumption of fossil fuels. It is the most popular and inexpensive habitual practice among adults of all ages [3–6]. Not only is regular walking recommended to keep people healthy through the prevention of many diseases, such as cardiovascular disease, obesity, and diabetes, but it also associated with positive social interactions, economic benefits, and their mental health [7–9]. Besides, the US National Research Council and US Institute of Medicine [10] reported: “The factors in the physical environment that are important to health include harmful substances, such as air pollution or proximity to toxic sites; access to various health-related resources; and community design and the built environment”. The solution for most of these dangerous threats can be discovered by physical activity resulted from the type of urban design and planning [11]. Increasing walking activities in cities through changes in the design of built environments is an outstanding policy with some advantages in several areas such as sustainability, health, social ties, economic transactions and traffic [12,13].

The need for research about the influence of the built environment on public health and their relationships has been stressed by the World Health Organization (WHO) [14–17]. Many health professionals invited architects and urban designers to react against the sedentary lifestyle by using the design of the built environments [18]. Therefore, the analysis of the urban environment has remarkably increased in the fields of urban planning and...
geography, and public health and well-being in recent decades for the encouragement and facilitation of walking [19,20]. Urban designers and planners have focused on the characteristics of better walkable cities or neighborhoods, the correlation between walking, walkability, and built environments, and measuring physical activities in cities [21–23]. In this case, in addition to improving the health-oriented urban spaces by regarding walking as an important priority in urban studies [24,25], they can achieve transportation and environmental goals (e.g., decreasing car dependency or reduction of exhaust fumes and emissions) [26,27].

2. Literature Review

2.1. Walkability

The term ‘walkability’ means compatibility, attractiveness, and opportunity of built environments in a street or a neighborhood for walking [20,28–31]. It is a general definition for this term although some recent literature has revealed a conflict in the interpretation of walkability and measuring its indexes [32,33]. The manner of defining walkability has significant connections to the perception of street networks, urban transportation, and the design of public spaces and streets [34]. The researchers considered walkability as a determinative factor for the quality of urban space and citizens’ lives [35,36], as well as quantitative aspects of walking [32]. It is referred to as characteristics of the built environment that can help people to walk for different purposes, either leisure or access destinations [29], compelling them not to use their cars [4,37]. In fact, a deeper understanding of walkability encompasses both selectable plans of walking (e.g., walking to the workplace, shopping center, etc.) or leisure-related mobility [32,38] for various types of citizens [39], and health advantages [40]. Numerous publications acknowledge the function of walkability as a supplier of public health [41] and positive relations between different amounts of walkability in cities and people’s physical activities [42,43].

Features of the urban built environment ranging from the form of the cities to improved pedestrian crossings can change our movement and whatever we do within the urban areas [44,45]. In particular, urban design can change and facilitate our travel behavior in cities, including the quantity and quality of walking, cycling, public transport, and commuting by personal cars [46,47]. A positive intervention in these features of the built environment supports active transportation (walking and cycling), encouraging populations to walk or ride a bicycle instead of using motor-vehicles [11,12,31,48]. Accurate design of the built environment plays a vital role in walkability because it promotes more accessible, convenient, attractive, and efficient local neighborhoods [1,49], which in turn produces notable health benefits [50].

Frank et al. [41] proposed the first composite walkability index that includes land use mix, connectivity, and residential density within a buffer around a residence. Since then, many scholars have identified that several variables within a framework of 3D’s are the cornerstone of the definition and assessment of walkability: Density, land use Diversity (Land use mix), and pedestrian-oriented Design (Street connectivity) [4,41,51–53]. These are three large-scale features of the design of neighborhoods associated with walking and physical activity [54,55].

Density gathers more people and places in walkable spaces [32]. For instance, residential density is one of the most influential built environment factors that change people’s interests in walking or cycling instead of other types of transportation [45,56]. The land use mix provides a greater variety of walkable destinations and activities in a geographic location [45,51]. In other words, mixed land use leads to provide daily destinations of a spectrum of people within closer proximity and with less distance travel [57]. Furthermore, better street connectivity provides shorter routes and better traffic flows [32,51].

2.2. Street Connectivity

In contemporary decades, urban planners and researchers of transportation have analyzed walkability in urban environments and predicted more than 56 various items
or indicators that can be useful for walking behaviors. Among the most notable of these items are accessibility, land use mix, safety, comfort, density, connectivity, attractiveness, proximity, public transport supply, street layout, and so on [44]. One of the main environmental features that could exert direct or indirect impacts on active transport and physical activity is connectivity [48]. In a general view, street connectivity refers to the density of connections and the directness of links in the road network of cities [4,31,41] to simplify the movement between the origins (e.g., houses) and the destinations (e.g., shops) [55].

In the definition of this index, a well-connected road system should have numerous short links (a street between two intersections or from a dead-end to an intersection) and several nodes (including three- or four-way intersections and end of dead-end streets) with a few numbers of cul-de-sacs [44]. A road network with better connectivity contributes to more road options and more direct routes [58], minimizes distances between origins and destinations [14,59], increases walkability [48], and consequently, makes physical activity, bicycling, and walking more appealing and convenient [35]. In fact, “Research has generally shown more people walk in neighborhoods that have connected sidewalks and provide shorter walking distances and more route choices to destinations” [60] (p. 2). The main determinant factors in people’s decisions for walking are shortness, directness, and continuity of paths that are all under the influence of street connectivity [61].

Many studies have investigated connectivity based on various variables. In this research, 10 variables were studied: intersection density, street density, block density, cul-de-sac density, average block length, median block length, connected node ratio, link node ratio, alpha index, and gamma index. The definition and the methods of measurement of each variable in the built environment will be discussed, respectively.

This research aims to evaluate the impact of street connectivity as one of the most important criteria of walkability on the amounts of walking and cycling of the residents in a neighborhood area and whether better street connectivity in a district necessarily leads to an increase in the physical activities of people in it. By comparing the measurement of street connectivity in a town and the residents’ outdoor physical activities, we can achieve a better understanding of the role of connectivity of streets in walkable neighborhoods.

3. Research Methods

Several methods emerged from various fields of study (urban planning and architecture, transport engineering, public health, social sciences) to measure walkability in a determined urban area [62]. These methods entailed audit tools, checklists, questionnaires, surveys, inventories, level-of-service scales such as IPAQ (International Physical Activity Questionnaire) to assess the physical activity [63], Neighborhood Environment Walkability Scale (NEWS) [64], Indicators of Accessibility and Attractiveness of Pedestrian Environments (IAAPE) [62], Walk Score [65], Walkability Index [66], as well as Connectivity of streets [48,67]. After reviewing the backgrounds about the importance of urban design in public health, the role of connectivity of streets on walkable neighborhoods, and the way walkability of neighborhoods affects the physical health of citizens, it is required to measure the variables of street connectivity.

3.1. Variables of Street Connectivity

Ten variables related to street connectivity were selected in this research. The variables are:

1. Intersection density: This indicator measures the ratio of intersections in a unit area [29,68]. It shows the density of intersections in each district by dividing the number of three- or four-way intersections by the area of the district. A higher number means more intersections that lead to more connectivity [41]. In this research, we designate a weight of 0.5 for a three-way and 1 for a four-way intersection [69].
2. Street density: The street network density is measured as the total length of streets per unit of an area [58]. To calculate this variable, we need to divide the sum of the length of all links by the area of the district. A higher density is equal to a higher connectivity [67].
3. Block density: Block density or census block density is the total number of blocks in a district divided by its area. Higher block density means smaller blocks and, as a result, higher connectivity [70,71].

4. Cul-de-sac density: This index of connectivity is defined as the number of all cul-de-sacs per square km [72]. The fewer cul-de-sacs, the more intersection, and the higher connectivity [73].

5. Average block length: “Block lengths can be measured from the curb or the centreline of the street intersection. The Geographic Information System (GIS) measures the street length from centre of intersections. Shorter blocks mean more intersections and therefore a greater number of routes available” [58] (p. 6). To measure this variable, the total length of links should be divided by the number of nodes in an area. There is an inverse relationship between the average length of streets and connectivity [70].

6. Average block section: Other block-based connectivity variables such as block area, perimeter length, and face length are not reliable because of some underlying flaws in their ratios [74]. “An alternative block-based measure that resolves these issues is the ‘block section’, defined as the maximum distance between any two points on the perimeter of a block, or an area enclosed by the designated route network” [74] (p. 4). The minimum block section means better connectivity.

7. Connected node ratio: It is equal to the proportion of real nodes to the total of all nodes calculated by dividing the number of three-way and four-way intersection by the sum of all nodes, including cul-de-sacs within a study area. The maximum ratio is 1 representing a more connected street network [48,75].

8. Link node ratio: This variable is defined by dividing the number of streets (links) by the total number of real nodes in a district [64]. Notwithstanding, the perfect value for a grid network is 2.5, a link node ratio of 1.4 or more is a desirable target for urban planners in the term of connectivity of street [76].

9. Alpha index: The alpha index is the proportion of the number of real circuits to the highest possible number of circuits [41]. This feature of geography studies ranges from almost 0 for poorly connected networks to about 1 for higher connectivity [58]. The formula of the Alpha index is as follows:

\[
\alpha = \frac{\#\text{Links} - \#\text{Nodes} + 1}{2(\#\text{Nodes}) + 5}
\]

10. Gamma index: “The gamma index builds further on the link node ratio and is a ratio of the number of streets in the network to the maximum possible number of streets between intersections” [41] (p. 38). This is a good index to represent the street network. The higher ratio for the gamma index results in better connectivity [48]. It was calculated as below:

\[
\gamma = \frac{\#\text{Links}}{3(\#\text{Nodes} - 2)}
\]

The GIS is a digital technology to analyze, visualize, and record spatial data with a combination of hardware and software [77]. It enables users to map geographic aspects of data from different resources and integrate them [78]. The framework of GIS has a great capacity of surveying to deal with plenty of spatial issues in several interdisciplinary subjects [79]; therefore, the GIS software (ArcView version 3.3) was used to determine the value of each variable of street connectivity based on their mentioned definition within each district individually. Subsequently, the self-reported physical activity of the residents was measured with IPAQ. This standard questionnaire was used to measure the amount of walking and physical activities of participants in the past seven days [46]. In a validation study in 12 countries, self-reported data of IPAQ demonstrated acceptable reliability [63].
3.2. Sample Size

The sampling was a simple random method. To calculate an ideal sample size, we used Cochran’s Formula (\(z = 1.96\), \(q = p = 0.5\)).

\[
n = \frac{z^2pq}{d^2} \left( 1 + \frac{z^2pq}{d^2N} \right)
\]

In this case, through considering 115,000 for the total population (\(N\)) and 0.05 for the desired level of precision (\(d\)), the number of 383 was determined for the number of all participants (\(n\)). Thus, 96 participants are sufficient in every district. Adults living and working (if they had a job in the last week) in a district were randomly chosen to answer the questionnaire. Finally, Pearson’s formula has been used to clarify the correlation between the parameters of street connectivity and walkable districts in Golsar. The results are described in the next section meticulously.

3.3. Statistical Analysis

For a better analogy, the values of street connectivity in Table 1 were normalized between 0 and 1 in Table 2. The higher scores for the applied variables signify the better condition for walkability according to street connectivity. The following formula was applied to normalize the values. Assuming: \(Z_{ij}\) = value of criterion \(j\) for county \(i\); then:

\[
r_{ij} = \frac{Max Z_{ij} - Z_{ij}}{Max Z_{ij} - Min Z_{ij}}
\]

where \(r_{ij}\) is the required normalized value of a variable. However, for three variables (cul-de-sac density, average block length, average block section), in which fewer values mean better connectivity, this formula is as follows:

\[
r_{ij} = \frac{Z_{ij} - Min Z_{ij}}{Max Z_{ij} - Min Z_{ij}}
\]

Table 1. Values of 10 variables of street connectivity in four districts of Golsar.

| Variables             | District 1 | District 2 | District 3 | District 4 |
|-----------------------|------------|------------|------------|------------|
| Intersection Density  | 135.01     | 154.61     | 130.84     | 111.29     |
| Street Density        | 25.49      | 27.10      | 25.52      | 24.56      |
| Block Density         | 90.40      | 95.63      | 80.22      | 72.18      |
| Cul-de-sac Density    | 48.77      | 71.19      | 59.51      | 57.14      |
| Average Block Length  | 72.33      | 66.60      | 70.70      | 76.56      |
| Average Block Section | 91.39      | 95.70      | 96.38      | 100.02     |
| Connected Node Ratio  | 0.767      | 0.724      | 0.730      | 0.685      |
| Link Node Ratio       | 1.339      | 1.302      | 1.272      | 1.290      |
| Alpha Index           | 0.169      | 0.150      | 0.135      | 0.144      |
| Gamma Index           | 0.450      | 0.437      | 0.427      | 0.433      |
Table 2. Normalized values of the street connectivity in four districts.

| Variables          | District 1 | District 2 | District 3 | District 4 |
|--------------------|------------|------------|------------|------------|
| Intersection Density | 0.54       | 1          | 0.45       | 0          |
| Street Density     | 0.36       | 1          | 0.37       | 0          |
| Block Density      | 0.77       | 1          | 0.34       | 0          |
| Cul-de-sac Density | 1          | 0          | 0.52       | 0.62       |
| Average Block Length | 0.42     | 1          | 0.58       | 0          |
| Average Block Section | 1        | 0.50       | 0.42       | 0          |
| Connected Node Ratio | 1         | 0.47       | 0.54       | 0          |
| Link Node Ratio    | 1          | 0.44       | 0          | 0.27       |
| Alpha Index        | 1          | 0.44       | 0          | 0.26       |
| Gamma Index        | 1          | 0.43       | 0          | 0.26       |
| **Total**          | **8.09**   | **6.28**   | **3.22**   | **1.23**   |

3.4. Correlation Coefficient

At the end of the results and discussion, the Correlation Coefficient (Pearson’s $r$) was used to find the correlation of the street connectivity and physical activity. It is a useful theorem of statistics to measure the linear correlation between the two types of variables ($X$ and $Y$). In this study, these variables referred to street connectivity (normalized values assuming as $X$) and the average time for walking and cycling based on IPAQ (minutes per week assuming as $Y$) in the districts of Golsar. The formula of Pearson’s $r$ for a sample is:

$$r_{xy} = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2} \sqrt{\sum (y_i - \bar{y})^2}}$$

In this formula, $-1 \leq r_{xy} \leq 1$ where higher value means a perfect positive linear correlation, 0 is no linear correlation, and the lower value indicates a negative linear correlation.

4. Results and Discussion

This article firstly reviewed the literature on walkability, street connectivity, and its variables. In this section, walkability was analyzed in a case study and compared based on two methods: measuring the variables of street connectivity and physical activity to find the connection between street connectivity and real walking behaviors of residents. This process has been conducted to show a correlation of street connectivity and outdoor physical activities, and the role of the variables of street connectivity in public health, walking habits of people in Golsar, and urban development in this region.

4.1. Case Study

The selected case is Golsar town in Rasht, geographically located in the North of Iran, with an urban population of 748,711 in 2016 and with an area of 180 km$^2$. This town with around 115,000 population is one of the high-density residential areas in the city and can be considered as an upscale neighborhood (Figure 1). Based on the information of the municipality, four districts of Golsar were chosen to focus on neighborhood walkability and street connectivity (Figure 2). The research paper identified useful understandings of the positive and negative effects of street design in Golsar that are one of the main options of citizens of Rasht to buy or rent houses and apartments despite the high price of estates.
4.2. Street Connectivity

First, the definition of variables was explained in the Section 3. In this part, for the assessment of street connectivity, values of 10 variables for each district in Golsar town should be calculated by using GIS data. The information concerning the 10 variables was extracted via GIS software (ArcView) in each district (Table 1). In addition, the measures of variables are shown in Figure 3 in three groups of bar charts. Group 1 includes intersection (ID), street density (SD), and block density (BD). Group 2 consists of cul-de-sac density (CD), average block length (ABL), and average block section (ABS) in which a small number means a better one. Group 3 includes connected node ratio (CNR), link node ratio (LNR), alpha index (AI), and gamma indexes (GI). As shown, District 1 ranked the first in six variables, including cul-de-sac density, average block section, connected node, and link node ratio, as well as alpha and gamma indexes. It means that regarding these measures, the total measure of connectivity of streets in District 1 is better than others. However, District 2 possessed better connectivity according to these four variables: intersection, street, and block density, as well as average block length. District 4 had the worst condition in six variables in comparison with other districts. Additionally, District 3 had a similar condition with a minimum amount in the last three variables: link node ratio, alpha, and gamma indexes.
The assessment of street connectivity in the four districts demonstrates a complicated pattern of correlation. Measures of the variables in Group 1 are positively related to each other but inversely associated with cul-de-sac density. The ranking order of districts in measures of block features (average block length and section) is different. It was predictable that there are strong positive relationships between the variables in Group 3. Additionally, there was a meaningful discrepancy between variables in Group 1 and Group 2.

The normalized results presented in Table 2 will be \(0 \leq r_{ij} \leq 1\), with higher \(r_{ij}\) values being more desirable for walkability. The analysis revealed that District 1 with 8.09 had the maximum, and District 4 with 1.23 had the minimum score of street connectivity in the Golsar town. District 2 with 6.28 and District 3 with 3.22 possessed the middle positions.

The choropleth maps in Figure 4 show the results of normalized variations of the above table for each variable and total amount in four districts of Golsar town. A choropleth map is a type of thematic map used for visualizing the values of a parameter over a geographical area through the color spectrum. In this figure, colors changed from light to dark green (from 0 to 1) to represent the changing of the values of the variables of street connectivity in Golsar. Darker green displays a better normalized value and lighter green displays a worse one. The variation of the total values from 0 to 10 can be seen in the largest frame. District 1 has the first rank in six variables including cul-de-sac density, average block section, connected node ratio, link node ratio, alpha index, and gamma index. However, District 2 has the most value in the remaining variables. Except for cul-de-sac density, which in District 2 has the lowest value among all districts, District 3 or 4 possesses the last rank in the other nine parameters of street connectivity.

4.3. Physical Activity

Statistic population of this study was in the 18–69 age group among 115,000 people living and working in Golsar. The details of demographic variables (age, sex, employment rate, and living location) of the mentioned population can be found in Table 3.

The IPAQ, as a reliable standard questionnaire, has been designed to evaluate the physical activity of a population across all domains of their work, transportation, leisure-time, and household tasks. In this step, the walking and cycling of people for their work, transportation, and leisure-time have been examined and compared because our focus is on their outdoor physical activities. The participants were 32.3 ± 12.7 years old, 50.2% of them were male, and 49.8% were female. As well, 45% of respondents (\(n = 173\)) had paid or unpaid jobs in the last week; thus, their job-related walking has also been evaluated in our study.
Figure 4. Choropleth maps of the variation of the variables of street connectivity in the 4 districts of Golsar.

Table 3. Demographic characteristics of participants (n = 384).

| Demographic Variables     | District 1 | District 2 | District 3 | District 4 | Total |
|---------------------------|------------|------------|------------|------------|-------|
| Age Mean                  | 32.1       | 32.4       | 31.9       | 32.9       | 32.3  |
| SD 1                      | 13.5       | 11.6       | 11.8       | 13.9       | 12.7  |
| Median                    | 30.5       | 32         | 31         | 31         | 31    |
| Min, Max                  | 18, 69     | 18, 67     | 18, 66     | 18, 69     | 18, 69|
| Male Count                | 48         | 49         | 49         | 47         | 193   |
| Male Percent              | 50%        | 51%        | 51%        | 49%        | 50.2% |
| Female Count              | 48         | 47         | 47         | 49         | 191   |
| Female Percent            | 50%        | 49%        | 49%        | 51%        | 49.8% |
| Employment rate 2         | 44         | 43         | 44         | 42         | 173   |
| Male Count                | 45.8%      | 44.7%      | 45.8%      | 43.7%      | 45%   |
| Female Percent            | 50%        | 49%        | 50%        | 51%        | 49.8% |
| The standard deviation of the age distribution; ^ paid or unpaid job in the last week.

As illustrated in Table 4, the average time which is dedicated to walking and cycling in District 1 ranked the first with 223.3 min per week which was more than District 2 with 218.4 min per week. The average time in Districts 3 and 4 were approximately equal, although this amount for District 4 (214.2 min per week) was about half a minute more than District 3. District 1 possessed the most average time in cycling and walking for commuting, and District 2 enjoyed the maximum amount for job-related and leisure-time walking. On the other side, Districts 3 and 4 had the lowest average time for all types of physical activities.
Table 4. Average time (minutes per week) for walking and cycling of respondents in Golsar.

| Physical Activities | District 1 | District 2 | District 3 | District 4 |
|---------------------|------------|------------|------------|------------|
| Job-Related Walking | 39.7       | 41.1       | 36.5       | 40.3       |
| Transport Walking   | 124.4      | 118.3      | 122.2      | 118.8      |
| Leisure-Time Walking| 42.7       | 44.4       | 41         | 41.4       |
| Cycling             | 16.5       | 14.6       | 14.1       | 13.7       |
| Total               | 223.3      | 218.4      | 213.8      | 214.2      |

1 Different types of outdoor physical activities based on IPAQ (International Physical Activity Questionnaire) (minutes per week).

4.4. Correlation between the Two Methods

As mentioned, based on total normalized values of street connectivity in Golsar, District 1 with 8.09, District 2 with 6.28, District 3 with 3.22, and District 4 with 1.23 possessed the first to fourth positions. Additionally, regarding the results of IPAQ, the same ranking applies to the amount of physical activity of people in these districts except for District 4, which ranked the third with a slight difference with District 3. Therefore, according to Pearson’s $r$ formula, for this study, $r_{xy} = 0.93$ shows a strong positive correlation between the total amounts of street connectivity and the time which people have spent on walking and outdoor physical activities in the four districts of Golsar. Thus, the result of this research indicated that connectivity in this town has a direct positive effect on the public health of people and the duration of walking in the streets.

This study was limited to evaluate the influence of street connectivity on the walkability in Golsar. There are also suggestions for further research. For example, the evaluation of other indexes of walkability such as proximity, pedestrian design, land use mix, safety, and density can improve our knowledge about the walkability of this region, indicating the amount of impact of each index on walking behavior of residents.

5. Conclusions

This paper concerns the association between street connectivity and outdoor physical activity (walking and cycling) of the population in Golsar’s districts. As a result, the study resulted in a strong linear correlation ($r = 0.93$) between the street connectivity of each district of Golsar and the duration of physical activities of residents in these districts. Due to this correlation, it is apparent that the relationship between street connectivity and walkability in this town is a strong and direct one.

Comparison between the variables of street connectivity in each district and the results of IPAQ vividly revealed that the design of the streets’ network in Golsar directly has been able to take a dominant role in the walkability of neighborhood areas and enhancement of the average time of walking among residents. The more desirable design of street connectivity in District 1 provides a better design of the street network for more physical activity of residents compared with other districts. Consequently, the difference in the measures of walkability between the four districts can lead to a change in the amount of walking of people and may improve the indexes of public health among people.

Author Contributions: All the authors conceived, designed, and wrote the study. P.M. conducted the field survey, analyzed, and visualized the data. L.T. and M.H. reviewed the manuscript and supervised the process. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to express their sincere acknowledgment to Farhad Rezaei for his help during GIS data collection and processing.
Conflicts of Interest: The authors declare no conflict of interest.

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