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Land Suitability of Urban and Industrial Development Using Multi-Criteria Evaluation (MCE) and A New Model by GIS in Fasa County, Iran

Masoud Masoudi [1,*], Mostafa Aboutalebi [2], Elham Asrari [2] and Artemi Cerdà [3,*]

[1] Department of Natural Resources and Environmental Engineering, School of Agriculture, Shiraz University, Shiraz 71441-1331, Iran
[2] Department of Civil Engineering, Payame Noor University, Tehran 19395-3697, Iran; abootalebi@shiraz.ir (M.A.); e_asrari@pnu.ac.ir (E.A.)
[3] Soil Erosion and Degradation Research Group, Department of Geography, Valencia University, 46010 Valencia, Spain
* Correspondence: masoudi@shirazu.ac.ir (M.M.); artemio.cerda@uv.es (A.C.)

Abstract: Land use planning is a science that specifies the optimized use of land based on ecological and socioeconomic characteristics. In many parts of Iran, the selection and management of land use (development, especially) is performed regardless of land capability, which causes disinvestment and reduces the environmental capacity. The main objective of this study is to evaluate and reform the ecological model of urban, rural, and industrial development in the study area. This study was conducted in Fasa County in the southern part of Iran, and the investigated methods included Weighted Linear Combination (WLC) or Multi-Criteria Evaluation (MCE), with two views, without limitation and with limitation, and the proposed geometric mean method through the integration of maps in GIS. The results showed that the geometric mean evaluation model (with kappa = 0.69) is the best and easiest compared to other models in the estimation of environmental capability. It should be mentioned that the lowest precision (with kappa = 0.59) between the methods was observed in the MCE method without a limiting factor, and it is clear that the limiting factor has a decisive role in assessing ecological capability and increasing accuracy. It is concluded that the proposed geometric mean method, due to the simplicity and high accuracy of the calculations, has a significant contribution to increasing efficiency and reducing the costs associated with the assessment of ecological capability.

Keywords: land use planning; ecological capability assessment; geometric mean; multi-criteria evaluation

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1. Introduction

It is worth noting that policy assessments have gradually become more efficient in the policy-making process [1]. The Organization for Economic Co-operation and Development and other organizations have made noteworthy contributions to increasing awareness about sustainability in policy assessments. Recent research highlights the importance of assessing the potential impacts of proposed policies as a way to achieve sustainable development [2]. Sustainability and sustainable development are increasingly gaining attention from various groups, including the media, the research community, and environmental activists [3,4].

When it comes to assessing sustainability, it is crucial to consider the economic, social, and environmental dimensions [5–9]. Understanding the land's capabilities is also essential. To achieve sustainable outcomes in policies, plans, programs, or projects, utilizing indicators on different objective levels can be the key to success. Soil- and water-related elements are especially important to consider [10–13].

Sustainable development of an urban area requires urban land use planning [14]. Land use planning tries to plan optimal uses to be replaced and to protect against incompatible changes and potential changes [15,16]. Such management strategies make an urban area sustainable through land use planning. Therefore, land use planning is vital in planning a city and its suburbs [17].

Although comprehensive land use planning is a complex decision-making process, the invention of new technologies in the GIS environment has simplified such complex assessments in two ways—(1) GIS allows experts to work with a large number of datasets; (2) with several methods, techniques, or models, the analysis of land use capacity can be evaluated in GIS [18–20]. A large number of physical and environmental, social, and economic indicators have been considered for proper planning of the development of urban and industrial areas. Geographical data are used in a GIS environment by using these indicators in various complex ways in the evaluation process of urban development planning. However, to use these datasets in GIS, spatial database management is required, especially when the datasets are complex and voluminous [21,22]. To build such a spatial database, at first, it is necessary to prepare a conceptual model so that their mutual relations are well defined and the database can be used to store, edit, and query data easily. Then, some models or multi-criteria decision-making (MCDM) techniques embedded with GIS can be used to evaluate land use capability [23–25]. To weigh the indicators, the Analysis Hierarchy Process (AHP), which is a technique in MCDM, can be used for urban development planning using GIS. McHarg (1969) [26] showed that land capability assessment is an important step in land use planning. It is also very important to choose the appropriate evaluation method for land use planning [27]. Mitra and Ilangova (2004) [28] have pointed out that GIS has a very important role in the location of land uses. GIS typically stores and evaluates extensive data in the form of digital maps [29]. Pourkhbaz et al. (2014) [30] conducted a good evaluation of agriculture in the Qazvin-Takestan plain in Iran by using multi-criteria evaluation (MCE) methods and by using AHP and simple incremental weight (SAW). Their results showed that the application of MCE can be useful in evaluating agricultural potential. Jokar et al. (2021) [25] evaluated and reformed the ecological model of the development of ecotourism in Sepidan County, Iran. The results showed that the geometric mean evaluation model and its calibration are better than other models (Iranian Evaluation Model of Ecological Capability based on Boolean logic; the maximum limits proposed method (Boolean logic), and the arithmetic mean) in the estimation of environmental capability.

Parry et al. (2018) [31] were able to determine urban development potential through AHP and MCE using a set of geophysical and socio-economic criteria in urban areas of Srinagar and Jammu, India. For better urban development planning and appropriate decision making, their study provided information about the suitability of the area's lands for creating urban welfare development in the future.

A decision method for deriving combined maps using GIS is the Weighted Linear Combination (WLC) technique. It is one of the most commonly used decision-making models in the GIS field. However, the application of the method often occurs without a full understanding of the assumptions behind the approach. In many case studies, because analysts (decision makers) ignored or were unaware of the assumptions, the WLC model has been misapplied with questionable results. When it comes to the WLC method, there are specific challenges in weighting and standardizing indicators that should be taken into account. Evaluation methods face a problem with this method, as they need to consider the constraints to avoid lax evaluation and to maintain accuracy in determining the ecological range for the indicators. Weighting indicators can also lead to mistakes, and standardization of indicators can result in errors by evaluators [23]. This is why it is crucial to prepare an evaluation model that does not have these challenges to ensure reliable land evaluation.

In this research, according to the mentioned cases, two WLC evaluation methods without constraints and with constraints and considering the AHP weighting method to determine the weight of indicators were evaluated to assess the ecological capability of urban and industrial development in Fasa County in the south of Iran. Additionally, Fasa County's sufficient data and good ecological diversity made it an excellent candidate for land evaluation. Then, the accuracy of the above two methods was measured with a new and lenient evaluation method based on the evaluation of indicators based on the geometric mean. The hypothesis of this research is that the geometric mean method has higher accuracy than the WLC method without constraints and that it has equal or higher efficiency than the WLC method with constraints due to its ease of implementation. Therefore, the main objective of this study is to develop a newly proposed method in comparison to WLC or MCE (using fuzzy-AHP)-based averaging methods. This proposed method may have the ability to evaluate land for urban and industrial development more easily and accurately.

2. Materials and Methods

2.1. Study Area

Fasa County (Figure 1) is located in the southern part of Iran. Its area is 4188 Km^2. Fasa is one of the cities of the Fars province and the center of Fasa County. The city of Fasa is located at 53°40′ E and 28°58′ N at an altitude of 1370 m above sea level, and it is a city with a distance of 145 km from Shiraz, the capital of the Fars province. Fasa County is the fourth most populated city in the province, with a population of 208,000. Fasa is located in the semi-arid temperate region. The highest temperature in the summer reaches 42 °C, and the lowest in the winter reaches −8 °C; the average rainfall of the County is about 380 mm per year. The economy of this county is based on agriculture and animal husbandry. Fasa boasts of its thriving agricultural industry, particularly in wheat production, which is the highest production in Iran. The city's climate is well suited for the growth of tropical palm trees and various fruit trees, such as oranges, tangerines, pomegranates, pistachios, almonds, and walnuts. Moreover, animal husbandry contributes significantly to the local economy, with livestock and dairy products, wool, leather, and meat being among the prominent products. In general, nearly 40% of Fasa County is plain, and the rest is mountainous. The elevations in Fasa County extend from the Zagros Mountain range and follow a northwest-to-southeast direction. The mountains consist mainly of limestone and chalk, while the plains of Fasa County are relatively flat with little variation in elevation, and they are covered by alluviums from the Quaternary period. Based on the American comprehensive system, the soils in Fasa County can be categorized as either Antisol or Inceptisol. Moreover, these soils fall into three main subgroups (Arenosol, Cambisol, and Calcisol) under the international FAO system [32].

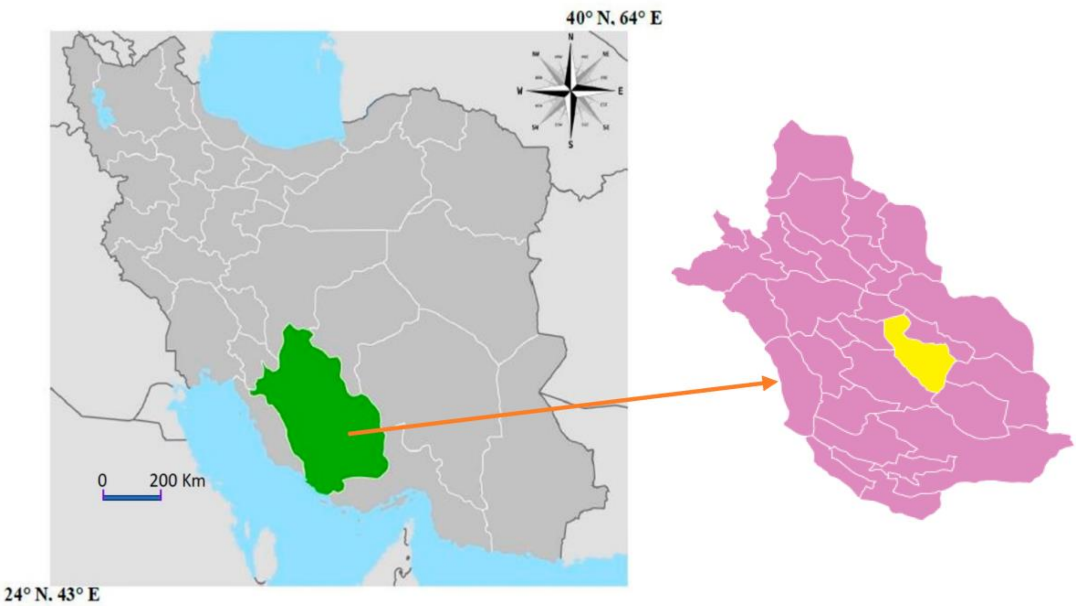


Figure 1. The map of Iran shows the location of Fars province and Fasa County in the southern region of Iran.

2.2. Methodology

The general methodology consists of two parts. (a) description and reclassification of indicators, and (b) evaluation and formulation of two models based on the geometric mean and WLC. Figure 2 shows the working method flow diagram of the programmed model. The obtained data include two types: (1) digital data and (2) map data, mainly in a vector format with the spatial reference of the UTM Zone 39N projection with semi-detailed to detailed information (with scales of 1:50,000 to 1:100,000). All of these data used by the regional and main offices of the Ministries of Energy and Agriculture of Iran have been prepared and processed using different methods in GIS to carry out this research (Table 1). The slope index was prepared from the Digital Elevation Model (DEM) map, and the land type index was prepared from the land unit map. Climate indices, like precipitation, temperature, etc., were provided from synoptic and climatology stations of the study area. Soil and geology maps with their parameters were provided based on existing maps. Also, the geometric and descriptive features of the maps were modified using Global Positioning System (GPS) tools along with fieldwork. Buffer maps of faults and rivers were obtained from the geological and stream maps. Data on the quantity of water were provided by the regional water office. It should be mentioned that we used existing maps with field surveys and modifications for vegetation parameters.

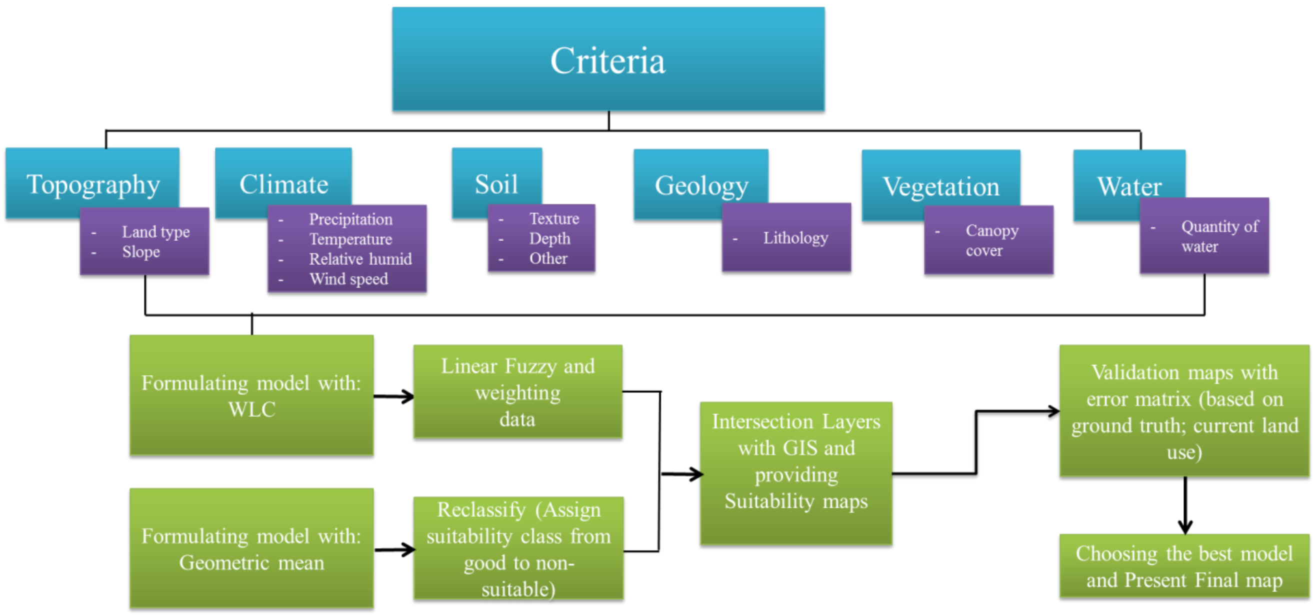


Figure 2. Flowchart of the methodology performed to assess ecological capability in this study.

Table 1. The parameter classes for the ecological capability assessment of development [23].

Criteria	Indicators	Classes of Ecological Capability and Their Rating Score		
		Highly Suitable (2)	**Moderately Suitable (1)**	**Poor to Not Suitable (0)**
TOPOGRAPHY	**Land type**	Plains except for floodplains	Plateau and upper terraces, alluvial and colluvial fans	Mountainous and hilly areas, floodplains
	Slope (%)	0–15	15–30	>30
CLIMATE	**Precipitation (mm)**	501–800	51–500 or >800	<50
	Temperature (°c)	18.1–24	24.1–30 or <18	>30
	Relative humidity (%)	40.1–70	<40 or 70–80	>80
	Wind speed (km/h)	1–35	36–60	>60

Table 1. *Cont.*

Criteria	Indicators	Classes of Ecological Capability and Their Rating Score		
		Highly Suitable (2)	**Moderately Suitable (1)**	**Poor to Not Suitable (0)**
SOIL	**Texture**	Moderate (often)	Light (often)	Heavy (often), Regosols, Lithosols
	Depth (cm)	Deep (> 80)	Semi-deep (50−80)	Shallow to very shallow (<50)
	Gravel percent	0–25	26–50	>50
	Drainage (cm/hr)	Good (2–6)	Moderate (0.1–2 or 6–25)	Poor (<0.1 or >25)
	Erosion	None to slight	Moderate	Severe to very severe
	Granulating	Moderate	Fine or coarse	Very fine
	Evolution	Perfect	Moderate	Low
GEOLOGY	**Lithology**	Sediments of the continental shelf, Ophiolite of melange color, and Sandstone	Middle Eocene pyroclastic rocks, limestone and dolomite, granite, shale, alluvial cones, conglomerate, claystone, loess, and alluvial terraces	Schist and gneiss and amphibolite, calcite marble and dolomite, quartzite, marl, salt domes, gipsum domes, sand dunes, floodplain, and Buffer maps for faults and rivers [1]
VEGETATION	**Canopy cover (%)**	0–25	26–50	>50
WATER	**Quantity of water for everyone (Lit/day)**	<225	150–225	<150

[1]—Major Fault = 1 km, Minor Fault = 300 m, River = 1 km (based on guidelines of the Department of Energy and the Department of Housing and Urban Development).

2.2.1. Description and Reclassification of Indicators

The selection of indicators and their classification method are derived from the evaluation model of the Iranian assessment of ecological capability for development use [33] based on the evaluation of Boolean logic, including three (3) classes. Of course, because the classification of indicators in the above model is not clear for the evaluators, the new classification method shown in Table 1 has been created to facilitate its use. Thus, new classes have been introduced, including highly suitable (good), moderately suitable, and poor to not suitable (Table 1). The selection of indicators in the evaluation model of the ecological capability of different utilizations in Iran is based on those indicators that are important in the evaluation of the ecological capability of residential and industrial development, such as various indicators of topography, climate, soil, geology, vegetation, and water.

Table 1 shows that the classification range of the above indices is quantitative for most of the indices and qualitative for the rest due to the descriptive nature of the index (such as land type or lithology type). Of course, as Table 1 shows, for the above two cases, the ecological capability score of the classes (0 to 2) for the averaging evaluation method is given in the form of a geometric mean. Of course, this score range for classification by the WLC method usually includes the range of 0 to 1 or 0 to 255.

2.2.2. Evaluation and Formulation of the Proposed Model Based on the Geometric Mean and WLC

Multi-criteria evaluation (MCE) or WLC: First, data or indices in vector format were converted to raster data. Then, linear fuzzy classification (0 to 1) was performed on these parameters based on their thresholds (Table 1). Linear fuzzy classification explains the fuzzy membership function based on the maximum and minimum fuzzy membership of 1 and 0. The Table 1 classification was used to classify and determine the fuzzy numbers. Suitability classes with scores of 0 and 2 will represent fuzzy values of 0 and 1, respectively.

In the next step, the mentioned indicators were weighted based on the AHP method with specialist discernment. Then, the WLC method was used to weigh the input data. With a weighted linear combination, the indices were combined by applying a weight to each index and then classifying the results to obtain a suitability map (Equation (1)).

$$X1 = [(W1 \times \text{Indicator1}) + (W2 \times \text{Indicator2})\ldots + (Wn \times \text{Indicator n})] \times Ci \quad (1)$$

W = obtained weight for each parameter.

Ci = constraints; in this study, WLC was investigated based on both existing constraints and without constraints. Ci should be 0 (existing constraints) or 1 (without constraints) in each pixel.

Finally, a natural breaks method was performed for the final classification of the fuzzy map in 3 classes.

Geometric mean: According to the indicators listed in Table 1, each indicator in a vector format was given a weight from 0 to 2 (0 indicates poor to unsuitable ecological status, and 2 indicates suitable ecological status for development). Then, each criterion was evaluated according to the geometric mean of the indicators presented in Equation (2):

$$criterion\_x = (layer1 \times layer2 \times \ldots \times layern)^{1/n} \quad (2)$$

In this formula, *criterion_x* is a criterion, the *layer* is an indicator of the criterion (such as slope and land type parameters in the topography criterion), and n is the number of indicators. Next, the criteria were multiplied using the geometric mean (Equation (3)).

$$\begin{gathered}\text{Final score of land suitability for Development} \\ = (Topography \times Climate \times Soil \times Geology \times Vegetation \times Water)^{1/6}\end{gathered} \quad (3)$$

In this formula, the final score helped us to prepare the final suitability map. Then, the land capability classes for development use were determined using Table 2 in the GIS environment.

Table 2. Land capability classes for development use based on their points in the polygons prepared in the final map.

Suitability Classes	Good (1)	Moderate (2)	Poor to Not Suitable (3)
Scores of polygons	1.5–2	0.5–1.5	<0.5

2.2.3. Validation Models

To validate the obtained map, it should be compared with ground reality samples [34]. In the current research, the first settlement area (Fasa City as the main city) defined in the current land use map is equivalent to a good class, other cities and rural areas are equivalent to a moderate class, and the dense and semi-dense forest in the mountains and desert lands (saline and bare land) are equivalent to the poor and not suitable class (Table 3). After that, samples of these regions (Table 3) were collected in ArcGIS 9.3 environment using the "Create Fishnet" algorithm, both systematically and randomly [35]. Then, these points were placed on land capability maps for validation. The results of validation can be seen in a table called the "error matrix" or agreement matrix (Table 3). In this table, quantitative indicators of accuracy, such as the "kappa coefficient, overall accuracy, and in-class index," are estimated [36]. The in-class coefficient is an accuracy index to estimate the correct preparation of appropriate classes for each use, such as the main city in the land map [35].

Table 3. The Error matrix for development use in the region.

	Ground Reality		
Classes	Fasa City (Main)	Other cities and rural areas	The dense and semi-dense forest in the mountains, desert lands
1	*		
2		*	
3			*
Point number	510	276	675

3. Results

Table 4 shows the weight of the indicators used in WLC methods with a Consistency Ratio of CR < 0.1. According to this method, the water index has the highest weight, and the land type and lithology indices are in the next ranks.

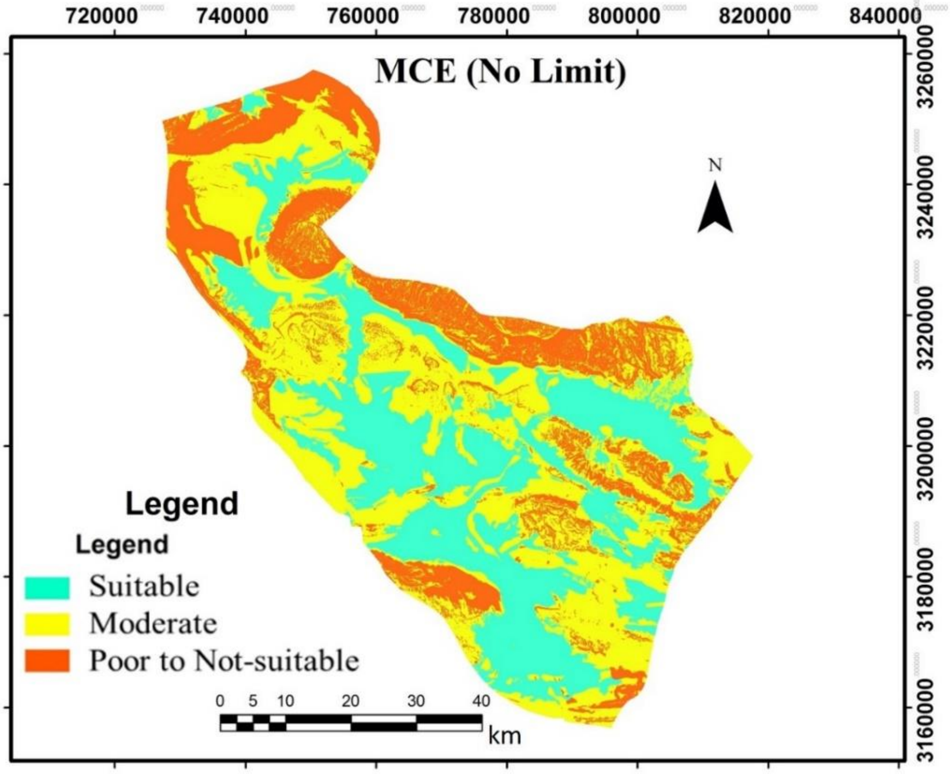
Table 4. The weight of the indicators used in the development model based on the AHP method.

Factor	**Factor Weight**
Slope	0.091
Land Type	0.115
Rainfall	0.078
Temperature	0.039
Relative Humidity	0.019
Wind Speed	0.021
Soil Texture	0.039
Soil Depth	0.107
Soil Drainage	0.042
Soil Erosion	0.072
Lithology	0.114
Vegetation	0.047
Quantity of Water	0.216
CR	0.05

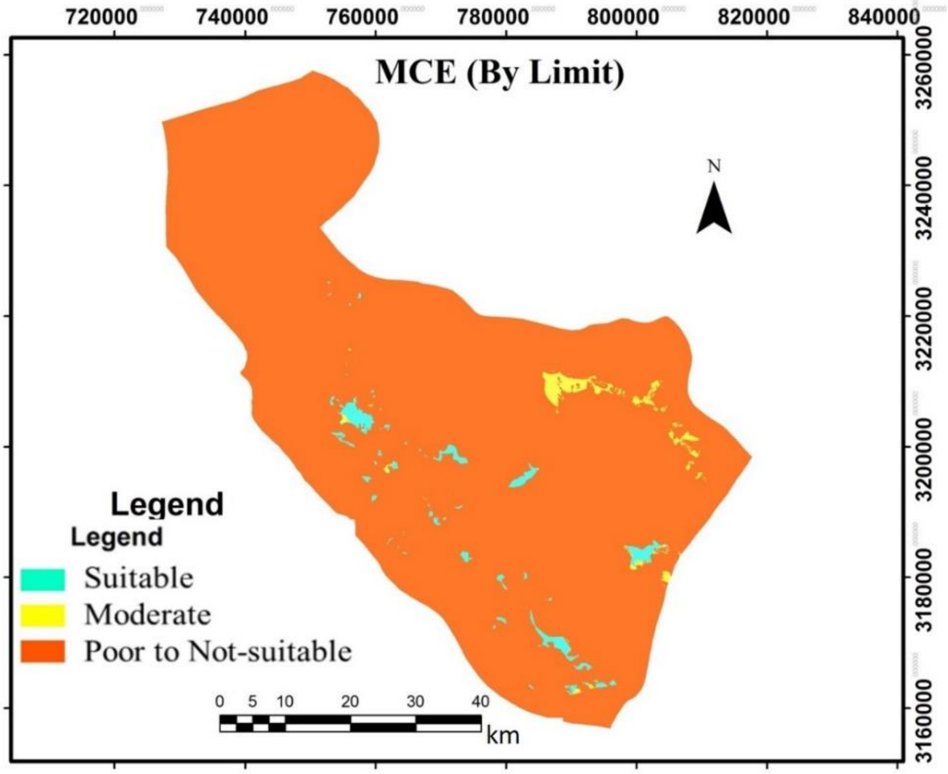
The capability map with the best accuracy prepared by the geometric mean is observed in Figure 3. Table 5 shows the accuracy assessment indexes in the used models. The results showed that the WLC method without constraints has the lowest accuracy, and it is clear that the limiting factor has a decisive role in assessing ecological capability and increasing the accuracy. Also, the proposed method including three classes by geo-mean is close to WLC with constraints, with high accuracy. Figure 4 also shows the proximity of the expansion of capability classes in these two methods, but it should be mentioned that the geometric mean evaluation model is simpler than WLC because this method does not need a weighting process. This issue indicates that the evaluation with a geometric mean with three final capability classes can be a suitable method for finding potential urban and industrial development areas. The final map prepared, based on the proposed method, is placed between 0 and 1. Therefore, this method has a high capability in separating classes and locating them compared to other evaluation perspectives.

Table 5. Values of validation indices, kappa coefficient, overall accuracy, and in-class coefficient in the used models.

Land Use	**Model / Index**	**MCE (WLC)**		**Geometric Mean**
		Without Constraints	**With Constraints**	
Development	Overall Accuracy	74	82	82
	Kappa Coefficient	0.59	0.69	0.69
	In-Class Coefficient	2.18	5.29	5.13

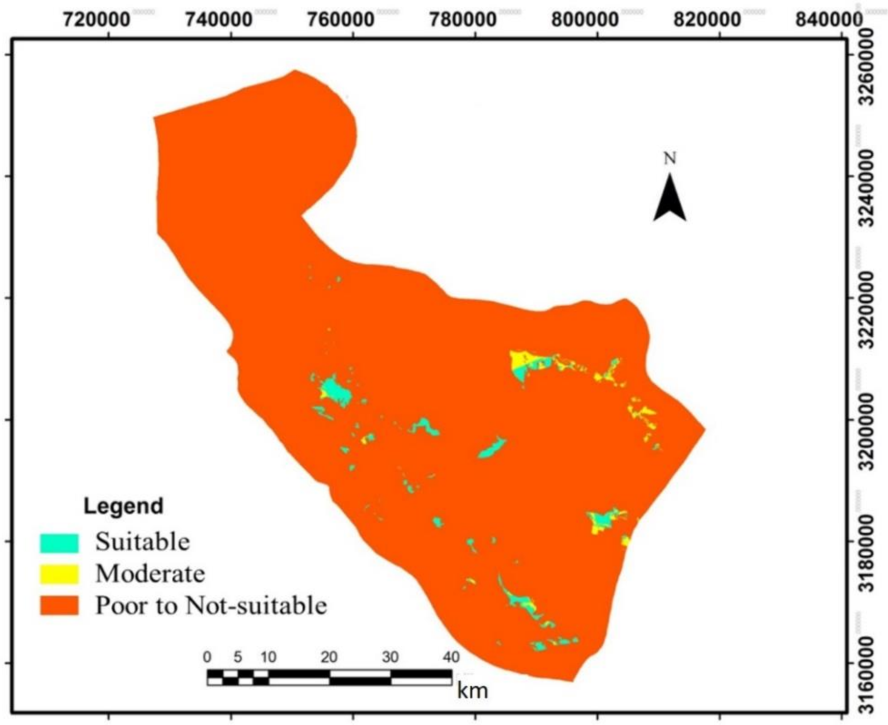


(**a**) WLC (without constraints)



(**b**) WLC (with constraints)

Figure 3. *Cont.*



(**c**) Geometric mean method

Figure 3. Maps of the ecological capability of urban and industrial development prepared by (**a**) WLC (without constraints), (**b**) WLC (with constraints), and (**c**) geometric mean method.

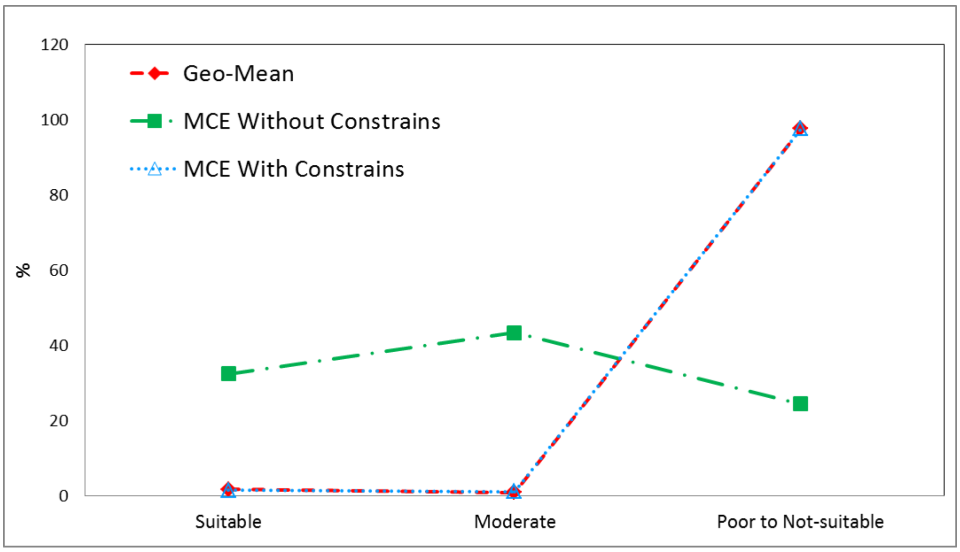


Figure 4. The percentage of lands under different capability classes for different methods of evaluating development potential in this research.

4. Discussion

Considering the ecological capacity of an area is crucial to sustainable land use planning, especially for urban and industrial zones. This approach ensures that land use is sustainable and that it caters to the needs of both the environment and humans. Urban areas play a significant role in achieving Sustainable Development Goals by providing safe and affordable housing, water, and sanitation, as well as improving transportation systems to make them accessible and sustainable for all. By prioritizing these factors, cities become safer, more resilient, and sustainable, and they contribute to a more sustainable future.

In this study, the model of the ecological capability of development use was investigated using different evaluation methods (WLC and geometric mean) and with an all-around approach to the environmental characteristics of Fasa City. It is worth mentioning that in the review of the topographic criteria for evaluating the urban development potential, changes were made compared to Iran's ecological model [33]. In this way, the land type index (based on Iran's ecological model) was added to the above model, and the height above the sea level index was removed from the above land use model. Considering that there are some suitable urban areas in the world that are at low altitudes, such as in Europe, as well as areas that are located in the plains but at high altitudes, in the current urban development model, the height index was removed. Therefore, the topography criterion was evaluated by considering the slope and land type indicators. In research conducted by Monavari et al. (2008) [37] in order to evaluate the ecological capability of the Zakhard watershed area in the northwestern part of Shiraz City in the south of Iran, the results of the study showed that upon considering all of the ecological parameters, the entire area is unsuitable for urban development. However, by removing the height index from the region, about 9% of the basin will have suitable capability for urban development.

In this research, the accuracy of the model in the geometric mean conditions was better than the WLC ecological model without considering the limiting factor and almost equal to WLC with the limiting factor considered. In relation to the evaluation method in general, it can be said that in the WLC method without considering the limiting factor or the simple WLC without weighting, which are non-strict methods, the majority of the region tends towards the appropriate classes. But, in stricter methods based on Boolean logic, such as Iran's ecological models, FAO models for evaluating agriculture and natural resources [38], and maximum limit methods, the majority of the region moves towards inappropriate classes. It is rare to find areas with suitable and moderate capability in a region. But, the evaluation methods based on the geometric mean and WLC, considering the limiting factor, are placed between these two views. However, the majority of the region tends towards the weak or medium classes due to the consideration of the limiting factor or the consideration of the zero number in the method of multiplying by the geometric mean. Therefore, the results of this research are consistent with the results of Davidson et al. (1994) [39], Baja et al. (2006) [40], Najafinejad et al. (2013) [41], and Jokar et al. (2021) [25].

In FAO models, the way to evaluate the capability of land uses is based on the maximum limit approach, which, like Iran's ecological models, has a strict decision regarding the location of land uses. This type of decision making (maximum limitation and systemic method) is based on the type of attitude towards the environment and the examination of its components, as well as estimating the capability without prejudice and only based on the inherent potential of the land [41]. However, these pure and idealistic attitudes towards the environment ignore social and economic factors and make an incomplete estimate of the real capability of the land [42]. In other words, the above methods have a limited attitude towards land evaluation. The model of ecological capability should, in addition to showing the limiting conditions, also express the climax and the peak capability of an ecosystem to create a utilization in the current conditions. This climax condition, which indicates the high capability of utilization, can be searched in its current condition. That is, if a land use has been able to settle well in the land, the possibilities and conditions of its climax have existed, and the model should be able to recognize it. This research showed that the proposed geometric mean model derived from the EMOLUP model [23,43] plays a more appropriate location approach to determining climax conditions and also involves limiting factors in land zoning.

In the EMOLUP geometric mean method, determining the evaluation criteria reduces the effect of some criteria, such as soil, with more indicators, compared to other criteria, such as topography, with fewer indicators (for example, two indicators). In this way, the weight of both the soil and topography criteria is considered equivalent, which is not seen in prominent models, such as WLC. It is worth remembering that the proposed model is also a type of multi-criteria evaluation (MCE) method. Also, by putting the number zero in the equation, the ecological intervals that create a limit or hazard for the earth (such as mountainous lands or with low water content) tend towards the wrong side with the process of geometric multiplication. With this approach, the attitude that the fans of maximum limitation have towards modeling and limiting factors is also taken into account.

It is worth mentioning that implementing the geometric mean evaluation method is easier compared to the current conventional methods (which are more difficult to implement and have ambiguities for the evaluator), such as using Boolean methods based on AND logic and the current WLC. In the current WLC, the evaluator needs to give weighting, there is a possibility that the experts estimating the weight of the indicators may make a calculation error; sometimes, there is a mistake in the standardization of the indicators (determining the ecological range between zero and one), and these are challenging cases. AHP is a broadly used weighting approach in WLC methods, and it was started by Saaty. It is easily implemented as one of the WLC techniques [44–46]. Therefore, according to the reasons mentioned and the high accuracy, and according to the equality of the kappa coefficient of the geometric mean and the weighted arithmetic mean (WLC) methods with the application of the limiting factor, the geometric mean is more convenient than this method of evaluation. It has superiority and can be recommended for evaluating other regions of the world. Some researchers, like Asadifard (2015) [47], Razaghi (2016) [48], and Jokar et al. (2023) [49], compared the methods of the geometric mean and multi-criteria evaluation in Iran. Their results showed the relative superiority of the geometric mean method for the multi-criteria evaluation.

5. Conclusions

Land preparation should be performed with a coordinated approach to development and environmental protection. Achieving this goal will lead to the sustainable development of the environment with the approach of evaluating the ecological potential and choosing the best option for the use of the land. The main goal of this research is to implement the ecological model of urban, rural, and industrial development of Fasa County in the southern part of Iran and to compare the proposed geometric mean method derived from the EMOLUP model with the weighted index arithmetic mean (WLC) with and without applying the limiting factor in the study area using GIS. The maps of land capability for urban development were prepared. Finally, the best and easiest capability assessment map was selected based on the geometric mean method derived from the EMOLUP model. It is concluded that the proposed geometric mean method, due to the simplicity and high accuracy of the calculations, has a significant contribution to increasing efficiency and reducing the costs associated with the assessment of ecological capability. To effectively implement urban and industrial development policies, it is imperative to concentrate on regions with high and medium suitability, as indicated on the production map. It is essential to avoid weak and unsuitable areas at all costs. However, it is worth noting that certain areas may become suitable with the removal of restrictions. Overall, the study results can be applied in land use planning in other regions with similar conditions. So, the results of this research can be used by different managers and other stakeholders for proper land use management.

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