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Use of a Hybrid MCDM-GIS Model for Planning and Ranking Rural Service Centers: Case Study: Central Zone of the Indica County

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Authors' contributions

This work was carried out in collaboration between all authors. Author AB conceived and designed the project. Authors MO, EM and HP acquired the data. Authors AB and OK analyzed and interpreted the data. Authors AB and MO wrote the paper. All authors read and approved the final manuscript.

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ABSTRACT

The aim of this study was to develop a method for spatial zoning and the establishment of rural service centers in the central zone of Indica county with consideration of environmental, social, and economic criteria. The research type is applied and the research method is descriptive-analytical. First, using the Delphi method, the most important factors influenced in the establishment of rural service centers were identified. Boolean logic was used to assess the status of existing settlement centers, and hybrid MCDM_ GIS method was used to plan for the establishment of new rural service

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centers. Finally, results of the research proposed a model for organizing the establishment of rural service centers in the study area. The analysis of the identified zones suggests that the areas which were more populated and had higher levels of infrastructure facilities and services were located in the most suitable zones. Moreover, among the natural factors, the land slope played the greatest role in selecting a location for the establishment of a rural service center.

Keywords: Rural service centers; MCDM-GIS model; Geographic Information Systems (GIS); Indica; Delphi method.

1. INTRODUCTION

One of the main reasons for the backwardness of rural areas which discourages rural population to remain in such areas is the weaknesses of service delivery centers or lack of people's easy access to the service centers, because rural service centers play an important role in providing facilities and services for the villages under their coverage. In view of that, rural service providers are considered as a platform for mobility which increases people's desire to live in rural areas [1]. As one of the policies for rural development planning, it is necessary to identify and enhance service networks in rural areas and to manage related facilities and services, because it not only helps to optimize the distribution of resources in rural areas, but also leads to the physical integrity and the right spatial structure of rural settlements [2]. To develop rural areas in the future and to optimize the process of locating service centers in rural areas, it is essential to consider the capabilities of each region and make careful planning for the most convenient location at the lowest cost [3].

Today, with the progress of geographic information systems (GIS), it has become possible to store, organize, process, and manage large volumes of spatial and descriptive information. These systems, due to their characteristics, are used by a wide range of users, engineers, and specialists from different fields of science [4]. Given the difficulties in people's access to services in the area under the study and because of the effectiveness of GIS in this field, it seemed necessary to utilize this system in order to meet the practical and scientific needs of this research.

This study was conducted on the villages located in the central zone of Indica county because they are not only faced with dispersion, deprivation, difficulties in providing services, infrastructure problems, lack of proper development of economic activities, and difficulties in people's access to rural service centers, but also there is the lack of a unified and coordinated model to organize the hierarchy of the rural service centers in the mentioned zone of Indica county. The results of this research can be utilized in order to fulfill the objectives of rural development. Accordingly, we evaluated various economic, social, and environmental aspects and utilized appropriate models and techniques to propose a model for the establishment of rural service providers in the area under the study. The objectives of this research were to promote equal access to services in rural areas, expand and develop the concept of spatial justice, and utilize optimized procedures for the establishment of rural service centers in the studied area.

2. BACKGROUND

The first research that was systematically conducted to promote the delivery of service in rural areas in various fields of health, education, agriculture, etc. was a 24-volume report which was conducted and prepared by Setcop Consulting Engineers Co, in collaboration with Partia consulting engineers Co [5]. This study was about the development of Khorasan Province and was carried out in 1972. Considering natural and human factors, this document suggested three main levels for the classification of rural areas including: primary, intermediate, and central villages.

Yasori [6], Conducted a study entitled "hierarchy of rural settlements and ranking rural services (a case study of Sarakhs County)". Using field data, expert's opinions, and GIS, this study assessed the hierarchical level of rural settlements and rural services and classified them into galaxies, collections, zones, and subsidiaries. The study also provided the related maps.

Shayan [7] presented the results of a study on ranking rural service centers in Mashhad County in 2003. This study was aimed to enhance and strengthen the performance of service centers, increase effective access to services, create more links between rural settlements, and make a relative balance between urban and rural areas in terms of the ranks of rural services in Mashhad County.

Mahdavi and Karimzadeh [8] conducted a study entitled "Zoning central part of Vazraqan County for rural service centers". Taking into consideration natural and human factors, the study tried to locate rural service centers in order to achieve a better distribution of services in rural areas. The results of this study indicate that villages which are located in relatively flat areas benefit from infrastructure facilities and services more than their surrounding villages and have more favorable conditions for the establishment of rural service centers.

Azghami and Hashjin [9] conducted a study entitled “Planning for development of rural services from a geographical perspective (a case study of Tolam in Somesara County)”. The researchers tried to propose a plan for the development of rural services while focusing on geographical factors and they concluded that the studied zone was faced with the lack of services in the area; moreover, the distribution of service centers and their performance were not homogenous across the studied area. In addition, in villages far from the central part of rural galaxy and sub-galaxy there was a significant service gap, particularly in infrastructure services.

Faraji Sabkar et al. [10] conducted a study entitled "Analysis of land suitability for the establishment of rural service centers". Using PROMETHEE method and paired comparisons in the GIS environment, the researchers tried to detect the best areas for the establishment of rural service centers so the centers have the highest level of coverage.

3. THEORETICAL FRAMEWORK OF THE STUDY

The most important factor for locating appropriate places for the establishment of rural service centers in a village or in a collection of rural areas is to determine and set the hierarchical levels in those areas, because it facilitates the distribution of services and helps rural communities to take more advantage from service facilities established at higher hierarchical levels [11]. In view of the abovementioned issue, today, planners in developing countries have been deeply convinced that the process of locating infrastructure services and facilities play an important role in the development of rural areas in these countries. In addition, it is proved that improving rural communities' access to basic services is an important tool in accelerating the regional development. Now, it has been fully accepted that locating services not only can influence the operation efficiency, but also can affect the related costs and quality [12]. Based on such a framework, each of the centers at different levels, depending on their capabilities and functions, differ from other centers in many ways. As a result, in order to assess every center, first it is necessary to consider the level of specialty, functions, quality, and spatial scope of services, then it is essential to evaluate the functionality and contributions that each center can made in fulfilling the basic needs of consumers in a rural area and investigate how they provide economic, social, and cultural services [13].

3.1 Multiple Criteria Decision Making (MCDM) Methods

Multiple-criteria decision-making (MCDM) or multiple-criteria decision analysis (MCDA) is a sub-discipline of operations research that explicitly considers multiple criteria in decision-making environments. There are two types of MCDM methods; the first category includes methods for decision makings based on several criteria that is called MADM (multi-attribute decision making), and the second category includes methods for decision making based on different objectives that is called MODM (multi-objective decision making). MCDM methods is usually used for selecting the best option when the related criteria are probably in conflict with each other [14]. MODM, on the other hand, can simultaneously focus on multiple objectives that are contradictory, and using mathematical programming methods, it can offer the best solution. Hybrid methods, distance methods, and relative superiority methods are the common types of MCDM [15].

3.2 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is one of the most popular methods of MCDM, which first calculates the relationship between weights and criteria and then estimates the overall value of each item based on the calculated weight of each item. The model was first introduced in

1980 by Thomas L. Saaty [16]. As this method is mainly designed for paired comparisons, it helps managers, regional planners, and all those who are active in the field of decision making to study various scenarios.

3.3 Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is one of the other methods of MCDM. It is used to select the best alternative via considering the minimum distance from any positive ideal option and the maximum distance from the negative ideal [17]. TOPSIS technique was first introduced in 1981 by Hwang and Yoon. This method is based on the concept that the final choice should be closest to the positive ideal solution (best possible) and had the maximum distance from the negative ideal solution (worst case). This method can use a combination of negative and positive criteria [18]. Given the characteristics of TOPSIS method, it is recommended for and used in certain conditions where there are both positive and negative criteria. The methods used for the normalizing information, calculating distances, and determining the index weights are optional and can be adjusted with the type of information in question. When there are some cost criteria and the goal is to reduce them, or when there are some profit criteria and the goal is to increase them, TOPSIS can easily achieve the ideal answer and present a combination of the best obtainable values [19].

4. RESEARCH METHODOLOGY

Considering the research content and theoretical structure, this study used a descriptive analytical method. The required data was collected via library studies (literature review), content analysis, questionnaires, and interviews. In this study, the Delphi method was used to identify the effective criteria. To apply this method in the present study, first available resources were reviewed and possible criteria were identified. A total of 20 Criteria were listed and presented to the experts. Then a total of 10 questionnaires were sent to experts who were familiar with the subject. In the next step, the experts were asked to score the listed criteria using the nine-point Saaty scale (Analytical Hierarchy Process). As a part of the questionnaire, the experts were requested to write the criteria that had not been mentioned in the questionnaire used for the first step of data collection. After this stage, the questionnaires completed by the experts were analyzed and very unimportant and irrelevant criteria were excluded. The complementary questionnaires included 11 criteria which were top rated by most of the experts.

5. MATERIALS AND METHODS

5.1 Study Area

Andika is a county in Khuzestan Province in Iran. The capital of the county is Qaleh-ye Khvajeh. It was separated from Masjed Soleyman County in 2007. At the 2006 census, the county's population was 49,430, in 8,708 families. The county has one city: Qaleh-ye Khvajeh.

Andika is located between 49 ° and 53 ' to 49 ° 52 ' east longitude from Greenwich meridian and between 31 ° 43 ' to 32 ° 39 ' north latitude from the equator in the eastern part of Khozestan province. This county is bordered to Izeh to the East, Lali County to the North West, Sardasht Dezful to the North, Chahar Mahal Bakhtiari province to the North East, and Masjed Soleiman to the South and South West. Indica County has a total of 568 villages, of which 135 villages are located in the central zone of the county. Of all, 37 villages have more than 20 households. The center of the county is Ghaleh Khajeh which is located 60 km from the North East of Masjed Soleiman County. Indica County has three zones including central zone, Abejdan, and Chelo [20].

5.2 Research Criteria

Using the available questionnaire, the paired comparison matrix corresponding to each parameter were completed by different experts and professionals; the process of completing the questionnaire has continued until a consensus was achieved (in this study it was done in 3 steps). Finally, the most important and effective criteria for determining an optimal model for the establishment of rural service centers were identified which are as follows:

- Population size criterion: The size of population in each settlement determines the relative importance of that settlement. In fact, the size of population reflects the role and function of a village in giving responses to people’s needs for welfare services [21].
- Slope: The land slope is one of the natural factors which have a strong influence in

determining suitable locations for facilities and infrastructure. According to experts, the cost of construction in areas with a steep slope increases greatly, thus residential areas or centers should preferably be placed in areas with a slope of up to 10% [22]

- Land use and capability: In fact the objective of evaluating the capability of the land is to determine the value of the land in terms of its agricultural and irrigation capabilities. This classification is based on the main types of land (irrigated agriculture, dry land, forests, meadows, etc) [23].
- Access to water resources: Water is one of the other natural factors that have long played an important role in locating cities and villages. Since water is considered as the most essential item required for human life, human community centers, both in urban and rural areas, mainly have been located in the areas close to the sea and rivers [22].
- Form and shape of the land: Form of the land (mountains, plains, etc.) and its height is effective in establishing facilities and even in cultivating plants. Based on this general rule, with an increase in height, it becomes more difficult to create infrastructures and perform agricultural activities.
- Health care criterion: It includes rural health houses and health centers. Because of the hierarchical nature and the important role that health centers play in providing services to surrounding villages, this criterion was included in this study[21].
- Infrastructure criterion: In this study, infrastructure facilities were limited to tap water services and electricity. It is financially and economically more affordable to establish service centers in rural areas where facilities and infrastructures such as tap water, electricity, and telephone are available [24].
- Educational services criterion: In this study, the educational services criterion included the presence of elementary school, guidance school, and high schools in settlements. It was evaluated through utilizing spatial statistics run in GIS environment [24].
- Access to roads criterion: Rural areas can have different types of roads (paved road, gravel road, dirt road, and animal path). Access or lack of access to such roads plays an important role in the establishment of a rural service center. In this study, we considered the access to main road (due to its importance relative to other minor roads) [25].
- Distance from a fault: This criterion is included for safeguarding people life and their facilities, and also for providing facilities and equipment required for dealing with probable earthquakes [21].

5.3 Evaluation of the Current Status of Rural Service Centers Using Boolean Logic

The Boolean maps of all criteria were combined and the rankings of rural settlements were evaluated. In the final map, the pixels that contain number 1 showed the places in which the rural service centers had been established based on the given criteria and standards; on the contrary, the pixels whose values are zero represent places in which the desired optimal criteria for establishing rural service centers have not been considered.

Of a total of 37 rural centers in the study area which had the minimum demographics and infrastructure features required for the study, 24 villages found to be unable to establish rural service centers. Moreover, the villages of Talpa, Taherabad, Qaleh zaras, Qaleh Khajeh, Cheshmeh Chelvar, and Abdareh, which were functioning as rural service centers, were not in a good condition. However, Chegarman village, as a major rural service center in the study area, had a good condition. Nevertheless, considering the selected criteria, other existing rural service centers often did not have the ability to provide services to other settlements.

5.4 Weighting the Selected Criteria Using AHP Model

The AHP analytical model was used to estimate the impact factor of the selected criteria. In this study, the paired comparisons were based on experts' opinions which were obtained via using Delphi method. After normalization the matrix of pair-wise comparisons, the weights of the selected criteria were calculated as follows. The calculated weights were used as an input for the final model (Table 1).

Table 1. Normalized matrix of pair-wise comparisons

Normalized matrix and the relative weights of criteria	**Access to roads**	**Infrastructural facilities**	**Land capability**	**Land slope**	**Land use**	**Access to water resources**	**Distance from fault**	**Form of land**	**Population size**	**Educational services**	**Health services**	**Relative weight of criteria**
Access to roads	0.079	0.167	0.025	0.143	0.063	0.048	0.188	0.182	0.143	0.143	0.162	0.122
Infrastructural facilities	0.026	0.056	0.076	0.036	0.063	0.060	0.125	0.091	0.048	0.048	0.054	0.062
Land capability	0.238	0.056	0.076	0.143	0.125	0.048	0.063	0.091	0.048	0.143	0.162	0.108
Land slope	0.040	0.111	0.038	0.071	0.063	0.120	0.063	0.091	0.048	0.095	0.108	0.077
Land use	0.040	0.056	0.015	0.071	0.063	0.120	0.031	0.045	0.048	0.048	0.054	0.054
Access to water resources	0.397	0.222	0.379	0.143	0.125	0.239	0.188	0.136	0.286	0.143	0.162	0.220
Distance from fault	0.026	0.028	0.076	0.071	0.125	0.008	0.063	0.091	0.071	0.048	0.054	0.060
Form of land	0.020	0.028	0.038	0.036	0.063	0.080	0.031	0.045	0.048	0.048	0.054	0.044
Population size	0.079	0.167	0.227	0.214	0.188	0.120	0.125	0.136	0.143	0.143	0.108	0.150
Educational services	0.026	0.056	0.025	0.036	0.063	0.080	0.063	0.045	0.048	0.048	0.027	0.047
Health services	0.026	0.056	0.025	0.036	0.063	0.079	0.063	0.045	0.071	0.095	0.054	0.056

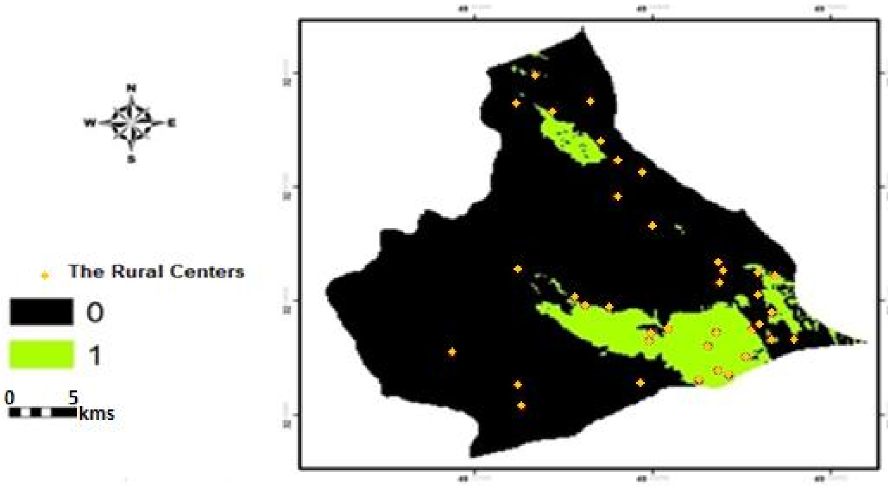

Fig. 1. Assessment Map for study and evaluated of existing rural service centers by Boolean logic

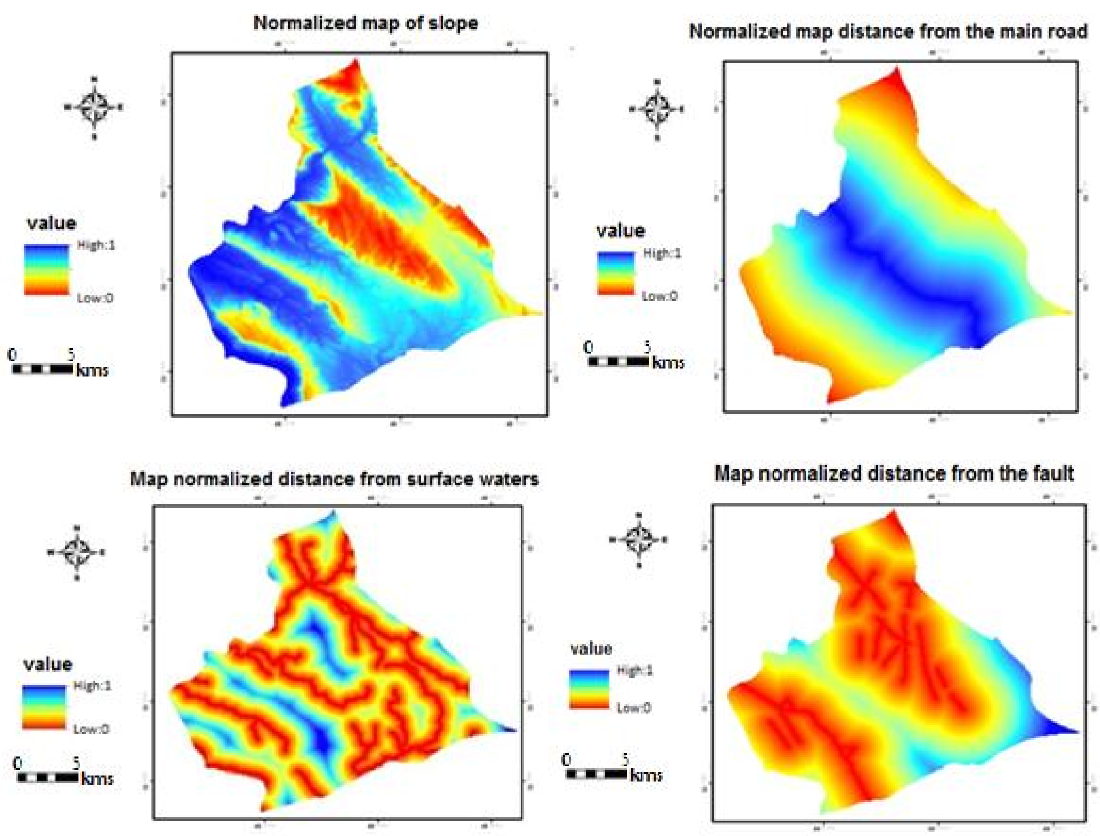

Fig. 2. Normalized layers for each criterion

To achieve goals the study, local leaders, including the governor and Agriculture Organization experts as well as members of the village council, village administrators and academic elite in rural areas, as society has considered responsive.

5.5 Spatial Zoning of Service Centers Using TOPSIS Model

To operationalize TOPSIS model, mathematical equation were applied on raster data. The selected criteria had become comparable and dimensionless via normalization. In this study, normalization was raster type and was performed by means of mathematical functions run in ArcGis. Fig. 3 shows the normalized layers of some indicators.

In the second stage, the weights obtained from AHP analysis were multiplied by dimensionless layers and weighted layers for each criterion were achieved. Then, the normalized layers were multiplied by their weights and the dimensionless numerical layers were obtained. Fig. 4 shows the dimensionless numerical weighted layers for surface water and distance from faults.

Pixels with dark blue color represent the areas that are closest to the positive ideal; on the contrary, pixels with brown color represent the negative ideal. In the next step, the sum of the positive ideal and negative ideal for each criterion was determined. The best values for positive criteria were the largest pixels while for negative criteria were the smallest pixels. In addition, the worst values for positive criteria were the smallest pixels and for negative criteria were the largest pixels. Afterward, the distances of the pixels from the positive and negative ideals were calculated. For example, the following figures depict the positive ideal and negative ideal distance from the fault for the places at risk of earthquake.

After obtaining the distance from the positive ideals, all the criteria were summed up and their square root was calculated through SQRT function. This layer indeed calculates the size of separation in the TOPSIS model. This process was repeated for the negative ideal too. The maps obtained were si^+ and si^- which are shown in the Fig. 5.

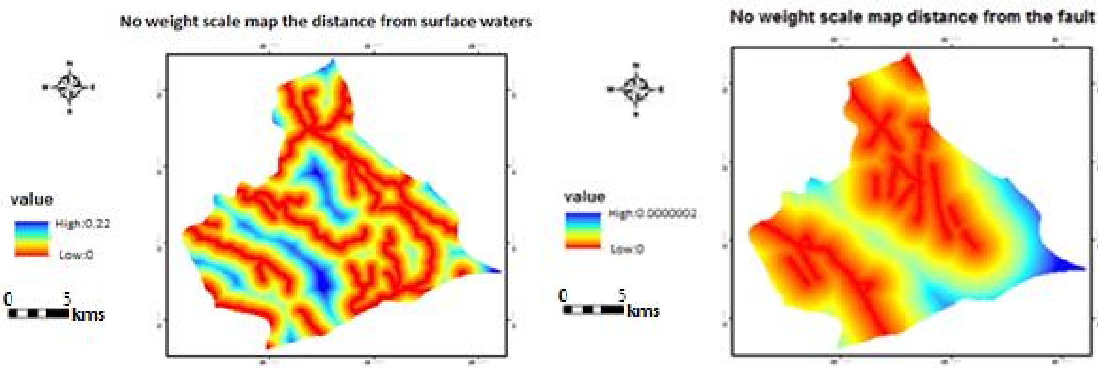

Fig. 3. Weighted normalized layer

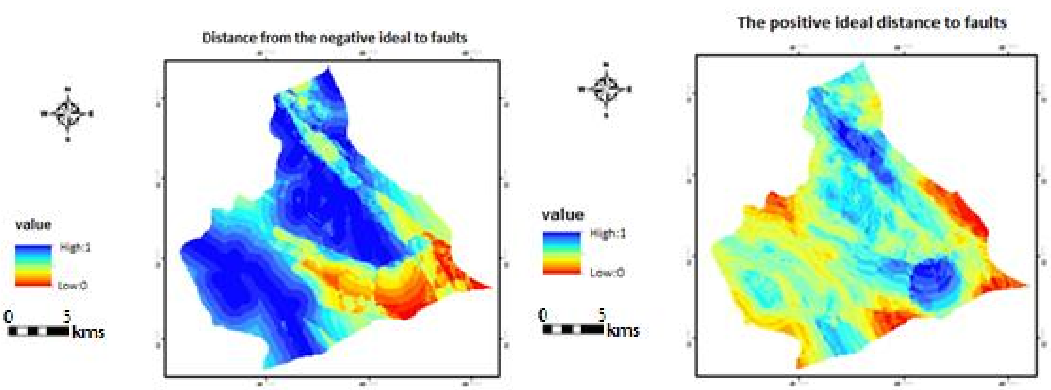

Fig. 4. Measuring positive and negative ideal distance from the fault layer

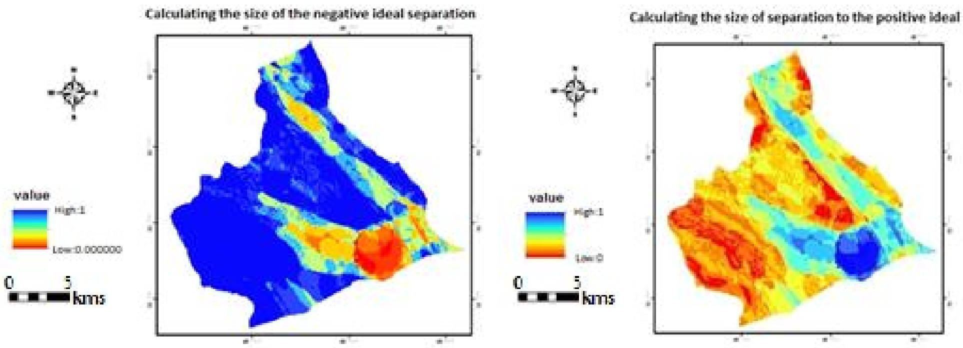

Fig. 5. Calculating si^+ and si^- for the criteria

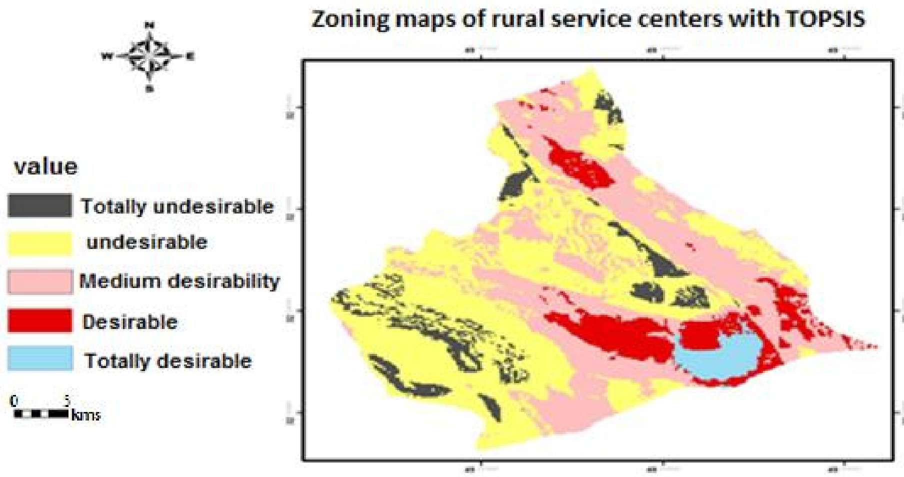

Fig. 6. Zoning map for the establishment of rural service centers

In the final step, the maps obtained from the previous step were combined using the following equation and the spatial zones suitable for the establishment of rural service centers were proposed. As shown, the final map shows the zoning of different regions to be considered for the establishment of rural service centers.

6. CONCLUSION

In this study, a hybrid method was used which was based on geographic information system and multi-criteria decision-making methods. Using the identified criteria, we assessed different areas for the establishment of rural service centers so that scattered and sparsely populated villages have appropriate access to these centers. To achieve this objective, first the selected criteria and options were evaluated via collecting experts' opinions; then, TOPSIS was used to analyze the collected data and finally the best zones for the establishment of service centers were identified. The analysis of the identified zones suggests that they were the most populated areas with more infrastructure facilities and services. Moreover, among the natural factors, land slope had the greatest influence in choosing a place for the establishment of a rural service center. The studied zone did not have a totally desirable area because it covered places with steep slopes. On the other hand, the ease of access to other villages also plays a crucial role in selecting the final zone. Some villages it is not possible to provide services and access the service centers. For instance, there are many villages in the North and North East area which are located in desirable zones however they are remote villages with no access to rural service centers. So, in case of allocation of budgets for the establishment of new rural service centers at this region, this zone should be considered as a priority. In order to have a proper process of decision making, without taking into account the tastes and trends of directors, it is recommended to use the proposed method for the allocation of rural service centers in other areas.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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