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Sustainable Bicycle Path Planning for Medium-Sized Cities by Using GIS-Based Multicriteria Decision-Making Analysis: A Case Study From Turkey

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Abstract: The world's population is increasing rapidly and consequently, urban areas are also expanding and developing rapidly. This growth and development in cities leads to the differentiation of urban transportation systems and, in particular, the increase in the number of motor vehicles. This increase in the number of motor vehicles in order to provide transportation leads to many problems (air pollution, traffic congestion, carbon gas emission etc.). In order to prevent these problems, many researchers and decision makers state that sustainable transportation systems such as public transportation, walking and cycling should be used. The objective of the research is to develop a sustainable bike path proposal for cities through GIS-based multicriteria decision-making analysis, taking into account physical, environmental and visual factors of medium-sized cities. In this context, the physical, environmental and visual factors of the city of Nigde, Turkey, which is considered to be a medium-sized city, were evaluated with GIS-based multicriteria decision-making analysis, and a sustainable bike path proposal was developed for Nigde according to the zoning plans.

Key words: Transportation system, bicycle, gis, multicriteria decision-making, ahp.

Gis Tabanlı Çok Kriterli Karar Verme Analizi Kullanarak Orta Ölçekli Kentlere Yönelik Sürdürülebilir Bisiklet Yolu Planlaması: Türkiye Örneği

Öz: Dünya nüfusu hızlı bir şekilde artmakta ve buna bağlı olarak kentsel alanlar da hızlı bir şekilde büyümekte ve gelişmektedir. Kentlerde yaşanan bu büyüme ve gelişme kent içi ulaşım sistemlerinin farklılaşmasına ve özelliklede motorlu taşıtlarda artış yaşanmasına neden olmaktadır. Ulaşımın sağlanması amacıyla motorlu taşıtlarda yaşanan bu artış beraberinde birçok sorunun (hava kirliliği, trafik sıkışıklığı, karbon gazı emisyonu vb.) ortaya çıkmasına sebep olmaktadır. Bu sorunları engellemek amacıyla çok sayıda araştırmacı ve karar verici toplu taşıma aracı kullanma, yürüyüş yapma, bisiklet kullanımı gibi sürdürülebilir ulaşım sistemlerinin kullanılması gerektiğini ifade etmektedir. Araştırmanın amacı, orta ölçekli kentlere ait fiziksel, çevresel ve görsel faktörler dikkate alınarak CBS tabanlı çok kriterli karar verme analizi ile bu kentlere yönelik sürdürülebilir bisiklet yolu önerisi geliştirmektir. Bu kapsamda orta ölçekli kent olarak değerlendirilen Niğde/Türkiye kentinin sahip olduğu fiziksel, çevresel ve görsel faktörler CBS tabanlı çok kriterli karar verme analizi ile değerlendirilmiş ve imar planlarına göre Niğde kentine yönelik sürdürülebilir bisiklet yolu önerisi geliştirilmiştir.

Anahtar kelimeler: Ulaşım sistemi, bisiklet, gis, çok kriterli karar verme, ahp.

1. Introduction

There has been a significant increase in the urban population in recent years due to an increase in the world population and migration from rural areas to city centers. The global urbanization rate was calculated as 29% in 1950, 37.4% in 1975 and 47.1% in 2000 [1,2]. Today, more than half of the world's population living in societies that are increasingly globalized and interacting with each other lives in urban areas. In this context, it is estimated that this increase in the urban population will continue steadily, and this rate is expected to be approximately 60% by 2030 [3,4]. In light of this worldwide development, the urban population in Turkey, particularly with post-1950 migration from rural areas to cities, has increased significantly. According to 2019 data from the Turkish Statistical Institute [5], 92.3% of the country's population lives in cities, while 7.7% lives in villages.

With the increase in the population, urban settlements have expanded, and consequently vehicle use has increased [6]. This increase in the number of motor vehicles to provide transportation has caused many problems. These problems arising from the existing transportation system necessitate the planning of different transportation systems. For example, the increase in global problems, such as climate change, the increase in oil production and use, traffic congestion and road safety, encourages the use of sustainable transportation systems, such as walking,

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cycling and public transportation [7,8]. In this context, these alternatives should also be considered in spatial planning studies.

Sustainable transport, defined by Black [9] as "meeting the current transportation and mobility needs without compromising the ability to meet the transportation and mobility needs of future generations," has recently become an important target in transport planning and research [10]. Sustainable bike path planning requires a systematic approach that takes into account the planning criteria of the zoning plans that are effective in the development of the city, and it necessitates the use of Geographic Information Systems (GIS) in conjunction with Multicriteria Decision-Making Methods (MCDM). In this context, the integration of GIS and Analytic Hierarchy Process (AHP) greatly simplifies the decision-making process [11,12,13,14]. It is possible to evaluate multicriteria decision-making analysis based on GIS, in two different sections. The first one is geographic information systems, and the other is a multicriteria decision-making analysis method.

GIS are used in many different fields (agriculture, geology, urban planning, etc.). One of these areas is research conducted for the planning of bike paths. For example, analyses such as determining the most suitable routes for bikes, analyzing the most cost-effective route, and estimating the demand for bike paths can be evaluated in this context [15,10].

Decision making is defined as the process of determining the best choice among all possible alternatives. However, there is no single method used by decision makers facing many different problems and alternatives to determine the best option [16]. In this context, the Multicriteria Decision-Making Method (MCDM) is one of the most important decision-making methods and serves to determine the best option among all existing solutions [17,18]. Despite debates in the academic field, the Analytic Hierarchy Process (AHP) method is one of the most preferred multicriteria decision making methods. Originally introduced by Saaty in the 1970s, this method has been updated, with changes made by different researchers to date [19].

In the field of transportation systems, the AHP method is used in fields such as planning traffic, planning transportation, prioritizing urban transportation options, planning the most appropriate rail network, and selecting light rail corridors and routes [20,21,22,23]. In addition, this method is also preferred for tasks such as evaluating the public transport fare system, classifying the sustainability of transportation investments, performing quality analysis of public transport service, and prioritizing public transport companies [24,25,23].

The objective of the research is to develop a sustainable bike path proposal for cities through GIS-based multicriteria decision-making analysis, taking into account physical, environmental and visual factors of medium-sized cities. In this context, the physical, environmental and visual factors of the city of Nigde, Turkey, which is considered to be a medium-sized city, were evaluated with GIS-based multicriteria decision-making analysis, and a sustainable bike path proposal was developed for Nigde according to the zoning plans.

2. Materials and Methods

2.1. Study area

Nigde, which is a medium-sized city in the Central Anatolia region of Turkey, was selected as the research area. Nigde is adjacent to the Adana, Kayseri, Konya and Mersin provinces, which are important major cities of Turkey. Located between 37°25′-38°58′ north latitude and 33°10′-35°25′ east longitude, Nigde Province has a surface area of 7.795,22 km² and an altitude of 1.229 meters [26,27]. In the city, which has a continental climate, agricultural and animal husbandry activities are carried out at a high rate (Figure 1).

According to the data obtained from the zoning plan reports, the city of Nigde was generally established on flat and near-flat areas around the hill where Nigde Castle is located and to its west. Since the first settlements were located on the hill and around the castle, today, the densest settlement area is also located in this area. Moreover, due to the influence of the municipality and government offices, which are located in the immediate vicinity of the hill, public institutions and organizations are located in this region. Thus, this region, where education, trade, administrative, health and cultural buildings coexist, forms the city center of Nigde [28].

The research area, which connects Bor Plain and Misli Plain, located between Melendiz Mountain and the Aladağlar and Bolkar Mountains, is currently being developed in a linear manner along a southwest-northeast line [14]. According to the zoning plans in force, dense residential areas were planned north of the city center. With the urban transformation project carried out in this region, the population density has shifted to this region.

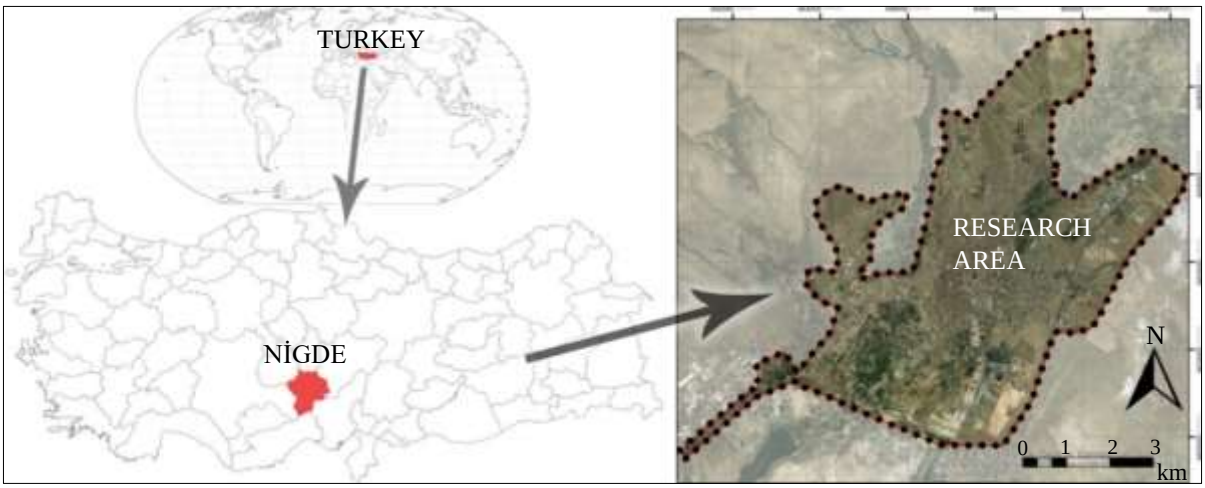

Figure 1. Location of the research area

2.2. Methods

This research was carried out in five stages in order to plan sustainable bike paths for medium-sized cities.

The first stage of the research consisted of obtaining the data related to the subject and field of the research. In this context, the social, cultural and physical data that will be used for the planning of sustainable bike paths for the research area were obtained from field studies, interviews with related institutions and organizations, and the extant literature. The existing plans for the research area were provided by the Municipality of Nigde, the Special Provincial Administration of Nigde and the Provincial Directorate of Environment and Urbanization.

The second stage of the research consisted of determining factors, subfactors and suitability values for sustainable bike path planning. A model for determining the route of a bicycle path was created in the Inner City Bike Paths Guide, prepared by the Turkish Republic Ministry of Environment and Urbanization. In this context, the criteria included in the determination of the bicycle path route are grouped under three main headings: physical (slope, roadway width, physical condition), environmental (land use type, user density, integration to transportation system, traffic density) and visual (building height, proximity to green spaces, building status) criteria. Physical criteria determine the effect of the physical conditions of the road on the model; the environmental criteria determine the effect of the number of users, usage type differences, the connection of the route with the transportation system to be determined, the status of ownership, and the traffic density in the model; and visual criteria determine the effect of the users' driving quality, feeling of safety, and the effect of the relationship with the items around him or her in the model.

Suitability values for the evaluation subfactors were determined from the most important to the least important using a 4-point likert scale. In the event that the evaluation subfactors affected the potential use of the settlement equally, both subfactors were given the same value as the slope and land use type factors included in the evaluation factors.

The third stage of the research consisted of calculating binary comparison matrices. To determine the suitability coefficients of the factors for the planning of a sustainable bike path by taking physical, environmental and visual criteria into account by expert groups, a questionnaire including binary comparison questions was prepared. The questionnaire was applied to 16 experts in the disciplines of architecture (3), urban and regional planning (4), landscape architecture (6) and civil engineering (3) on a voluntary basis. Binary comparison matrices were created according to comparisons made by experts. In this context, a relative importance scale (1-9) developed by Saaty (1983) was used to assign values to binary comparison matrices [14,28,29]. If one factor is more important than another, it receives values such as 1, 3, 5, and 9 (Table 1). If it is unimportant, it receives the values that are the opposite of these values (1/3, 1/5 et al.) [30,31].

Table 1. Description of the fundamental scale of values [32,33]

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgement slightly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order or affirmation
2,4,6,8	Intermediate values between adjacent judgments the two	
Reciprocals of above non-zero	If activity (i) has one of the above non-zero numbers assigned to it when compared with activity (j), then (j) has the reciprocal value when compared with (i)	A reasonable assumption
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

Once the binary comparison matrix is prepared, the matrix must be normalized. To normalize the matrix, the sum is taken for each column in the matrix, and the elements of the matrix are divided into the sum of the columns with which it is related. Then, the sum of the rows created for each alternative or criterion is taken in the normalized matrix. The resulting values are the priority values for the criteria or alternatives. The matrix formed by the priority values is defined as the "priority vector matrix."

For each criterion/alternative in the priority vector matrix, the priority value is multiplied by all of the elements in the column in the binary comparison matrix of that criterion/alternative, and the weighted total matrix is obtained. The row total values in the weighted total matrix are divided into priority vector matrix row values and the eigenvalue (λmax) is calculated by taking the arithmetic mean of the values in the last matrix created.

The following formulas were used to calculate the consistency ratio and consistency index of the generated matrix. In this context, the matrix is considered to be consistent if the consistency ratio is 10% or less [34,35]. In this research, the consistency ratio was calculated as 0.03.

$$CI= (\lambda max-n) / (n–1) \qquad CR= CI / RI \tag{1}$$

CR: Consistency Ratio, CI: Consistency Index, RI: Random Index, λmax: The largest eigenvalue of the matrix, n: Number of elements in the matrix.

Table 2. Random Index (36)

n	1	2	3	4	5	6	7	8	9	10
RI	0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49

The fourth stage of the research consisted of the preparation of the data infrastructure for the physical (slope, roadway width, physical condition), environmental (land use type, user density, integration to transportation system, traffic density) and visual (building height, proximity to green spaces, building status) criteria included in the process of determining the sustainable bicycle path route. In this context, data obtained from Nigde Municipality, Nigde Special Provincial Administration, the Provincial Directorate of Environment and Urbanization and field studies were digitized in shapefile format in the ArcGIS environment in accordance with the evaluation factors determined for sustainable bike path planning. This format was then converted to a raster data format after preliminary operations.

In the fifth stage of the research, specified evaluation factors and evaluation subfactors were grouped within themselves, and their suitability values were determined according to their relative importance values. Suitability values given to evaluation subfactors were multiplied by coefficients determined as a result of expert opinions, and the total weight of each factor was determined. Data were obtained by using the 'multi-layer weighted overlay method,' a spatial analysis method in the ArcGIS spatial analyst tools module. As such, routes for the sustainable bike path proposal were obtained (Figure 2).

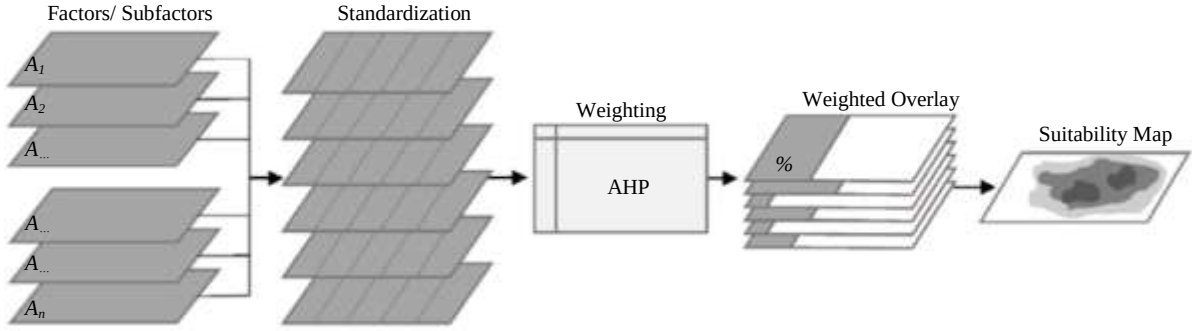

Figure 2. The structure of GIS-based multicriteria decision-making [37]

3. Results and Discussion

Research on the use of bicycles as a means of transport has shown that there are many environmental factors affecting the use of bicycles. In studies conducted by different researchers, it has been determined that factors such as the width of roads, type of land use (commercial, residential, public space etc.), population density, traffic density, and presence of open and green space affect individuals' bicycle use [38,39,40].

In addition, adverse conditions in topography/terrain conditions (steep slopes), road surface (uneven surfaces), traffic conditions (presence of heavy vehicles), and problems with the connection of roads are factors that negatively affect the use of bicycles. These factors need to be taken into consideration in order to increase the use of bicycles and to ensure more comfortable and safe travel for individuals who ride bicycles [41,42].

In the study conducted for sustainable bike path planning in the city of Nigde, when the weight values of the revealed groups and factors were calculated, it could be seen that physical criteria had the highest weight value (0.751). This was followed by environmental factors (0.178) and visual factors (0.070). When the weight degrees of the factors in these groups were calculated, it could be seen that slope had the highest weight level (0.731) among physical factors, traffic density (0.551) had the highest weight among environmental criteria, and closeness to green areas (0.691) had the highest weight among visual criteria. Similarly, in a study conducted by Habibian et al. (2017) in Shiraz, Iran, experts stated that the slope factor was the most important factor in the planning of bike paths (Table 3).

The slope criterion, road width criterion and physical condition of the roads criterion, which were included in the physical criteria for the research area, were examined under 5, 4, and 3 subcriteria, respectively.

The city has developed along a southwest/northeast axis due to the mountainous areas to the north and southeast of the research area. In this context, the slope is flat and close to flat in the central areas of the city. However, it is seen that the slope increases as we progress towards the north and southeast of the city. Especially in the north of the research area, the areas planned as residential areas in the zoning plans are the areas with the greatest slope.

The roads around the residential areas in the zoning plans have a width of over 30 m. The road widths are narrow at many points of the city due to the historical areas within the existing residential area of the city center and the unplanned development in previous periods. However, the width of the main arteries connecting the existing residential areas in the city center with the planned residential areas in the north and south of the city varies between 20 and 30 m. It can also be seen that there is no continuity of road widths at some points.

The physical condition of the existing roads was examined in the field studies carried out within the scope of the research. The roads in the research area are generally in good physical condition. However, deterioration in the coating of the roads in the south of the city has reduced the physical quality of the road. Since new roads will be built within the project determined in the zoning plans, their physical condition has been evaluated as good for this reseach (Figure 3). Land use type criterion, user density criterion, integration into transportation system criterion and traffic density criterion, which were included in the environmental criteria for the research area, were examined under 5, 4, 3, and 3 subcriteria, respectively. When the research area was evaluated in terms of land use type, there was not much forest area around and within the area.

Table 3. The evaluation factors used in the determination of sustainable bicycle path

Groups	Group priority	Main Criteria	Subcriteria	Score	Local Weight	Percent (%)	Consistency ratio (CR)	
							Local	Global
Physical Criteria	0.751	Slope (%)	0-2	4	0.731	73.1	0.06	0.03
			2.1-5	3				
			5.1-8	2				
			8.1-11	1				
			11<	1				
		Roadway Width	0-10 m	1	0.188	18.8		
			10.1-20 m	2				
			20.1-30 m	3				
			30 <… m	4				
		Physical Condition	Good	4	0.081	8.1		
			Middle	3				
			Bad	1				
Environmental Criteria	0.178	Land Use Type	Housing Zone	1	0.131	13.1	0.09	
			UrbanWork-Commerce Space	2				
			Public Space	4				
			Forest-Agricultural Space	3				
			Green Space	4				
		User Density (person/ha)	0-40	1	0.274	27.4		
			41-80	2				
			81-150	3				
			151<…	4				
		Integration to Transportation System	0-300 m	4	0.044	4.4		
			300-1000 m	3				
			1000<… m	2				
		Traffic Density	Intensive 120	4	0.551	55.1		
			Medium Density 40-120	3				
			Not Intense 0-40	2				
Visual Criteria	0.070	Building Height	0-10.5 m	4	0.091	9.1	0.05	
			10.5-30.5 m	3				
			30.5-50.5 m	2				
			Free Height	1				
		Proximity to Green Spaces	0-200 m	4	0.691	69.1		
			201-500 m	3				
			501-800	2				
			800<… m	1				
		Building Status	Detached Building	4	0.218	21.8		
			Attached Buildings	2				
			Semi-Detached Buildings	3				

As the research area is located between the Bor Plain and the Misli Plain, there are fertile agricultural lands in the northeast and southwest of the area. There are many active (park, sports field, children playground) and passive green spaces (cemetery, refuge, traffic island etc.) in the research area. In the study carried out by Olgun [28] for the city of Nigde, it was determined that there were 177 active green spaces with an area of 589,276.01 m^2 in the current state and 4.09 m^2 of active green spaces per capita. In the application zoning plan prepared in accordance with the 2035 projection, 647 active green spaces with an area of 2,717,293.15 m^2 were identified. Urban working areas and commercial areas are densely located to the east of the city center. The residential areas are densely located on flat and nearly flat areas to the west and around the hill where Nigde Castle, the first settlement of the city, is located. In the zoning plans, the areas located to the north of the city center were planned for residential areas. Therefore, it was observed that the population density in the areas to the north of the city center is high in the zoning plans. In addition, there is an intense population increase in the western region, where there has been rapid construction activity recently. In areas where the population density is high, it was observed

that the traffic density is also high. Traffic along the main artery in particular is more intense than it is on other roads.

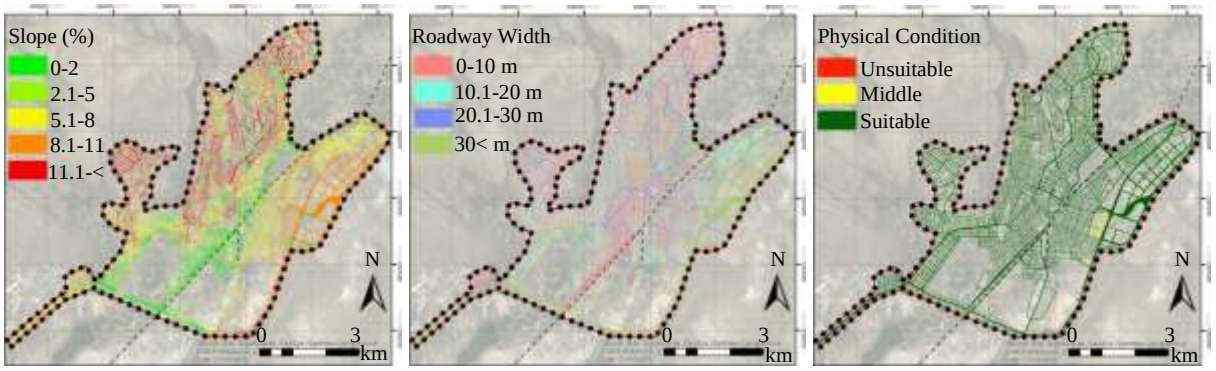

Figure 3. Analysis of physical criteria for sustainable bicycle path proposal

Research conducted in Turkey and in many countries around the world emphasize that bike routes should be integrated with the public transportation system. However, it is not possible to ensure safe and appropriate bike-public transport system integration in many cities in Turkey [43]. In terms of its transportation system, there is an intercity bus terminal to the south of the city center and a train station in the city center. There are also public transportation stops, which provide transportation within the city. Within this scope, the areas where the public transportation vehicles are densely located in the city have been taken into consideration in the integration of bike paths into the transportation system (Figure 4).

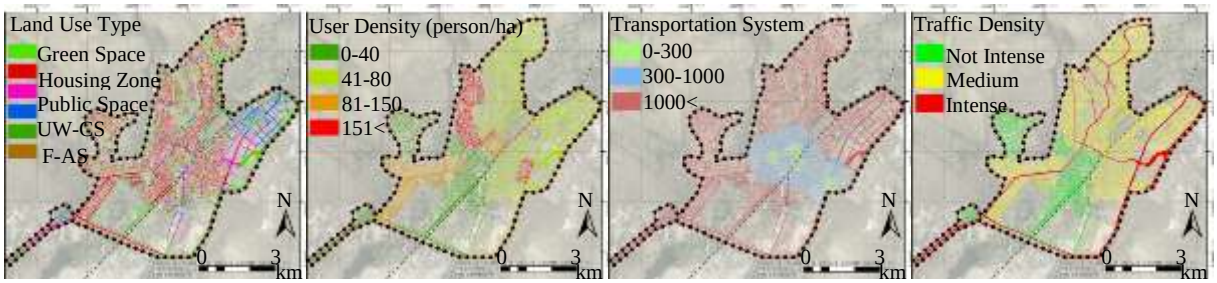

Figure 4. Analysis of environmental criteria for sustainable bicycle path proposal

Building height criterion, proximity to green spaces criterion, and building regulation status criterion, which were included in the visual criteria for the research area, were examined under 4, 4, and 3 subcriteria, respectively. According to the zoning plans, there are buildings with different height values within the research area. However, it can be seen that there are a large number of buildings with a height of 50.50 m in the whole research area.

According to the zoning plans, there are many green spaces in different regions within the research area. Some of these green spaces are at the level of a neighborhood park, while others are the size of a city park. When the influence area of the green spaces planned in the zoning plans was examined, the majority of the research area remained within 200 m of the influence area of the green spaces.

When the research area was examined in terms of the building regulation status, it can be seen that the overall research area was planned in the separate building order. However, it can also be seen that there is an adjacent and block building system in the city center and in the regions to the east of the city center (Figure 5).

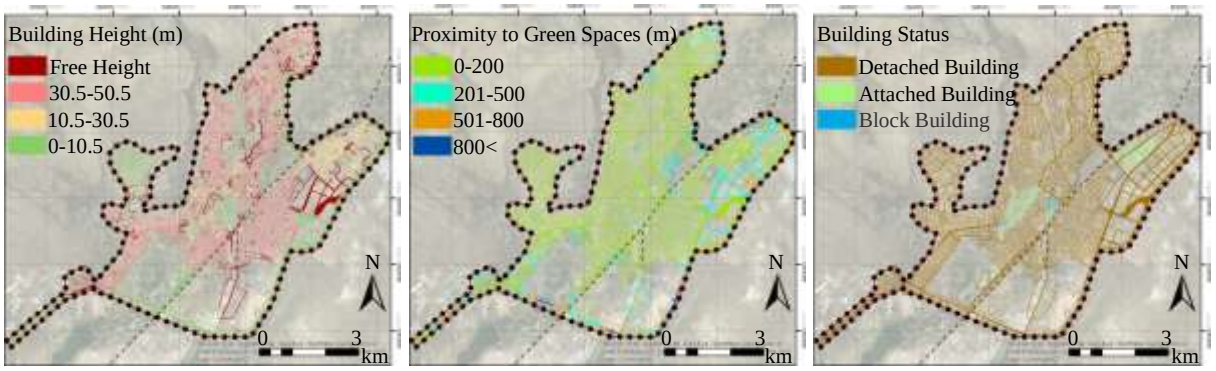

Figure 5. Analysis of visual criteria for sustainable bicycle path proposal

According to the results of the analyses, the land structure of the city, which is currently developed along a southwest-northeast axis in a linear manner stemming from the city center, does not have a high degree of slope. An integrated, sustainable bike path was determined in line with the city's axis of development, with the analyses taking into account the effect of slope and other factors/subfactors. However, due to the high slope of the planned settlement areas, particularly in the north of the city, inadequate road widths, user density and the effects of other factors in accordance with expert opinions, a bike path could not be proposed in this area in the current zoning plans (Figure 6).

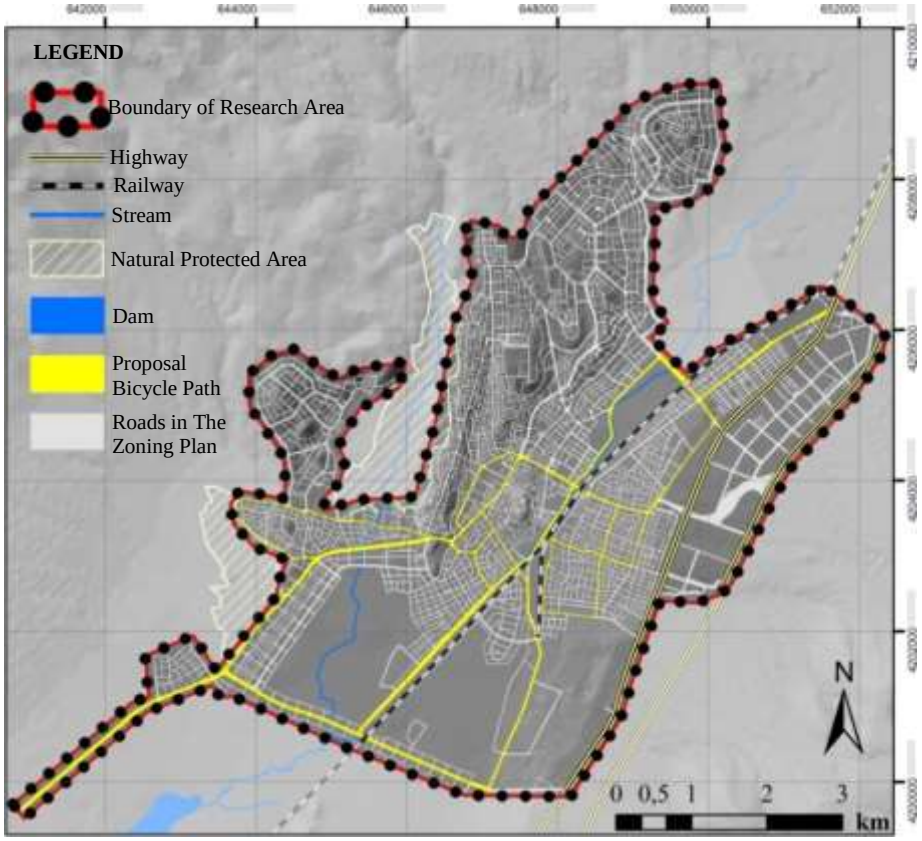

Figure 6. Sustainable bicycle path proposal map for the research area

Urban growth and an increase in housing and population, which emerge with the implementation of zoning plans prepared according to a specific projection, affect the transportation system of cities, necessitating the creation of new alternatives. Examining the relationship between urban growth and motor vehicle traffic density

in their study, Polat et al. [44] reported that an increase in the number of houses affected traffic density. In this context, the urbanization movements that gained momentum in the city of Nigde, especially in recent times, have caused the urban environment to change rapidly. Buildings constructed with developing technology, differentiated and proliferating transportation lines, an increasing number of vehicles, and decreasing green areas constitute the new face of the city of Nigde. Furthermore, the inability of the city center to handle the increasing population has led to the establishment of new residential areas outside of the city [28,45]. This necessitates the creation of new roads and transportation systems. Scientific research conducted by different researchers in various cities around the world has concluded that the presence of bike paths in cities increases the use of bicycles [46]. In this context, the implementation of sustainable bike paths that will be planned in the zoning plans of the research area will lead to an increase in the bicycle usage rate among individuals living in the city. Also developing the necessary infrastructure, raising the awareness of the local administrations and public will increase the use of bicycles [47].

4. Conclusions

Problems related to the transportation system are growing constantly due to an increasing population and urbanization. In this context, researchers are developing different suggestions for solving these problems. In this research, a sustainable bike path was proposed for the city of Nigde, a medium-sized city. The proposed bike path, which was designed by using AHP together with Geographic Information Systems and Multi-Criteria Decision-Making analysis methods, in line with the determined factors and subfactors, will have a sustainable structure, as it was created taking into account the natural and cultural values of the city. Due to the bicycle paths that will be integrated with the transportation system of the city, the use of bicycles will increase, and this will provide many benefits, both to individuals (fuel costs, health, road safety, social activities, etc.) and to the city (air pollution, natural and cultural assets, etc.). In addition, this study will guide planners and decision makers in sustainable bike path planning for medium-sized cities.

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