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Spatial Model for Appropriate Land use in Accordance with Environmental Capacities of Coastal Areas (Case Study: Bandar Abbas Coastline, Iran)

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A B S T R A C T

Objective: The primary challenge in the development of land uses is pinpointing optimal locations that harmonize expansion with the preservation of protected and conservation areas.
Methods: This study develops a precise methodology for determining suitable land uses in the coastal areas of Hormozgan province, Iran, using Geographical Information System (GIS) and Analytic Hierarchy Process (AHP).
Results: The research focuses on identifying optimal locations for agriculture, industry, and aquaculture, integrating environmental, economic, and social criteria. Key factors like topography, soil characteristics, water availability, and socio-economic aspects were weighted using expert opinions to create a capability map. The results indicate that approximately 687,132.4 hectares are viable for developmental purposes, with industrial development showing the highest potential, followed by agriculture and aquaculture.
Conclusion: This study not only provides critical insights for sustainable land use in Bandar Abbas Coastline but also sets a framework applicable to similar coastal regions worldwide, emphasizing the need for comprehensive, multi-criteria planning in coastal land management. This research innovates by focusing on environmental, economic, and social factors for sustainable development.

1. Introduction

Land degradation is a critical global issue, particularly acute in developing countries, where it poses significant threats to food security. This degradation not only impairs ecosystem services but also impedes sustainable regional development. Defined as a marked decline in land's productive capacity,

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land degradation is influenced by a confluence of factors, including climate change, land use alteration, and human management practices (Romshoo, et al, 2020; Bajocco, et al, 2012; Symeonakis, et al, 2007). In developing nations, the ramifications of land degradation are especially severe, with profound implications for food security. Ensuring sustainable land ecosystems, particularly in coastal regions, is vital for improving human livelihoods and fostering sustainable development (Abdolrahman, et al, 2019).

Population growth has historically been a predominant driver of land use changes, with distinct patterns emerging in developed and developing countries (Schlesinger and Ramankutty, 1992). In developed nations, land use shifts are economically driven, focusing on large-scale agriculture and urban development, coupled with a heightened commitment to biodiversity and environmental conservation for current and future generations (Anderson and Bouma, 1973). Contrastingly, in developing countries, rapid population growth, poverty, and economic constraints primarily influence land use changes (Schlesinger and Ramankutty, 1992). Recognizing land potential is an initial, crucial step in sustainable development-oriented land management, which involves a holistic assessment of natural, social, economic, and cultural factors. This approach aids communities in selecting optimal strategies to enhance and sustain land capacity to meet societal needs. A pivotal question in economics is the future location of economic activities, such as industrial areas (Jang and Jovanovic, 2003).

Land suitability analyses typically consider social, economic, and physical aspects of land, identifying opportunities and constraints for proposed uses. These analysis, however, focuses solely on the physical elements, such as elevation, slope, and soil characteristics(Yang et al., 2021; Abbaspour et al., 2011). Land suitability analyses often employ multi-criteria decision-making (MCDM) processes, integrating various elements(Abedi Gheshlaghi et al., 2020). The combination of Geographic Information Systems (GIS) and MCDM offers significant advantages, as the analytical capabilities of MCDM and the spatial benefits of GIS enhance effectiveness in diverse analytical applications.

Topuz and Deniz (2023) research focuses on creating a land use suitability map for the Demirci district using the Analytical Hierarchy Process and Weighted Overlay methods. Eleven factors such as soil characteristics, erosion, elevation, and climate were selected based on expert consultations and previous studies. The study utilized GIS software to create layer maps, which helped in analysing land use suitability for forest, meadow-pasture, and agricultural areas. It found significant mismatches between current and suitable land uses, particularly in agricultural land, indicating that many areas designated for pasture are currently used for agriculture and forestry. The findings aim to enhance local and national economy and ecosystem conservation by suggesting more suitable land uses.

Moreover, locating industrial areas, while preventing environmental degradation and optimizing land use, has emerged as a contemporary challenge (Ramya and Devadas, 2019). Identifying suitable locations for various land uses is a key aspect of land planning (El-Katiri and Fattouh, 2017). Location determination involves considering multiple criteria and indicators for land use development (Shao, et al, 2020; Ramamurthy, et al, 2020). In the context of the Hormozgan province's coastal area, Iran, this study aims to determine land use areas through a Multi-Criteria Decision Making (MCDM) methodology, employing Analytical Hierarchy Process (AHP) and Weighted Linear Combination (WLC) techniques. The proposed criteria and sub-criteria for locating land use areas will facilitate the creation of suitability maps and can be instrumental in planning industrial areas from a sustainable development perspective.

2. Materials and Methods Study Area

This research focuses on the coastal region of Hormozgan province, extending from east to west and encompassing the impactful coastal zones of the province. Geographically, this area is positioned between 50° 06' and 61° 54' east longitude, and 25° 04' to 30° 15' north latitude. The study encompasses the coastal territories of seven counties within Hormozgan province, each with its unique social, economic, and environmental characteristics. These counties are Persian, Bandar Length, Khamir, Bandar Abbas, Minab, Sirik, and Jask, all of which share borders with the coastlines of the Oman Sea and the Persian Gulf. Figure 1 in the study illustrates the geographic positioning of these seven cities relative to the coastal areas mentioned.

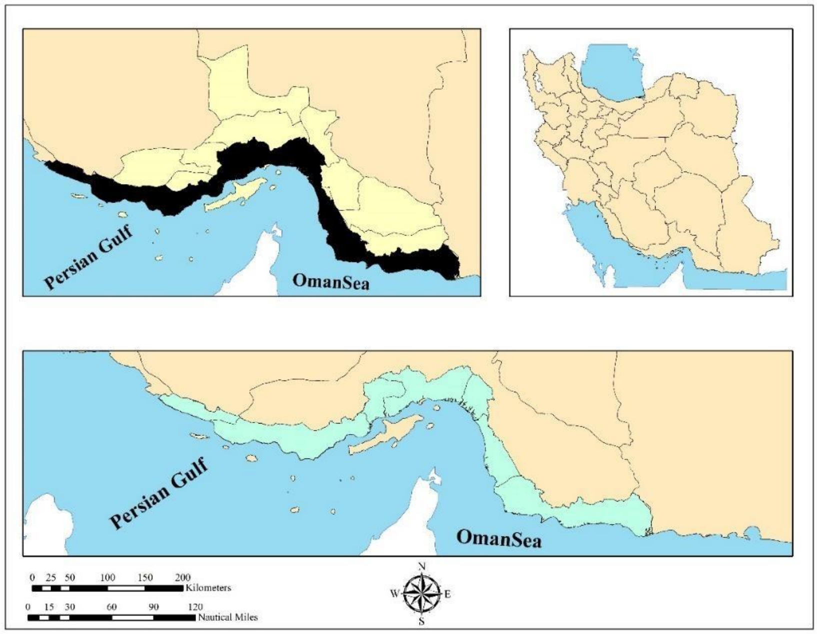

Fig.1, Geographical location of study area

2.1. Mapping of criteria and Indicators

In this phase of the study, attention is devoted to recognizing environmental patterns and adhering to existing rules and regulations concerning land capability. This involves proposing indicators and parameters pertinent to the development of land uses in coastal areas. Broadly, the variables identified for consideration (Topuz and Deniz, 2023) include slope, soil depth, soil fertility, soil drainage, lithology, water availability, and various limitations, as detailed in Table 1.

Table 1: Classes related to each of the criteria for site selection to activities (Agriculture, Industry, Aquaculture)

Topography	*Soil*			*Geology*	*Water*	*Limitations*
Elevation	Depth	Fertility	Drain	Lithology	(M3/h)	Areas
0 - 100	Low Depth	Alluvial	Weak	Weak	<500	Saline Lands
100 - 500	Semi Depth	Middle	Middle	Unlimited	500 - 1000	Forest Lands
500 - 1000	Depth	Good	Good	Sandy Sediments	>1000	Unauthorized

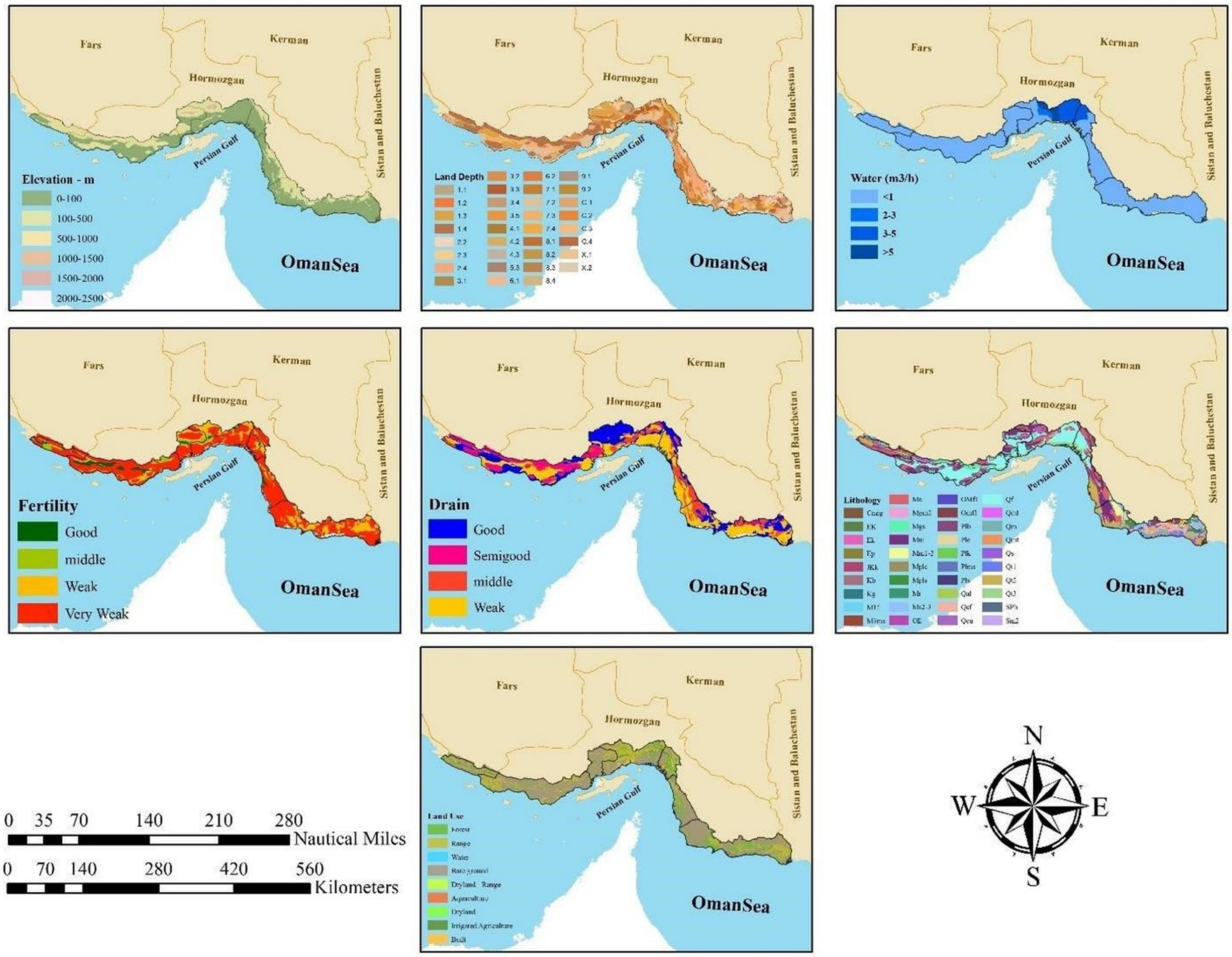

Fig. 2. Thematic maps used as constraint layers for site exclusions within the MCDA-AHP suitability analysis for the deployment of large-scale land use.

3. Result and Discussion

3.1. GIS-AHP-MCDA Model

The integration of Geographic Information System-based Multi Criteria Decision Analysis (GIS-MCDA) with Analytic Hierarchy Process (AHP) models has gained significant traction in recent research for creating potential land use development maps under diverse climatic and topographic conditions. A recurring theme in this body of literature is the critical role of site feasibility for large-scale solar farm deployment, which is heavily influenced by the selection and weighting of various study criteria within the AHP framework. The Analytic Hierarchy Process (AHP) stands out as an effective MCDA tool, utilizing ratio scale factors for pairwise comparisons. This approach facilitates decision-making through the weighting of multiple criteria (Asakereh et al., 2017; Saaty and Vargas, 2013).

AHP's ability to compare different criteria in pairs simplifies its application in complex GIS problems, allowing for spatial considerations by comparing two attributes at a time (Saaty and Vargas, 2013), and employing standard grading classification ranges as illustrated in Table 2. Our algorithm employs a pairwise comparison matrix for nine factors, utilizing a 9-point Likert scale for relative importance ranking as depicted in Table 4. The relative criteria weights were derived using the standard AHP priority-matrix normalization method (Saaty, 1990), and the AHP priority calculator from the Goepel model (Goepel, 2018).

Table 2. AHP pairwise likert grading criteria scale used for the GIS-MCDA algorithm.

Criteria relative importance		Description (Ranges)
1	Equally important	Both criteria contribute equally to the objective (within the CR)
2	Mildly low	Both criteria nearly contribute equally to the objective or, slightly favour one criterion over another (within CR and 12.5%)
3	Moderately low	The contribution moderately favours one criterion over another (within 12.5% and 25%)
4	Low	The contribution has a low tendency to favour one criterion over another (within 25% and 37.5%)
5	Medium	The contribution has a medium tendency to favour one criterion over another (within 37.5% and 50%)
6	Mildly high	The contribution has slightly higher than the medium tendency to favour one criterion over another (within 50% and 62.5%)
7	Moderately high	The contribution of one criterion over another is moderately high (within 62.5% and 75%)
8	High	The contribution of one criterion over another is high (within 75% and 87.5%)
9	Extremely high	The contribution of one criterion over another is at the highest in the grade (greater than 87.5%)

3.2. Standardization of Criteria and Indicators

To achieve uniformity across sub-criteria maps, standardization was employed, converting scales to a range of 0-1. In this context, 0 represents the lowest and 1 the highest suitability for land use area location. In our approach, sub-criteria were transformed using fuzzy functions available in Idris software, as delineated in Table 3 and Figure 3. Predominantly, sigmoidal function sets were applied to most sub-criteria. However, in cases where no direct correlation existed between the values and sigmoidal function sets, user-defined functions were deemed more suitable. Qualitative criteria were also standardized using user-defined fuzzy functions. For sub-criteria with uniformly increasing or decreasing values, only two control points were established in the fuzzy set. Conversely, when sub-criterion values displayed symmetry, all four control points were defined within the fuzzy set, facilitating a more nuanced standardization process (Eastman, 2003).

Table 3. group criteria and indicators for locating land use

Criteria	Indicators	Control Points				Membership Function*
		a	**c**	**b**	**d**	
Topography	Elevation	Very Low	-	-	Very High	MDS
Soil	Soil Depth	Very Low	-	-	Very High	UD
	Soil Fertility	Very Low	-	-	Very High	UD
	Soil Drain	Good	-	-	Very High-low	UD
Geology	Lithology	Limestone	-	-	Gypsy Marne	UD
Water	Water	Very Low	-	-	Very High	MIS
Limitations	Unauthorized	Protected Area	-	-	Dryland - bayrland	UD

MDS: Monotonically Decreasing, Sigmoidal; MIS: Monotonically Increasing, Sigmoidal; UD: User Defined

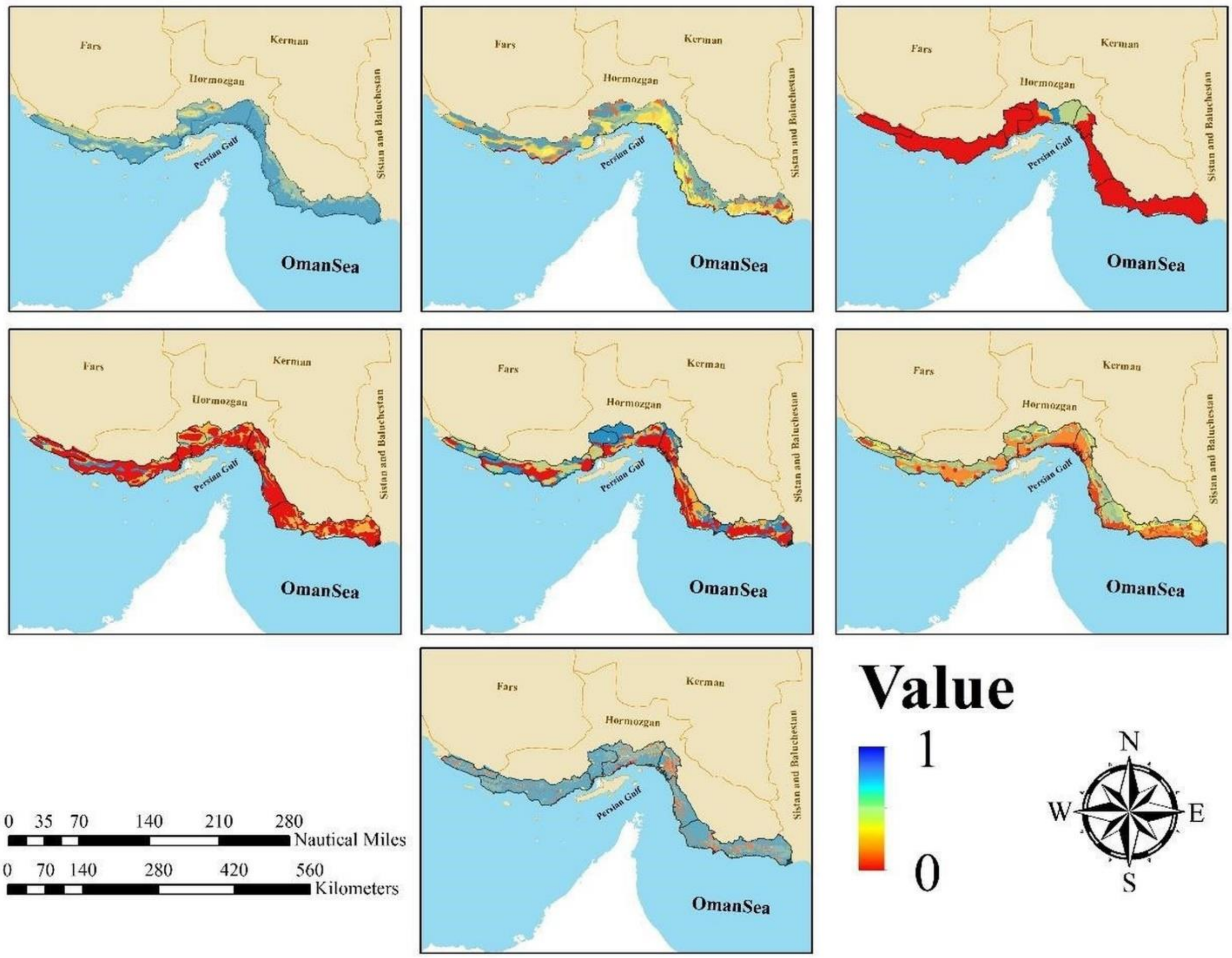

Fig. 3. Standardization indicators

3.3. Implementation of the AHP

In assessing site suitability, the Analytical Hierarchy Process (AHP) involves assigning a weight to each indicator, reflecting its relative importance or preference. This process is conducted through pairwise comparisons at each hierarchical level (Saaty and Vargas, 1980). The comparison utilizes a 9-point semantic scale for priority value assignment, with 1, 3, 5, 7, and 9 indicating criteria of equal, moderate, strong, very strong, and extreme importance, respectively. Intermediate values of 2, 4, 6, and 8 are also used. These preference values are determined through consultations with specialists and the review of technical documents and published international guidelines. Table 4 presents the AHP weightings for assessing land capability for developing agriculture, aquaculture, and industry along the coast of Hormozgan province. The weighting results indicate that water and soil criteria are pivotal for agricultural and industrial development in the study area. Similarly, for aquaculture development, the most significant criteria identified are water and geology.

Table 4. Criteria and Indicators weightings for the three discussed AHP approaches, Agriculture, Aquaculture and Industry

Criteria	Indicators	Land use		
		Agriculture	Aquaculture	Industry
Topography	Elevation	0.064	0.1	0.09
Soil	Soil Depth	0.11	0.09	0.15
	Soil Fertility	0.21	0.08	0.04
	Soil Drain	0.123	0.15	0.18
Geology	Lithology	0.1	0.21	0.16
Water	Water	0.273	0.25	0.26
Limitations	Unauthorized	0.12	0.12	0.12

3.4. Integration of Criteria Based on AHP-Derived Weights for Land Use Development Location

Following the establishment of weights through the Analytical Hierarchy Process (AHP), the Weighted Linear Combination (WLC) method was employed to create a capability map for land use development (Fig 4). Given the challenging drought conditions prevalent in the study area, identifying suitable locations for land use development has emerged as a crucial concern. According to our findings, approximately 687,132.4 hectares within the research area possess the potential for agricultural, aquaculture, and industrial development. The results further reveal that the highest land capability is associated with industrial development, followed by agriculture and aquaculture. Notably, certain zones are identified as having dual development potential, suitable for both industry-agriculture and industry-aquaculture combinations, as detailed in Table 5.

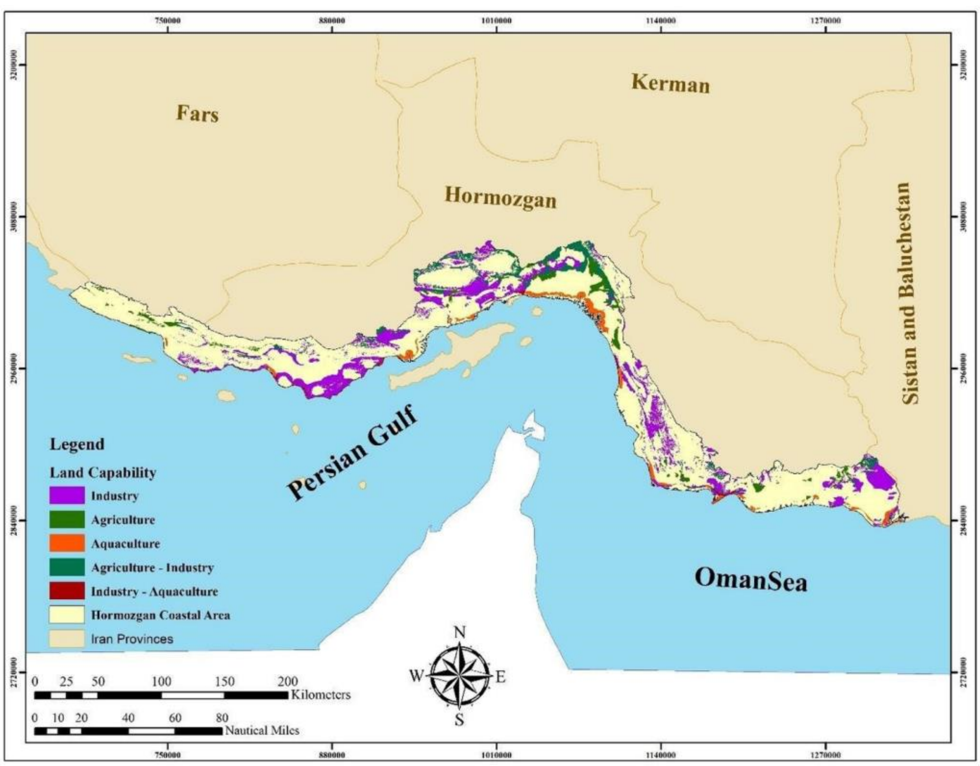

Fig. 4. Capability map to development land use (Industry, Agriculture, Aquaculture)

Table 5. Area (Hectares) and Percent (%) of each land use (Industry, Agriculture, Aquaculture)

Land use	Area (Hectares)	Percent (%)
Industry	399023	58.07076
Agriculture	86568.4	12.5985
Aquaculture	66538.1	9.683448
Agriculture - Industry	125424	18.25325
Industry - Aquaculture	9578.86	1.394034
SUM	687132.4	100

The core objective of this investigation was to formulate an effective method for assessing the developmental capacity of coastal lands, specifically for agriculture, industry, and aquaculture. These land uses are distinguished by their well-established functional and spatial frameworks. The identification of suitable areas for such development is critical in understanding and shaping the trajectory of spatial growth in coastal landscapes (Kyriakopoulos et al., 2023). In this study, we harnessed the capabilities of Geographic Information System (GIS) technology, augmented by the Analytic Hierarchy Process (AHP), to define a robust set of measurable criteria assessing the potential of lands within the study area.

A novel tool emerged from the integration of AHP-informed Multi Criteria Decision Analysis (MCDA) into a GIS platform. This tool encompasses layers incorporating topographical data, soil characteristics, geological information, water resources, and existing land use patterns. These layers function as pivotal criteria for pinpointing ideal locations for agricultural, industrial, and aqua cultural development.

In the realm of coastal land use planning using GIS and AHP methodologies, our study finds parallels and distinctions with contemporary research. The study by Nguyen Kim Loi et al. (2010) on land use suitability in Vietnam's Di Linh District, while similar in methodology, focused on a narrower set of criteria tailored to their specific geographic and socio-economic context. This contrast underscores the adaptability of GIS-AHP methods to varied environments, as evidenced by our broader criteria selection tailored to Iran's coastal regions.

Further, the research in Demirci district, Turkey (Topuz and Deniz, 2023), as detailed in a study published in the Humanities and Social Sciences Communications (n.d.), emphasized the integration of AHP and GIS for land use planning. This study shared a similar approach to ours, yet differed in the specific application of criteria and regional focus, highlighting the flexibility of these methodologies across diverse geographical settings.

4. Conclusion

This research aimed to develop a comprehensive method for evaluating the developmental potential of coastal lands for agricultural, industrial, and aquacultural purposes. Utilizing the capabilities of Geographic Information System (GIS) technology and the Analytic Hierarchy Process (AHP), a sophisticated tool was created. This integration led to the formation of a tool that combines various criteria including topography, soil characteristics, geology, water resources, and existing land use patterns, essential for identifying optimal development sites.

The study successfully established a robust and adaptable framework for assessing the potential of coastal lands for various developmental purposes. Through the integration of GIS and AHP, the research not only provides a practical tool for identifying suitable areas for development but also enriches the broader field of sustainable land use planning. By incorporating a diverse set of criteria and considering the specific characteristics of Iran's coastal regions, the study highlights the importance of tailor-made solutions in land use planning. This research marks a significant contribution to the ongoing efforts to balance development with sustainability in coastal landscapes.

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