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A HYBRID MULTI-CRITERIA-DECISION-MAKING METHOD AND GEOGRAPHIC INFORMATION SYSTEM FOR SELECTING THE LOCATION OF WOOD PRODUCTION FACTORIES USING PALM WASTE

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Annotation. In recent years, the shortage of forest resources and the increase in demand for wooden products have faced severe challenges in the wood and paper industry. According to the surveys conducted, the branches and waste from palm pruning can be used for conversion industries, including the production of chipboard and medium-density fiberboard (MDF). The surface of Iran has significant coverage of palm trees, and currently, a large amount of waste from these trees is thrown away and burned. Therefore, the topic chosen in this research is to determine the location for building the wooden products production factory, aiming at optimal use of palm waste and helping to compensate for the lack of wooden production in the country. First of all, suitable criteria for building a wooden products factory are determined through sources and experts" opinions. Then, they are prioritised and weighted using a questionnaire based on the BWM method. In the next step, ArcGIS software is used to apply the criteria on the level under investigation. Decision options are ranked using TOPSIS, ARAS, COPRAS, WASPAS, MULTIMOORA, VIKOR, SAW and CODAS decision-making methods. Then the obtained results are collected using the CRITIC method, and the best construction places are determined. When different decision-making methods are combined, the accuracy and strength of the obtained results also increase.

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JEL classification: C44, L73, Q55, Q56, R30.

Introduction

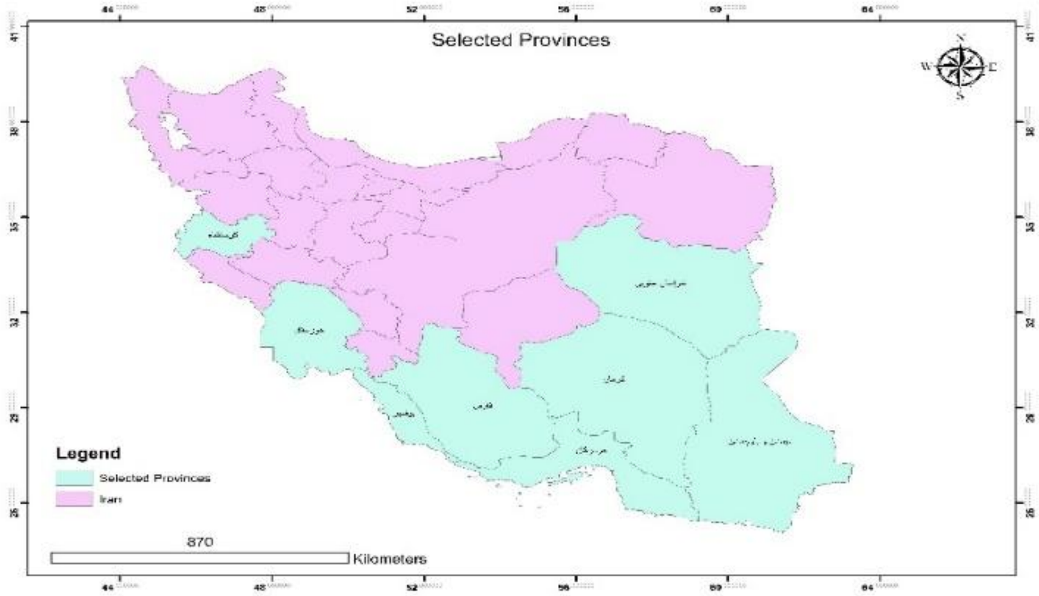
Wood and its byproducts have many applications in daily life and industry. Considering the challenges posed in recent years due to the shortage of wood products, the use of waste from wood industry units and branches and the identification and introduction of suitable lignocellulosic sources to production units are necessary issues (Azizi, 2007). Additionally, using agricultural waste has emerged as a promising policy to strengthen the global energy system (Morales Chavez et al., 2021). On the other hand, research has shown that the branches and wastes from palm tree pruning can be used in transformation industries, including the production of chipboard and MDF. Research has been done that focuses on the comparative study of using palm tree leaves to make different types of chipboard as a pure material or as a reinforcement of chipboard. The findings indicate that using palm leaves in chipboard production increases the boards" resistance properties with an acceptable apparent density and low water absorption (Kadhim Jawad et al., 2022). It can play an influential role in providing raw materials for wooden products. It should be noted that this will lead to the optimal use of the amount of waste produced in Iran. This research aims to build a factory that uses these wastes to make wooden products. Since the purpose of this research is to use agricultural waste to meet the needs of wood products at present, it will not pose a risk to meet the needs of future generations. For this reason, it can be said that the concepts of sustainability and sustainable development have been considered in this research. The idea of sustainability was developed in the 1960s due to poor resource management and in response to environmental concerns. The importance of this issue has been noted in many articles. For instance, an article in 2023 examined the effect of land suitability on mango production. Salunkhe and his colleagues identified the most important factors before and after protective measures in mango production by combining multi-criteria decision-making methods and GIS software. They showed that combining MCDM with AHP based on GIS creates a more reliable output (Salunkhe et al., 2023). Similarly, MCDM-based GIS analysis was employed to assess underground water potential in the Haran region, where areas were classified according to groundwater accessibility (Aslan, Çelik, 2021).

Location selection is one of the most critical factors in the construction of a factory for product manufacturing. A key objective in determining the optimal area for establishment is to minimise unnecessary transportation costs while ensuring the efficient delivery of raw materials and final products (Olayinka Waziri, 2023). The structure of this article is that first, the appropriate criteria for the construction of the factory should be determined, and the final indicators should be determined with the opinion of experts in the field of wood science and research. The BWM method is considered for prioritising and weighing indicators. In the next step, GIS software applies criteria and creates geographic layers to determine the most suitable areas. The geographic information system allows us to link data based on common geographic location (Hussain, 2016). The provinces with significant palm cover, which are considered for analysis, include Sistan and Baluchistan, Kerman, Hormozgan, Fars, Bushehr, South Khorasan, Khuzestan and Kermanshah. Therefore, the geographical scope of this study is primarily the southern regions of the country. Finally, GIS output options are prioritised using MCDM methods, and the final ranking is determined by collecting the results of these methods. The purpose of the simultaneous use of two or more ranking methods is to analyse and validate the results (Barak, Dahooei, 2018). On the other hand, using an MCDM method for prioritisation alone cannot produce accurate results (Barak et al., 2015). Therefore, to solve these problems and increase the accuracy of the results, many researchers have suggested using different MCDM methods (Varmazyar et al., 2016). Given the complexity of geographic data in this study, a hybrid approach integrating MCDM techniques with GIS is employed to determine the optimal location for the wood factory (Ghasempour et al., 2019).

The selection of locations for factories and industrial units is one of the most critical factors in establishing or expanding production facilities. Choosing appropriate locations based on well-defined criteria significantly influences the efficiency and success of these projects (Azizi et al., 2015). In 2013, a study was conducted that used the hierarchical analysis process method according to the cost and benefits point of view for the location of the fiberboard production factory in Mazandaran province (Azizi, Ramezanzadeh, 2013). A 2015 study identified the most suitable provinces for establishing furniture manufacturing facilities in Iran. The process of hierarchical analysis determined the weight of the indicators. These weights were used in TOPSIS to rank the options (Azizi et al., 2015). In another research conducted by Burdurlu, the Analytical Hierarchy Process (AHP) was used to select the location of furniture industry companies in Turkey (Burdurlu, Ejder, 2003). Choosing the right location for the facility is very important in logistics decisions (Pereira et al., 2015). A study identified criteria using expert consultations and GIS software to shortlist potential locations for a solar power plant in Iran. First, appropriate criteria are determined through relevant sources and experts" opinions, and the initial list of options is specified using GIS software. In the next step, the selected options were prioritised with MCDM methods, and finally, the CCSD method collected the results and identified the best location (Heidary Dahooie et al., 2022). Also, in 2017, a combination of geographic information system and 4 MCDM methods were used to select the best place to install wind power plants in Ecuador. The results provided by the four decision-making methods were similar. Therefore, it can be concluded that multi-criteria decision-making methods are a powerful tool for locating (Villacreses et al., 2017). In a study, Günen combined satellite data and a GIS system with the MCDM decision-making method based on the Analytical Hierarchy Process (AHP) (Günen, 2021). Hoa and his colleagues have conducted a study with the aim of determining the location for the use of solar energy in 13 provinces of Uzbekistan, which was used to value the criteria using the (SWARA) method and to prioritise the options using the (WASPAS) and (WSM) methods (Ao Xuan et al., 2022). In 2021, Saraswat et al. utilised GIS and MCDM methods to optimise renewable energy site selection (Saraswat et al., 2021).

1. Methodology

Due to the growing demand for wood and the decline of forest resources, identifying suitable resources for producing wooden products has become critical. According to the research, stems and wastes from palm tree pruning can serve as viable raw materials for wood production. The southern regions of Iran have extensive palm tree coverage, yet the waste from these trees is often discarded rather than utilised efficiently. Therefore, this study aims to identify the most suitable locations for establishing a factory that produces wooden products from palm tree waste. This initiative will enhance wooden product manufacturing, mitigate wood shortages in the country, and ensure the optimal utilisation of waste materials. Since only some of the country"s provinces have palm trees, to make the analysed data and the results obtained from GIS more accurate, only considering the provinces with palm cultivation areas can determine the optimal areas for building the factory. The provinces under consideration are highlighted in blue in *Figure 1*. Such research has yet to be conducted in Iran so far.



Source: created by the authors.

Figure 1. **Map of Areas with Palm Trees in Iran**

Table 1. Introducing the provinces with palm trees

Province	Description	Province area	Palm cultivation area
Southern Khorasan	After Kerman Sistan and Baluchistan, it is known as the third-largest province of Iran.	151,193 km^2	One thousand and 503 hectares
Kerman	Kerman province is the largest province in Iran, and the Kerman metropolis is located in its centre. It is located in the southeast of Iran.	183,285 km^2	Two million and 600 thousand palm trees
Sistan and Baluchestan	It is the second-largest province in Iran.	180,726 km^2	More than 56 thousand hectares
Hormozgan	Hormozgan has more than 13% of the country"s groves.	70,697 km^2	34 thousand hectares
Fars	Fars province, located in the south of the country, ranks second in terms of cultivated area.	122,608 km^2	36 thousand hectares
Bushehr	Bushehr province is located on the edge of the Persian Gulf.	27,653 km^2	More than 39 thousand hectares of palm forest and 6 million palm trees
Khuzestan	The south of Khuzestan province is located on the coast of the Persian Gulf. In terms of population density, it is Iran"s fifth province.	64,057 km^2	41 thousand hectares
Kermanshah	Kermanshah is the 17th largest province of Iran.	24,640 km^2	623 hectares of palm trees

Source: created by the authors.

The method of conducting this study includes several steps, which will be explained below (*Figure 2*).

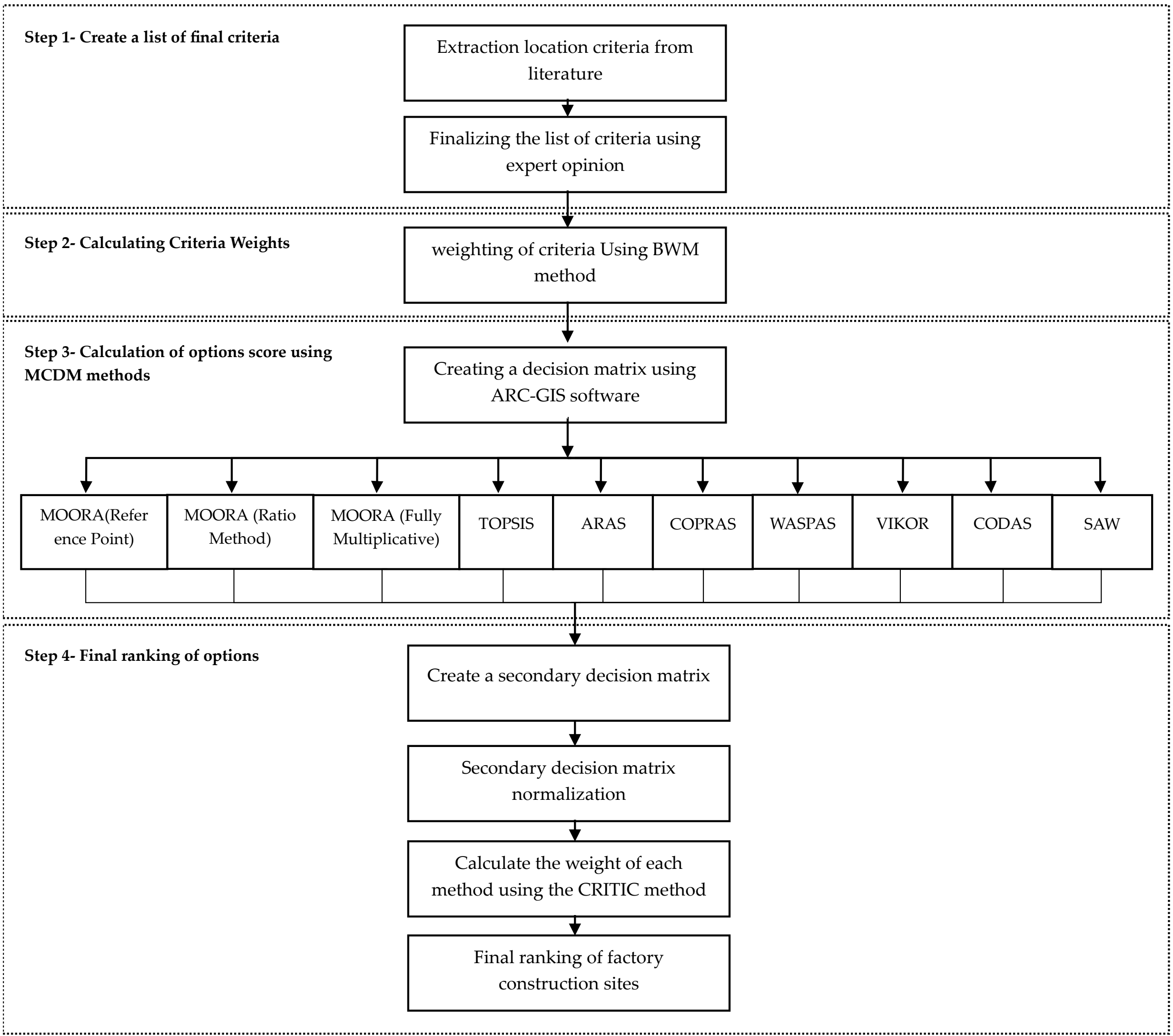


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Figure 2. **Steps to Choosing the Wood Factory Location**

1.1 Determining the Final Criteria List

Firms export refers to a company selling its products or services to markets outside its country (Zhou, Wen, 2022). This is an important part of international trade and involves cross-border business activities. Firm export is part of the internationalization strategy of firms (Holmlund *et al.*, 2007). It is significant for firms to expand market share, increase revenue, diversify risks, and obtain new growth opportunities. At the same time, firm export is also important in promoting national economic development, increasing foreign exchange reserves, and promoting international cooperation (Kenderdine, Ling, 2018).

1.1.1 Extraction of Primary Criteria from the Literature

The first step in conducting this research is to identify the essential criteria for choosing the location of the factories. According to the type of factory and the level of location selection (country, province, region, etc.), the number of indicators and their types are different (Azizi, Ramezanzadeh, 2013). Since no prior studies on this topic have been conducted in Iran, and existing research in this area is limited, the list of essential criteria required by studying related articles and sources, the feasibility projects of the wood factory, and familiarising with the manufacturing process of wooden products and raw materials needed for the wood factory and also consultation with several experts in the field of wood science were collected.

1.1.2 Finalising the List of Criteria

The preliminary list of primary criteria was presented to experts for review and validation. Through interviews with experts who were professors of the Department of Wood Science and Research of Tehran University and Tarbiat Modares University, the best criteria were determined according to the geographical conditions of Iran and the availability of necessary information. Although the altitude criterion is of minor importance in this study, it was included to enhance the accuracy of GIS-based output data. Conversely, while proximity to water sources is typically an essential factor for wood product factory site selection, it was removed from the final list based on expert consultation. This decision was made because water source data is already incorporated into the land use mapping criteria within the geographical database. Conversely, while proximity to water sources is typically an essential factor for wood product factory site selection, it was removed from the final list based on expert consultation. This decision was made because water source data is already incorporated into the land use mapping criteria within the geographical database.

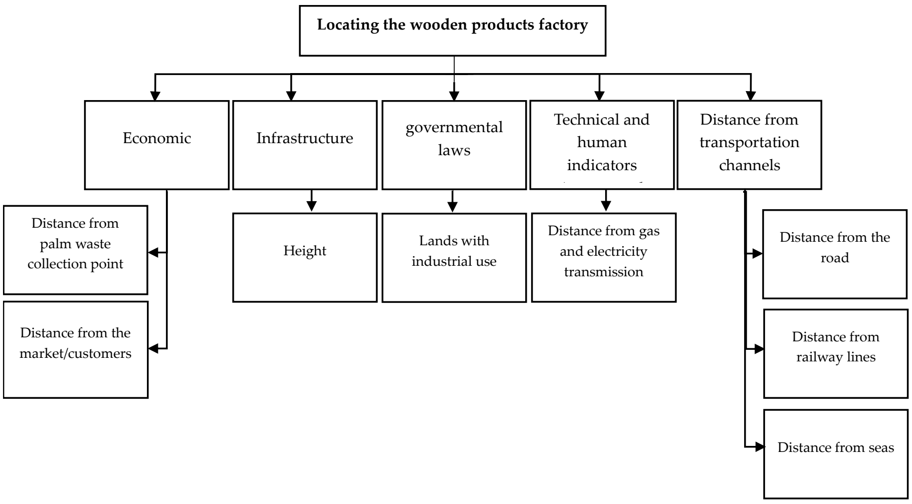

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Figure 3. **Required Criteria for Choosing the Location of the Wood Factory**

1.2 Determining the Final Criteria List

At this stage, expert consultation and agreement led to the selection of distance from palm trees (residue collection areas) as the most important criterion, while altitude was deemed the least significant. Next, using a questionnaire based on the Best-Worst Method (BWM), experts performed pairwise comparisons of the finalised criteria. The data of the questionnaires were implemented in model (1). Finally, the relevant model was implemented in the GAMS software, and the weight and final ranking of the criteria were determined by summing up the results of the questionnaires. According to the results obtained from the BWM method, as shown in *Table 2*, the criteria of distance from the palm tree, distance from energy lines, and distance from the road were recognised as the most important criteria with weights of 0.273, 0.169, and 0.135, respectively.

$$
\begin{aligned}
&\mathrm{Min}\ \xi^{L} \\
&\text{s.t.} \\
&\left|W_B - a_{Bj}W_j\right| \le \xi^{L}, \text{ for all j} \\
&\left|W_j - a_{jw}W_w\right| \le \xi^{L}, \text{ for all j'} \\
&\textstyle\sum_j W_j = 1 \\
&W_j \ge 0, \text{ for all j}
\end{aligned} \tag{1}
$$

Several methods have been proposed for criteria weighting; however, many of them lack precision (Dahooie *et al.,* 2018). This study employs the Best-Worst Method (BWM) for weighting and prioritising criteria. BWM is a MCDM method that uses pairwise comparisons to calculate the weight of criteria (Pamučar *et al.,* 2020). Compared to other decision-making approaches, BWM requires fewer pairwise comparisons while producing more logical and accurate results (Badi *et al.,* 2023). In this method, first, the best (most desirable) and worst (least significant) criteria are determined by the expert, and then these two criteria are compared with other criteria (Rezaei, 2016).

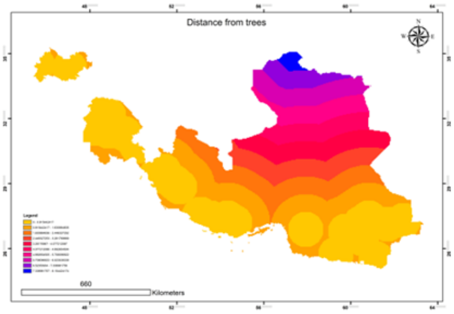
Table 2. Final weight of criteria by BWM method

Sorted by rank	Criteria	criteria weights (W_j)
q1	Distance from palm waste collection point	0.2728
q2	Distance from powerlines	0.1694
q3	Distance from the road	0.1353
q4	Distance from the market/customers	0.1129
q5	Distance from railway lines	0.0888
q6	Distance from seas	0.0812
q7	Lands with industrial use	0.0618
q8	Height	0.0289

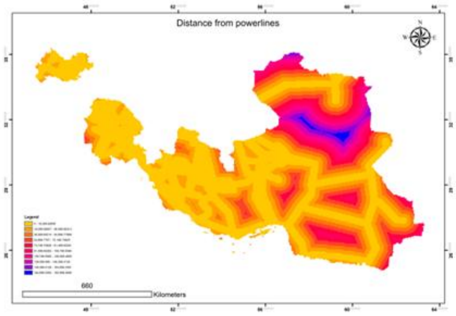
Source: created by the authors.

1.3 Determining Suitable Areas with ArcGIS Software

As outlined in the methodology section, this study focuses on eight provinces with significant palm tree coverage. The primary objective is to identify the most suitable location for constructing the wood product manufacturing factory within these provinces. GIS plays a crucial role in eliminating unsuitable locations.



(**a**)



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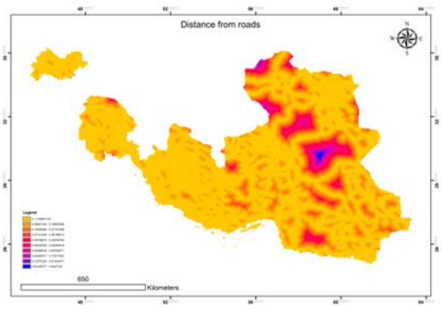

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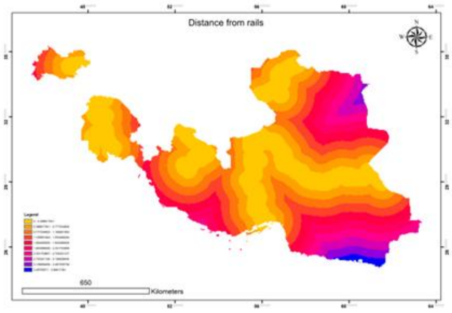
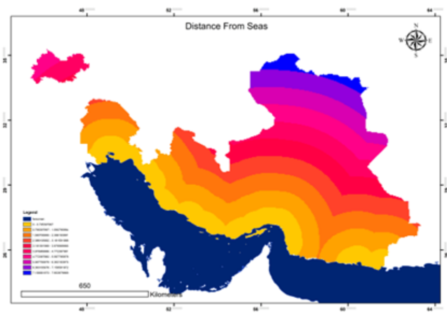
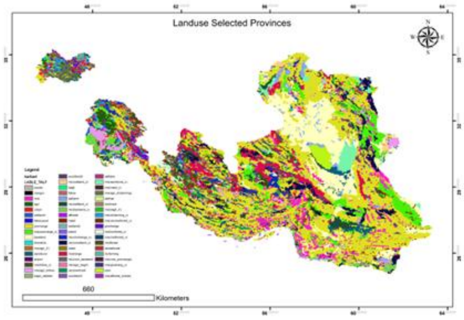


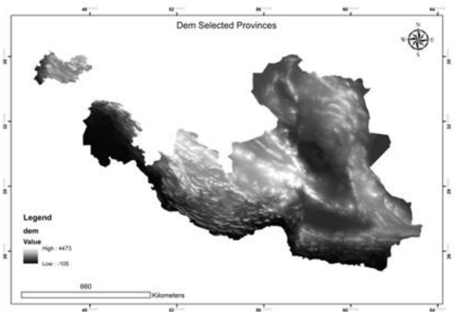
(**d**)



(**e**)



(**f**)



(g)

Source: created by the authors.

Figure 4. **Layers of Different Criteria ((a) Distance from Palm Trees, (b) Distance from Powerlines, (c) Distance from Roads, (d) Distance from Rails, (e) Distance from Seas, (f) Land Use, (g) Height)**

First, using ArcGIS software to choose suitable places, the map of the desired areas was collected and scored for each criterion. Using the ArcGIS software Spatial Analyst tool and Distance module for all layers, the desired distance was defined and classified into seven classes, as presented in Figure 4. Shorter distances received the highest value. Then, all the layers were produced in Raster format. By using AND logic, the intersection of the existing layers (indices) was obtained, and suitable areas were determined based on the desired indicators. This process and the analysis of the maps were done by ArcGIS 10.8.2 software.

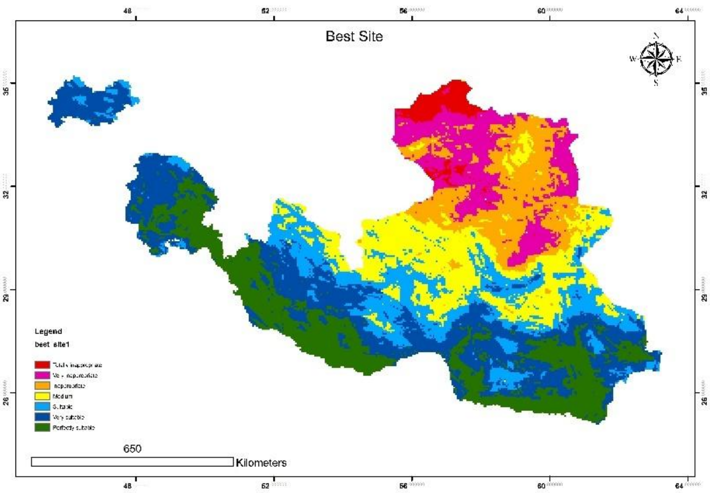


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Figure 5. **Suitable Areas for Building a Factory**

Finally, by placing the layers on top of each other, the best areas for construction were determined. These areas are introduced in green, as presented in *Figure 5*. Thirty-seven cities were placed in this optimal area, which were further investigated as options.

1.4 Calculate the Score of Each Candidate Using Different MCDM Methods

At this stage, the data extracted from ArcGIS software was used to construct a decision table for evaluating potential factory locations based on the selected criteria. *Table 3* presents the initial decision matrix where the first row of this table shows the weights of the criteria calculated by the BWM method.

To ensure comprehensive evaluation and ranking of potential factory locations, eight different MCDM methods were applied, including TOPSIS, ARAS, COPRAS, WASPAS, MULTIMOORA, VIKOR, SAW and CODAS; the final score of each option was calculated, and the necessary data for ranking the options was obtained. It cannot be said that one decision-making method is better than other methods (Mela *et al.,* 2012). Each MCDM method follows distinct principles and computational rules, which can lead to variation in ranking outcomes for the same problem (Mousavi-Nasab and Sotoudeh-Anvari, 2017). Using several MCDM methods and combining the results of the methods increases the accuracy and robustness of decision-making. *Table 4* presents the final values obtained by MCDM methods. The numbers in parentheses indicate the rank of each option.

Table 3. Primary decision matrix based on data collected from GIS

Weight criteria	0.27275	0.16940	0.13526	0.11287	0.08877	0.08124	0.06178	0.02882
Alternatives	q1	q2	q3	q4	q5	q6	q7	q8
Bushehr	0.452	7077.95	0.017	1	1.472	0.431	3	145.86
Dashtestan	0.239	8038.32	0.031	66	1.237	0.590	4	479.95
Dashti	0.230	3972.45	0.024	81	1.583	0.191	3	9.55
Dayyer	0.948	20861.10	0.020	205	1.785	0.276	1	168.38
Dilam	0.701	2817.08	0.023	178	1.270	0.278	5	99.05
Genaveh	0.507	4452.52	0.044	110	1.637	0.194	5	85.85
Jam	0.675	2848.40	0.026	252	1.756	0.464	2	555.73
Tangestan	0.565	6905.27	0.038	57	1.406	0.597	2	379.57
Firozabad	0.495	10684.81	0.047	114	0.991	1.115	7	1057.70
Jahrom	1.034	13420.50	0.026	189	1.101	1.436	5	1442.15
Kazerun	0.279	5657.09	0.034	133	0.759	1.014	4	1102.35
Lamard	0.241	15929.72	0.026	366	1.987	0.406	4	638.20
Lar	0.547	25214.51	0.069	342	1.424	0.993	3	857.20
Mamsani	0.613	8305.70	0.030	154	0.997	1.095	7	1389.65
Bandar Abbas	1.366	14127.51	0.064	1	0.289	0.399	3	475.72
Bandar Jask	0.817	15722.50	0.107	335	2.356	1.087	2	209.87
Bestak	0.404	18945.08	0.045	234	1.300	0.483	6	502.62
Minab	0.621	22142.69	0.058	110	1.347	0.451	2	513.90
Rodan	1.101	24175.98	0.064	110	0.968	0.589	5	540.46
Kahnuj	0.858	42677.37	0.131	322	1.567	1.373	2	662.64
Abadan	1.251	18285.83	0.065	120	0.388	0.220	6	2.07
Ahvaz	0.329	9341.10	0.044	1	0.147	1.030	5	26.82
Baghmolek	0.361	3398.85	0.023	145	1.031	1.228	4	827.20
Bandar Mahshah/Hendijan	0.707	11065.20	0.057	110	0.343	0.237	6	12.06
Behbahan	0.290	2722.41	0.018	201	0.900	0.589	5	268.14
Dasht Azadegan	0.318	28008.22	0.033	61	0.423	1.456	6	20.21
Izeh	0.695	4439.69	0.043	179	1.071	1.590	5	1270.32
Khorramshahr	0.922	16238.09	0.025	128	0.073	0.737	1	2.19
Suleiman Mosque	0.452	9225.51	0.041	143	0.569	1.672	2	687.22
Ramhormoz	0.309	5111.74	0.022	96	0.589	0.749	5	140.07
Shadgan	0.815	5502.13	0.060	98	0.238	0.364	6	4.35
Susa	0.227	4150.61	0.043	119	0.170	1.950	3	127.83
Chabahar	0.429	27004.63	0.074	634	3.271	0.651	3	193.13
Iranshahr	0.661	47431.83	0.103	324	1.855	1.919	3	851.37
Khash	0.967	38101.63	0.073	179	0.880	2.969	2	1388.53
Nikshahr	0.435	53416.77	0.056	493	3.002	0.793	2	562.98
Saravan	0.453	40195.45	0.074	333	1.839	2.242	6	1273.49

Source: created by the authors.

1.4.1 Calculation of Candidate Score Using TOPSIS Method

The TOPSIS method is the second most important and practical MCDM method from the hierarchical analysis process. It was developed by Hwang and Yoon in 1981 (Hwang, Yoon, 1981). This method is simple and easy to use and applies to problems with a large number of criteria and options (Çelikbilek, Tüysüz, 2020). The TOPSIS method ranks alternatives by identifying the closest option to the ideal solution and the farthest from the negative ideal, enabling decision-makers to balance trade-offs between competing criteria (Zavadskas *et al.,* 2016).

1.4.2 Calculation of Candidate Score Using ARAS Method

In the ARAS method, the utility function that measures the overall relative efficiency of a viable alternative is directly linked to the relative impact of the values and weights assigned to the key criteria in a project (Zavadskas and Turskis, 2010). The method tries to get the best result by comparing many options and at the same time, eliminates the influence of different measurement units (Nana and Xu, 2021).

1.4.3 Calculation of Candidate Score Using COPRAS Method

The COPRAS method is designed to compare alternatives based on their proportional contributions to both positive and negative criteria (Zavadskas *et al.,* 1994). The method follows a step-by-step approach to evaluate options by 1) considering both beneficial and non-beneficial criteria in decision-making, and 2) prioritising alternatives based on their relative importance (Stefano *et al.,* 2015). This method is useful when ranking criteria in issues with more than one criterion (Hezer *et al.,* 2021).

1.4.4 Calculation of Candidate Score Using WASPAS Method

WASPAS is a weighted sum method representing one or more optimisation responses (Radomska-Zalas, 2023). WASPAS method can be expressed as a combination of two weighted summation methods (WSM) and a weighted product model (WPM). It is proved that the accuracy of aggregated methods is larger comparing to the accuracy of single ones (Zavadskas *et al.,* 2012). To use this method, the decision matrix is created based on the data, and after normalising the matrix, the criteria are compared (Chakraborty, Zavadskas, 2014). The WASPAS method is a comprehensive decision-making tool that improves the accuracy and ranking of alternatives by integrating additive and multiplicative models (Mardani *et al.,* 2017).

1.4.5 Calculation of Candidate Score Using SAW Method

The SAW method is a multi-feature method based on weighted summation. This method first creates the decision matrix based on the weight of the criteria, and the ranking of the options is determined by summing the values of the weight matrix. Additionally, the SAW method can be integrated with the geographic information system (Ibrahim and Surya, 2019). This method was introduced by MacCrimmon in 1968 (Kenneth, 1968).

1.4.6 Calculation of Candidate Score Using VIKOR Method

VIKOR is one of the multi-criteria decision-making methods introduced by Opricovic *et al*. (Opricovic, Tzeng, 2007). The main application of the VIKOR method is to determine the inconsistency between the analysed data and the ideal design (Luo and Yang, 2023). The VIKOR method begins by identifying the ideal and negative-ideal solutions for each criterion. Then, the distance of each alternative from these solutions is calculated. Based on these distances, compromise ranking is determined, aiming to minimise the maximum regret and find the best compromise solution (Mardani *et al.,* 2016).

1.4.7 Calculation of Candidate Score Using CODAS Method

In the CODAS method, two criteria have been introduced to rank options. The primary and most important criterion is the Euclidean distance, which calculates the distance of options from the ideal point. The second criterion is the taxi distance. The taxi distance is used if the options are not comparable to the first criterion (Keshavarz-Ghorabaee *et al.,* 2016). The option further away from the unfavourable point is better. Therefore, in the final step, the options are prioritised in descending order from the best to the worst (Kumari and Acherjee, 2021).

1.4.8 Calculation of Candidate Score Using MULTIMOORA Method

MULTIMOORA is composed of MOORA and of the Full Multiplicative Form of Multiple Objectives (Brauers and Zavadskas, 2010). MULTIMOORA uses the vector normalisation method and three sub-methods for ranking. These methods include a ratio system, reference point and complete multiplicative form approaches. These methods are not perfect and have flaws; therefore, MULTIMOORA uses more than one method to produce more accurate results. To perform the final ranking, combining the results obtained from the three sub-methods can produce a unified ranking list stronger than any individual ranking (Hafezalkotob *et al.,* 2019).

Table 4. Scores and ranking of alternatives in each method

Alternatives	MULTIMOORA				TOPSIS	ARAS	COPRAS	WASPAS	VIKOR	CODAS	SAW
	FM*	RM*	RP*	DT*							
Bushehr	5.6E+14	-0.061	0.015	4	0.831(7)	0.927(2)	0.831(5)	0.471(3)	0.118(9)	8.83(4)	0.518(3)
Dashtestan	2.7E+12	-0.058	0.012	5	0.867(2)	0.441(12)	0.826(6)	0.368(7)	0.051(5)	8.03(6)	0.459(8)
Dashti	5.4E+14	-0.049	0.016	3	0.863(3)	0.623(4)	1(1)	0.487(2)	0.048(4)	14.70(1)	0.599(1)
Dayyer	1.4E+11	-0.137	0.048	28	0.584(26)	0.273(26)	0.398(28)	0.207(26)	0.578(28)	-3.10(24)	0.268(26)
Dilam	1.6E+13	-0.080	0.032	14	0.741(15)	0.485(8)	0.646(11)	0.358(9)	0.288(18)	6.61(10)	0.457(9)
Genaveh	1.6E+13	-0.075	0.019	11	0.792(10)	0.426(13)	0.681(10)	0.331(11)	0.174(10)	3.24(13)	0.408(12)
Jam	3.2E+11	-0.103	0.030	22	0.708(20)	0.421(16)	0.523(21)	0.301(14)	0.343(20)	3.81(12)	0.396(13)
Tangestan	6.9E+11	-0.087	0.023	15	0.773(12)	0.298(23)	0.616(12)	0.249(20)	0.249(16)	-3.22(25)	0.286(23)
Firozabad	2.0E+11	-0.090	0.018	17	0.773(11)	0.291(25)	0.567(16)	0.244(22)	0.199(12)	-2.48(21)	0.3(22)
Jahrom	3.0E+10	-0.140	0.054	30	0.583(27)	0.240(27)	0.402(27)	0.193(27)	0.617(29)	-5.16(30)	0.244(28)
Kazerun	6.2E+11	-0.069	0.011	6	0.847(6)	0.426(14)	0.716(8)	0.341(10)	0.076(6)	6.17(11)	0.431(11)
Lamard	2.0E+11	-0.098	0.030	23	0.724(18)	0.420(17)	0.525(20)	0.328(12)	0.206(13)	7.80(7)	0.453(10)
Lar	7.1E+09	-0.152	0.030	27	0.597(25)	0.203(32)	0.362(30)	0.168(32)	0.392(24)	-6.76(31)	0.212(32)
Mamsani	1.8E+11	-0.093	0.026	21	0.748(14)	0.308(21)	0.552(17)	0.252(19)	0.268(17)	-2.15(20)	0.315(18)
Bandar Abbas	4.1E+13	-0.140	0.076	24	0.529(28)	0.779(3)	0.404(26)	0.288(16)	0.816(37)	-1.23(17)	0.314(19)
Bandar Jask	7.5E+09	-0.181	0.039	29	0.512(33)	0.161(34)	0.311(32)	0.136(34)	0.620(30)	-10.0(35)	0.162(35)
Bestak	2.2E+11	-0.098	0.022	20	0.736(16)	0.302(22)	0.527(19)	0.248(21)	0.193(11)	-1.08(16)	0.319(17)
Minab	6.8E+10	-0.122	0.026	25	0.668(23)	0.221(29)	0.443(24)	0.184(28)	0.367(22)	-6.93(32)	0.218(31)
Rodan	8.0E+10	-0.150	0.058	31	0.526(30)	0.194(33)	0.381(29)	0.161(33)	0.685(31)	-8.74(33)	0.189(33)
Kahnuj	8.4E+08	-0.226	0.053	36	0.368(37)	0.132(37)	0.249(37)	0.111(37)	0.759(35)	-11.3(36)	0.134(37)
Abadan	1.8E+14	-0.137	0.068	19	0.527(29)	0.423(15)	0.419(25)	0.233(25)	0.729(34)	-3.87(26)	0.279(25)
Ahvaz	8.6E+15	-0.054	0.011	2	0.861(4)	1(1)	0.865(4)	0.495(1)	0.042(3)	8.53(5)	0.509(5)
Baghmolek	8.5E+11	-0.072	0.012	8	0.830(8)	0.465(10)	0.698(9)	0.358(8)	0.088(7)	7.01(9)	0.460(7)
Bandar Mahshah/Hendijan	1.2E+14	-0.086	0.032	12	0.722(19)	0.368(19)	0.601(14)	0.273(18)	0.307(19)	-2.68(22)	0.313(20)
Behbahan	1.1E+13	-0.053	0.016	7	0.857(5)	0.594(6)	0.872(3)	0.452(4)	0.038(2)	13.91(2)	0.588(2)
Dasht Azadegan	2.5E+13	-0.084	0.034	13	0.735(17)	0.372(18)	0.586(15)	0.301(13)	0.213(15)	2.25(14)	0.364(14)
Izeh	9.1E+10	-0.111	0.031	26	0.701(21)	0.317(20)	0.484(23)	0.243(23)	0.366(21)	-1.96(19)	0.307(21)
Khorramshahr	1.6E+14	-0.111	0.046	16	0.638(24)	0.621(5)	0.490(22)	0.276(17)	0.5(25)	-0.98(15)	0.333(16)
Suleiman Mosque	1.2E+11	-0.097	0.018	18	0.767(13)	0.292(24)	0.546(18)	0.234(24)	0.209(14)	-2.84(23)	0.282(24)
Ramhormoz	2.2E+13	-0.048	0.008	1	0.895(1)	0.474(9)	0.941(2)	0.389(6)	0(1)	7.38(8)	0.471(6)
Shadgan	5.6E+14	-0.087	0.039	9	0.698(22)	0.449(11)	0.604(13)	0.298(15)	0.369(23)	-1.75(18)	0.335(15)
Susa	1.4E+13	-0.067	0.021	10	0.815(9)	0.573(7)	0.754(7)	0.410(5)	0.110(8)	11.10(3)	0.511(4)

Table 4 (*continuation*). Scores and ranking of alternatives in each method

Alternatives	MULTIMOORA				TOPSIS	ARAS	COPRAS	WASPAS	VIKOR	CODAS	SAW
	FM*	RM*	RP*	DT*							
Chabahar	1.3E+10	-0.183	0.052	32	0.518(31)	0.229(28)	0.307(33)	0.183(29)	0.526(26)	-3.95(27)	0.245(27)
Iranshahr	8.8E+08	-0.217	0.059	37	0.410(36)	0.154(35)	0.263(36)	0.129(35)	0.709(33)	-9.35(34)	0.164(34)
Khash	1.1E+09	-0.209	0.049	34	0.426(35)	0.144(36)	0.267(35)	0.118(36)	0.770(36)	-11.32(37)	0.138(36)
Nikshahr	2.2E+09	-0.203	0.067	35	0.461(34)	0.214(31)	0.269(34)	0.170(31)	0.694(32)	-4.46(29)	0.231(30)
Saravan	2.4E+09	-0.182	0.050	33	0.514(32)	0.219(30)	0.322(31)	0.178(30)	0.545(27)	-4.06(28)	0.243(29)

Notes: [1] Fully-multiplicative (FM)/Ratio-method (RM)/Reference-point (RP)/Dominance theory (DT).

Source: created by the authors.

1.5 Final Ranking of Alternatives

As mentioned in the previous sections, the final ranking of options is done by aggregating the points obtained from different MCDM methods. The final ranking process is explained below:

1.5.1 Formation of Secondary Decision Matrix

Table 4 introduces the secondary decision matrix. The points value of the options in this table is used to perform the final aggregation. The secondary decision matrix is defined as $X = (x)_{n\times 10}$. n shows the number of options, which is 37 in this research. The matrix has ten columns. The first three columns represent the option scores in three MULTIMOORA methods (Ratio System (RS), Reference Point (RP), and Full Multiplication Form (FM)), and the rest of the columns are related to other MCDM methods.

1.5.2 Secondary Decision Matrix Normalisation

After forming the decision matrix and determining the value of the options according to MCDM methods, the matrix is normalised using relations (2) and (3). *Table 5* presents the normalised decision matrix.

$$z_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}}, i = 1, \dots, n; j \in \Omega_b, \tag{2}$$

$$z_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}}, i = 1, \dots, n; j \in \Omega_c, \tag{3}$$

In this equation, $x_j^{\min} = \min_{1\le i\le n}\{x_{ij}\}, x_j^{\max} = \max_{1\le i\le n}\{x_{ij}\}$. Also, Ω_b and $\Omega_c$are a set of positive and negative criteria indicators, respectively.

Table 5. Normalised secondary decision matrix

Alternatives	MULTIMOORA			TOPSIS	ARAS	COPRAS	WASPAS	VIKOR	CODAS	SAW
	FM*	RM*	RP*							
Bushehr	0.065	0.930	0.894	0.878	0.916	0.775	0.938	0.855	0.774	0.824
Dashtestan	0.000	0.945	0.937	0.946	0.356	0.768	0.669	0.938	0.744	0.699
Dashti	0.064	0.998	0.884	0.939	0.565	1.000	0.980	0.941	1.000	1.000
Dayyer	0.000	0.503	0.409	0.410	0.162	0.198	0.251	0.291	0.316	0.289
Dilam	0.002	0.824	0.651	0.708	0.407	0.528	0.642	0.647	0.689	0.695
Genaveh	0.002	0.853	0.841	0.805	0.339	0.575	0.574	0.786	0.559	0.588
Jam	0.000	0.693	0.677	0.646	0.333	0.365	0.495	0.580	0.582	0.563
Tangestan	0.000	0.785	0.784	0.769	0.191	0.488	0.359	0.694	0.311	0.328
Firozabad	0.000	0.766	0.853	0.769	0.183	0.423	0.347	0.757	0.339	0.357
Jahrom	0.000	0.488	0.325	0.408	0.124	0.204	0.215	0.243	0.237	0.237
Kazerun	0.000	0.885	0.955	0.910	0.338	0.621	0.598	0.907	0.672	0.638
Lamard	0.000	0.721	0.675	0.676	0.331	0.367	0.566	0.747	0.735	0.685
Lar	0.000	0.420	0.678	0.435	0.082	0.150	0.148	0.519	0.175	0.167
Mamsani	0.000	0.747	0.737	0.721	0.203	0.403	0.367	0.671	0.352	0.389
Bandar Abbas	0.005	0.486	0.000	0.305	0.745	0.207	0.462	0.000	0.388	0.388
Bandar Jask	0.000	0.257	0.537	0.273	0.034	0.082	0.065	0.240	0.051	0.060
Bestak	0.000	0.721	0.799	0.698	0.196	0.370	0.357	0.764	0.393	0.397
Minab	0.000	0.588	0.729	0.569	0.102	0.258	0.191	0.550	0.169	0.180
Rodan	0.000	0.431	0.259	0.300	0.071	0.176	0.131	0.160	0.099	0.119
Kahnuj	0.000	0.000	0.338	0.000	0.000	0.000	0.000	0.070	0.001	0.000
Abadan	0.021	0.504	0.113	0.302	0.335	0.226	0.318	0.107	0.286	0.313
Ahvaz	1.000	0.968	0.955	0.935	1.000	0.820	1.000	0.949	0.763	0.805
Baghmolek	0.000	0.870	0.932	0.877	0.383	0.597	0.643	0.892	0.704	0.700
Bandar Mahshah/Hendijan	0.014	0.789	0.645	0.672	0.271	0.469	0.422	0.624	0.332	0.385
Behbahan	0.001	0.973	0.874	0.927	0.532	0.830	0.889	0.954	0.969	0.976
Dasht Azadegan	0.003	0.798	0.623	0.696	0.277	0.449	0.495	0.739	0.521	0.495
Izeh	0.000	0.646	0.657	0.631	0.213	0.314	0.346	0.551	0.360	0.372
Khorramshahr	0.019	0.649	0.435	0.513	0.564	0.321	0.431	0.387	0.397	0.429
Suleiman Mosque	0.000	0.728	0.855	0.757	0.184	0.396	0.321	0.744	0.326	0.317
Ramhormoz	0.003	1.000	1.000	1.000	0.393	0.921	0.724	1.000	0.719	0.724
Shadgan	0.066	0.785	0.539	0.627	0.365	0.473	0.487	0.548	0.368	0.433
Susa	0.002	0.897	0.806	0.848	0.508	0.673	0.780	0.866	0.861	0.810
Chabahar	0.000	0.247	0.352	0.285	0.111	0.077	0.189	0.356	0.283	0.239
Iranshahr	0.000	0.055	0.246	0.081	0.025	0.019	0.046	0.130	0.076	0.065
Khash	0.000	0.098	0.391	0.110	0.013	0.024	0.018	0.057	0.000	0.010
Nikshahr	0.000	0.132	0.130	0.178	0.094	0.027	0.153	0.149	0.264	0.210
Saravan	0.000	0.251	0.387	0.278	0.100	0.097	0.174	0.332	0.279	0.234

Source: created by the authors.

1.5.3. Weight Calculation of Each Method via the CRITIC Approach

The CRITIC method is one of the methods used for weighting indicators. This method works based on the direct relationship between the criteria and is considered based on the deviation of the requirements (Aytac, Tuş, 2019). The CRITIC method analyses data based on the level of interference and conflict between factors or criteria (Diakoulaki *et al.,* 1995). Therefore, at this stage, based on the CRITIC method and using the data in *Table 5*, the weight of each MCDM method was calculated. The resulting weights are presented in *Table 6*.

Table 6. Weight of MCDM methods

Method	MULTIMOORA			TOPSIS	ARAS	COPRAS	WASPAS	VIKOR	CODAS	SAW
	FM*	RM*	RP*							
Weight	0.1645	0.0877	0.1284	0.0828	0.1225	0.0724	0.0723	0.1041	0.0872	0.0782

Source: created by the authors.

1.5.4 Final Ranking of Alternatives

In the final step, based on equation (4) and by multiplying the normalised values by the weights determined for each method, the weighted secondary matrix was calculated. In this way, the final value of the options was obtained for the final ranking. *Table 7* introduces the final value and ranking of options.

$$S_i = \sum_{j=1}^{10} \left(Z_{ij} \times \mathrm{W}_j\right), \tag{4}$$

W_j indicates the weight of the j method and Z_{ij} indicates the normalised value in the secondary decision matrix. The higher the final score (S_i) of an option, the higher the value of that option (region) and the higher it will be.

Table 7. Total value and final ranking of alternatives

Alternatives	Final score	Final rank
Ahvaz	0.9318	1
Dashti	0.7651	2
Bushehr	0.7370	3
Behbahan	0.7241	4
Ramhormoz	0.6899	5
Susa	0.6485	6
Dashtestan	0.6461	7
Baghmolek	0.6143	8
Kazerun	0.6082	9
Genaveh	0.5510	10
Dilam	0.5311	11
Lamard	0.5093	12
Dasht Azadegan	0.4714	13
Jam	0.4591	14
Firozabad	0.4548	15
Bestak	0.4450	16
Tangestan	0.4428	17
Suleiman Mosque	0.4413	18
Shadgan	0.4378	19
Bandar Mahshah/Hendijan	0.4315	20
Mamsani	0.4315	21
Khorramshahr	0.3902	22
Izeh	0.3849	23
Minab	0.3234	24
Lar	0.2739	25
Bandar Abbas	0.2725	26
Dayyer	0.2633	27
Jahrom	0.2284	28
Abadan	0.2280	29
Saravan	0.2037	30

Table 7 (*continuation)*. Total value and final ranking of alternatives

Alternatives	Final score	Final rank
Chabahar	0.2037	31
Bandar Jask	0.1630	32
Rodan	0.1615	33
Nikshahr	0.1223	34
Khash	0.0792	35
Iranshahr	0.0762	36
Kahnuj	0.0508	37

Source: created by the authors.

2. Comparison

In this step, Borda and Ensemble methods aggregated the results. The results of these methods are presented in the last two columns of *Table 8*. Also, the ranking results of different MCDM methods are included in this table, along with the final ranking result that was obtained in the previous section.

Borda"s and Copeland"s laws are standard methods for summarising results (Leake, 2001). Borda"s method focuses mostly on pairwise comparison to rank the options. Copeland"s method complements Borda"s method, in which experts calculate the difference between the number of wins and the number of failures to prioritise options (Favardin *et al.,* 2002). The introduced methods usually consider the same weight for all MCDM methods and make the final comparison by ranking the options (Heidary Dahooie *et al.,* 2022).

Table 8. Comparing the ranking of different implemented methods with the final ranking

Alternatives	MULTI-MOORA	TOPSIS	ARAS	COPRAS	WASPAS	VIKOR	CODAS	SAW	The final ranking of the previous section	Borda	Ensemble ranking
Bushehr	4	7	2	5	3	9	4	3	3	5	3
Dashtestan	5	2	12	6	7	5	6	8	7	6	5
Dashti	3	3	4	1	2	4	1	1	2	1	1
Dayyer	28	26	26	28	26	28	24	26	27	26	26
Dilam	14	15	8	11	9	18	10	9	11	12	11
Genaveh	11	10	13	10	11	10	13	12	10	11	10
Jam	22	20	16	21	14	20	12	13	14	14	14
Tangestan	15	12	23	12	20	16	25	23	17	17	16
Firozabad	17	11	25	16	22	12	21	22	15	15	15
Jahrom	30	27	27	27	27	29	30	28	28	28	27
Kazerun	6	6	14	8	10	6	11	11	9	9	9
Lamard	23	18	17	20	12	13	7	10	12	10	12
Lar	27	25	32	30	32	24	31	32	25	29	29
Mamsani	21	14	21	17	19	17	20	18	21	23	21
Bandar Abbas	24	28	3	26	16	37	17	19	26	21	24
Bandar Jask	29	33	34	32	34	30	35	35	32	33	34
Bestak	20	16	22	19	21	11	16	17	16	16	17
Minab	25	23	29	24	28	22	32	31	24	27	25
Rodan	31	30	33	29	33	31	33	33	33	31	33
Kahnuj	36	37	37	37	37	35	36	37	37	37	37
Abadan	19	29	15	25	25	34	26	25	29	25	28
Ahvaz	2	4	1	4	1	3	5	5	1	2	2

Table 8 (*continuation*). Comparing the ranking of different implemented methods with the final ranking

Alternatives	MULTI-MOORA	TOPSIS	ARAS	COPRAS	WASPAS	VIKOR	CODAS	SAW	The final ranking of the previous section	Borda	Ensemble ranking
Baghmolek Bandar	8	8	10	9	8	7	9	7	8	8	8
Mahshah/Hendijan	12	19	19	14	18	19	22	20	20	19	19
Behbahan	7	5	6	3	4	2	2	2	4	3	4
Dasht Azadegan	13	17	18	15	13	15	14	14	13	13	13
Izeh	26	21	20	23	23	21	19	21	23	22	22
Khorramshahr	16	24	5	22	17	25	15	16	22	24	23
Suleiman Mosque	18	13	24	18	24	14	23	24	18	20	20
Ramhormoz	1	1	9	2	6	1	8	6	5	4	6
Shadgan	9	22	11	13	15	23	18	15	19	18	18
Susa	10	9	7	7	5	8	3	4	6	7	7
Chabahar	32	31	28	33	29	26	27	27	31	34	31
Iranshahr	37	36	35	36	35	33	34	34	36	35	35
Khash	34	35	36	35	36	36	37	36	35	36	36
Nikshahr	35	34	31	34	31	32	29	30	34	32	32
Saravan	33	32	30	31	30	27	28	29	30	30	30

Source: created by the authors.

In this step, Spearman"s correlation coefficient and equation (5) were used to evaluate the proposed method"s performance. The degree of similarity of the results obtained from the final ranking method with the results of other methods was also examined. Spearman is Pearson"s correlation coefficient between two ranked variables (Zavadskas *et al.,* 2014).

$$r_s = 1 - \frac{6\sum_i d_i^2}{(n^3 - n)}, \tag{5}$$

In Spearman"s relationship, *n* represents the number of options, and d_i is the difference between the rank of each method and the final aggregation method. Finally, *Table 9* presents the value of Spearman"s correlation coefficient for each method.

Table 9. Spearman rank correlation coefficient value between MCDM methods and final aggregation method

Alternatives	MULTIMOORA	TOPSIS	ARAS	COPRAS	WASPAS	VIKOR	CODAS	SAW	Borda	Ensemble ranking
The final ranking	0.926	0.959	0.817	0.961	0.955	0.943	0.935	0.947	0.986	0.994

Source: created by the authors.

The results indicate that the final ranking method exhibits a high correlation with most MCDM methods, while the lowest correlation value is associated with the ARAS method. This discrepancy can be attributed to differences in ranking procedures and logical frameworks across various methods, which may lead to a slight reduction in the Pearson correlation coefficient (as observed in the case of the ARAS method). Despite these variations, the correlation levels among most methods remain consistently high and closely aligned. Furthermore, an examination of the Pearson correlation coefficient for aggregation methods (Borda and ensemble ranking) reveals a strong similarity between their results and those of the final ranking method.

Conclusions and Discussion

Wood is widely used in industry and human life. The increase in demand for wood products in recent years and the shortage of forest resources have made wood and paper industries face serious problems. Therefore, finding a suitable source to compensate for this need is significant. On the other hand, the researchers found that the branches and wastes from palm tree pruning can be used in the transformation industries, including the production of chipboard and MDF. This study aimed to build a factory that uses waste and trunks of palm trees to produce wooden products. This study will help compensate for the need for more wood in the country and the optimal use of the volume of produced waste. Since building a factory in the wrong place causes a waste of resources and energy, it is essential to find the best place to make it. Considering that not all provinces of Iran are covered with palm trees, the most crucial criterion in this research was to reduce the distance from the areas with palm trees, so to increase the accuracy of the results, only the areas with palm trees were examined, which included eight provinces, including Sistan and Baluchistan, Kerman, Hormozgan, Fars, Bushehr, South Khorasan, Khuzestan, and Kermanshah, in the southern part of the country.

At first, the appropriate criteria were determined by studying the sources and the conducted research, and with the opinion of wood science and research experts, the final indicators were defined. The BWM method was used for prioritising and weighting the indicators in such a way that a questionnaire was designed to perform a pairwise comparison between the data and their ranking, and it was given to a number of experts in this field. In the next step, the data required for the GIS software was collected according to the criteria and applied to the software. Finally, by combining these layers, the best and most suitable cities for the construction of the factory were determined. Several different MCDM methods were used to rank these options, including TOPSIS, ARAS, COPRAS, WASPAS, MULTIMOORA, VIKOR, SAW, and CODAS. The results of the methods were collected for the final ranking, and the CRITIC method was applied. In this study, the combination of geographic system (GIS) and MCDM has been used as an effective method to find the factory"s location due to diverse geographic data. The results show that using several decision-making methods increases the accuracy of the final results.

According to the results, the proximity index to palm areas is most important, followed by access to energy lines and distance from other indicators. Also, Ahvaz, Dashti, Bushehr, and Behbahan are the best areas for construction. To choose the best place to build a factory, investors examine the results obtained and the available capital and limitations and finally decide how to implement the project.

To carry out further research, more criteria can be used, and details such as factory construction costs, regional weather conditions, access to other raw materials for production, availability of technical manpower, factory production capacity, and other issues can be considered. It is also possible to consider uncertainty in this problem and use fuzzy-intuitive methods. In future research, this issue can be implemented through the location model.

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HIBRIDINIS DAUGIAKRITERIŲ SPRENDIMŲ PRIĖMIMO METODAS IR GEOGRAFINĖ INFORMACINĖ SISTEMA MEDIENOS GAMYBOS NAUDOJANT PALMŲ ATLIEKAS ĮMONĖS STATYBOS VIETAI PARINKTI

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Santrauka. Pastaraisiais metais miško išteklių trūkumas ir išaugusi medienos gaminių paklausa medienos ir popieriaus pramonėje susidūrė su reikšmingais iššūkiais. Remiantis atliktais tyrimais teigtina, kad nugenėtos palmių šakos ir atliekos gali būti naudojamos perdirbimo pramonėje, taip pat medžio drožlių plokščių ir vidutinio tankio medienos pluošto plokščių (MDF) gamyboje. Irano teritorijoje yra daug palmių, o šiuo metu daug šių medžių atliekų išmetama ir sudeginama. Todėl šio tyrimo tikslas – nustatyti medienos gaminių gamybos vietą siekiant optimalaus palmių atliekų panaudojimo, padedant kompensuoti medienos produkcijos trūkumą šalyje. Remiantis literatūros šaltinių analize ir ekspertų nuomonėmis buvo nustatyti kriterijai medienos gaminių gamyklos statybos vietai įvertinti. Pasitelkus klausimyną, pagrįstą BWM metodu, buvo įvertinti jų prioritetai. Kitame žingsnyje ArcGIS programinė įranga buvo naudojama kriterijams nagrinėjamose teritorijose analizuoti. Sprendimų variantai reitinguoti pritaikius TOPSIS, ARAS, COPRAS, WASPAS, MULTIMOORA, VIKOR, SAW ir CODAS sprendimų priėmimo metodus. Tada CRITIC metodu agreguoti gauti rezultatai ir nustatytos geriausios gamyklos statybos vietos. Derinant skirtingus sprendimų priėmimo metodus didėja gautų rezultatų tikslumas ir patikimumas.

Reikšminiai žodžiai: statybos vieta; daugiakriteris sprendimų priėmimas; geografinė informacinė sistema; MCDM; agregavimo metodas.