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Analysis and Prioritization of Socio-Environmental Economic Drivers of Timber Smuggling: A Case Study of Western Mazandaran

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Abstract

The present study aims to prioritize the factors influencing the occurrence of timber smuggling in western Mazandaran Province using two multi-criteria decision-making methods: the Analytic Hierarchy Process (AHP) and Decision-Making Trial and Evaluation Laboratory (DEMATEL). The statistical population consists of managers and staff of the natural resources department of Western Mazandaran. In this study, four main criteria, economic, legal, socio-environmental, and supervisory, were considered, and data were collected through a questionnaire administered to 15 experts. The findings obtained from both methods indicate that economic factors rank first, legal factors second, socio-environmental factors third, and supervisory factors fourth in terms of their influence on timber smuggling. Furthermore, among the sub-criteria, "high inflation," "high unemployment rate," and "increased timber import tariffs" (all belonging to the economic criteria group) received the highest scores.

Keywords: Timber smuggling, Analytic hierarchy process.

1 | Introduction

Smuggling is defined in the Legal Terminology Dictionary as "the movement of goods from one place to another. In some cases, these two points are within the country, which is referred to as domestic smuggling, and in other cases, one point is inside, and the other is outside the country, which is referred to as international smuggling. This movement occurs in violation of transportation regulations in such a way that it contravenes a legally established prohibition or restriction" [1]. Smuggling encompasses various types, and according to Articles 18 and 22 of the Anti-Smuggling Law, specific penalties have been prescribed for each. Accordingly,

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any individual who engages in the smuggling of goods or currency, or in their transportation and storage, will not only have the goods confiscated but will also be subject to monetary fines in accordance with the law. If the goods are no longer available, the offender shall, as applicable, be required to pay an amount equivalent to their value, unless the loss of the goods occurred beyond the offender's control. In addition, proceeds obtained from the smuggling of prohibited goods, as well as the tools and equipment used in the production of such goods, shall also be confiscated in accordance with the law.

Timber smuggling is considered a form of goods smuggling. Given the unique importance and characteristics of the northern forests of Iran, features that are not found in other forests, whether natural or plantation-based, and their unparalleled status among similar forests worldwide (Daliri [2], the encroachment by forest dwellers and communities residing along forest margins is regarded as one of the main drivers of forest degradation and timber smuggling. One of the primary underlying causes of this encroachment is the high level of unemployment and severe poverty prevailing in forest-dependent communities. Consequently, many rural men exploit natural resources as a means of livelihood. Unless the issue of unemployment among forest dwellers, who constitute some of the most underprivileged segments of society, is effectively addressed, the problem of timber smuggling will persist [3]. Moreover, news reports frequently highlight incidents related to smuggling, indicating that this adverse phenomenon has increasingly evolved into a serious challenge that threatens the nation's natural capital, resources that are not solely the property of the present generation. The rising number of discoveries and seizures suggests an increasing trend in timber smuggling across the country. This trend can be attributed, in part, to the implementation of the forest harvesting ban (the "Forest Breathing Plan"), as well as significant increases in timber prices. When prices rise, legal harvesting is restricted or prohibited, and timber imports face various barriers, many individuals turn to illegal logging and smuggling, thereby exacerbating the problem.

However, with the large-scale destruction of the world's forest areas, the motivation for conserving natural ecosystems has intensified. At the same time, the commercial exploitation of forest timber is currently regarded as one of the most important revenue-generating sectors of forests and holds a prominent position in government policies. A review of the existing literature indicates that one of the factors influencing timber smuggling in the domestic wood market is the performance of forest protection units. In addition, macroeconomic variables such as Gross Domestic Product (GDP) per capita, exchange rates, and inflation [3], as well as microeconomic factors including the costs of exporting and importing wood products [4], the level of wood product output [5], and timber prices [6], have been identified as key determinants affecting timber smuggling. Beyond these factors, other dimensions, such as legal, supervisory, and social factors, also play a significant role in timber smuggling. Therefore, the present study seeks to examine the individual effects of each of these factors on timber smuggling.

2 | Literature Review

The phenomenon of timber smuggling, as one of the major challenges in natural resource management, particularly in the forested regions of northern and western Iran, has consistently attracted the attention of scholars across various disciplines, including forestry, economics, sociology, law, and natural resource management. This phenomenon not only inflicts irreversible damage on national assets and forest ecosystems but also stems from complex economic, social, legal, and managerial dimensions. A review of the literature indicates that most domestic studies have focused on identifying the causes of timber smuggling and proposing preventive strategies. Among these, economic–livelihood factors (such as unemployment, poverty, and the lack of alternative income sources) and managerial–legal factors (such as weak monitoring, administrative corruption, and legal gaps) have been identified as the most critical axes of analysis. However, limited research has addressed the prioritization of the causes of timber smuggling in specific regions, such as western Mazandaran, using multi-criteria decision-making methods such as the Analytic Hierarchy Process (AHP) and the Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique.

The following section presents a review of the most significant domestic and international studies in this field. In one of the earlier studies, Mostafanejad and Sadati [7] examined the causes of forest degradation. They concluded that factors such as excessive exploitation for industrial timber and fuelwood supply, overgrazing, improper implementation of forest management policies, incomplete execution of livestock removal plans, and the lack of education and promotion of natural resource conservation culture are among the main drivers of forest degradation. Similarly, Afrand et al. [8], in designing a model to determine target areas for combating timber smuggling in the Siahroud forest management plan in Amlash, emphasized that due to the economic and social roots of this phenomenon, public participation cannot be effectively relied upon unless the livelihood issues of forest-dependent communities are addressed. They argue that timber smuggling is a complex problem for which purely enforcement-based or legal solutions are insufficient. In the same region, Afrand Sorkhani et al. [3] employed Geographic Information Systems (GIS) to identify hotspots of timber smuggling. They demonstrated that wood-related crimes occur in only 24% of the total forest area. At the same time, no offenses are recorded in the remaining areas, highlighting the importance of spatial approaches in preventing timber smuggling.

On the other hand, Sotoudeh Foumani et al. [10], adopting a macroeconomic perspective, examined the relation between wood export and import of Iran and a number of major macroeconomic variables, such as oil price, gross domestic product, population, exchange rate, unemployment rate, inflation, and domestic wood production during 1980–2014. The results revealed that, at the 5% significance level, there is a statistically significant relationship between wood exports (as the dependent variable) and several independent variables, including oil prices, GDP, population, exchange rate, and domestic wood production. In addition, a significant association was also found between wood imports and oil prices, exchange rates, and domestic wood production. The findings further show that among all the independent variables considered, oil prices exert the strongest influence on wood imports in Iran over the period under study. Furthermore, Hejazyian and Lotfalian [11] investigated the consequences of unprincipled reductions in timber harvesting and demonstrated that sustainable and proper utilization can only be achieved through the implementation of forest management plans. These plans not only contribute to forest conservation but also promote employment and regional economic development. Similarly, Hosseini and Ghahramani [12], in another study, confirmed that Golestan Province, compared to Gilan, has a higher share of timber smuggling due to its larger areas lacking forest management plans. They also analyzed trends in timber smuggling seizures across the three provinces of Gilan, Mazandaran, and Golestan, finding a decreasing trend in the first two provinces and an increasing trend in Golestan. It appears that the relatively large extent of unmanaged forest areas in Mazandaran has also contributed to the intensification of timber smuggling.

Studies adopting sociological and legal approaches have also provided valuable insights. Hajatnia [13], using the Delphi method in Gilan Province, identified unemployment and the need for income, particularly among youth, administrative corruption, profiteering motives, poverty among forest dwellers, and ineffective enforcement against smuggling actors as the most significant causes of timber smuggling. He proposed solutions such as stakeholder participation in forest management, the establishment of local informant networks, and the identification of repeat offenders. Mohseni [14], from the perspective of environmental justice, critically examined Supreme Court Ruling No. 749 and demonstrated that, although the ruling appears to concern the determination of competent jurisdiction, it in fact contributes to the realization of environmental justice and is aligned with both scientific and religious justifications, despite certain criticisms. Mahdavi [15], in assessing the factors affecting timber and charcoal smuggling in local communities of Ilam and Helilan using factor analysis, concluded that three groups of factors, economic-livelihood, legal-institutional, and socio-cultural, account for 62.15%, 10.45%, and 9.63% of the variance, respectively. Furthermore, the AHP results indicated that economic-livelihood factors (with a mean weight of 0.379) exert the greatest influence, while legal factors (with a mean weight of 0.285) have the least impact.

In two more recent studies that are directly related to the focus of the present research (western Mazandaran and multi-criteria approaches), noteworthy findings have been reported. Biranvand et al. [16], in an article entitled "Investigating the Causes and Drivers of Timber Smuggling in Northern Iran," published in the

journal Forest and Wood Products, employed the grounded theory approach and conducted interviews with 51 stakeholders to develop a paradigmatic model consisting of causal, contextual, intervening conditions, actions/interactions, and consequences. They identified the "collapse of the forest management system and the absence of a coherent conservation plan" as the primary cause of timber smuggling, while contextual conditions such as unemployment, poverty, and livelihood challenges, and intervening conditions such as weak monitoring and control systems, were found to exacerbate the phenomenon. The ultimate consequences of this process were identified as forest degradation, loss of biodiversity, and increased flooding and landslides.

On the other hand, Alipour et al. [17], in a study titled "Evaluation and Analysis of Economic–Livelihood and Managerial-Legal Factors Affecting Timber Smuggling in West Azerbaijan Province (Case Study: Urmia County)," published in the Journal of Geography and Regional Planning, utilized the Friedman and Mann-Whitney tests to prioritize factors from the perspectives of experts and local communities. The results indicated that, from the viewpoint of local communities, poverty and financial deprivation, unemployment, lack of alternative income sources, inflationary pressures, scarcity of legally available timber, and weak government support were the most influential factors, respectively. From the experts' perspective, inflationary pressure, unemployment, poverty, and weak economic infrastructure were identified as the most significant drivers. Furthermore, experts highlighted managerial-legal factors such as shortages of protection personnel, lack of equipment, absence of effective monitoring systems, and insufficient use of modern technologies as key contributors. Ultimately, the study concluded that a sustainable solution lies beyond short-term measures and is rooted in the establishment of a "participatory governance model" and the formation of joint management committees.

At the international level, although direct studies on timber smuggling in Iran are limited, several international studies provide valuable insights. Buehn and Eichler [18], in a study titled "Smuggling of Legal and Illegal Goods across the U.S.-Mexico Border: A Structural Equation Modeling Approach," demonstrated that the smuggling of legal goods (including timber) is often associated with tax and tariff evasion, and that tariff differentials between countries increase the incentives for smuggling. Although this study was not conducted in the Iranian context, its emphasis on the role of economic and tariff-related factors is consistent with the findings of domestic research. The literature review indicates that, despite numerous studies, a significant research gap remains in the prioritization of the causes of timber smuggling in western Mazandaran using integrated multi-criteria decision-making methods, such as the AHP and the DEMATEL technique, that are capable of identifying causal relationships among factors. The present study seeks to address this gap by applying these methods to provide more precise priorities for policymaking and management interventions in the region.

3 | Methodology

The present study is applied in terms of purpose and falls within the category of descriptive–survey research in terms of nature and methodology. The statistical population consists of all managers and expert staff of the Natural Resources and Watershed Management Organization in western Mazandaran Province. A purposive sampling approach was employed based on criteria such as relevant professional experience in forest protection, familiarity with timber smuggling issues, and willingness to participate. Ultimately, a panel of 15 experts was selected. Data were collected using two types of instruments. First, library-based research was conducted to identify the theoretical foundations and review prior studies through academic articles, theses, and specialized publications. Second, field data were gathered using pairwise comparison questionnaires designed for the AHP and interaction assessment questionnaires specific to the DEMATEL technique. The validity of the questionnaires was confirmed through expert judgment, and their reliability was verified by calculating the consistency ratio, which was below 0.10 for all matrices. The hierarchical structure of the study comprised four main criteria (economic, legal, socio-environmental, and supervisory) and a total of 18 sub-criteria, developed based on the literature review and expert interviews. Data analysis of the AHP

questionnaires was performed using Expert Choice software to calculate weights and rank the criteria and sub-criteria.

To complement the findings and examine causal relationships among the main criteria, the DEMATEL technique was applied. In this process, the direct-relation matrix was constructed, normalized, and subsequently used to compute the vectors of influence degree (D), influenced degree (R), as well as the indices (D+R) and (D−R). The consistency ratio for all pairwise comparison matrices in AHP was less than 0.09, indicating a high level of reliability in expert judgments. In the DEMATEL analysis, a cause–effect diagram was employed to classify factors into "cause" and "effect" groups. It is noteworthy that the temporal scope of the study spans six months (from March 2021 to September 2021), the spatial scope is the Natural Resources Administration of western Mazandaran, and the thematic scope lies within forestry engineering and timber smuggling. In this study, the hierarchical structure of the problem is shown in *Fig. 1* and *Table 1*.

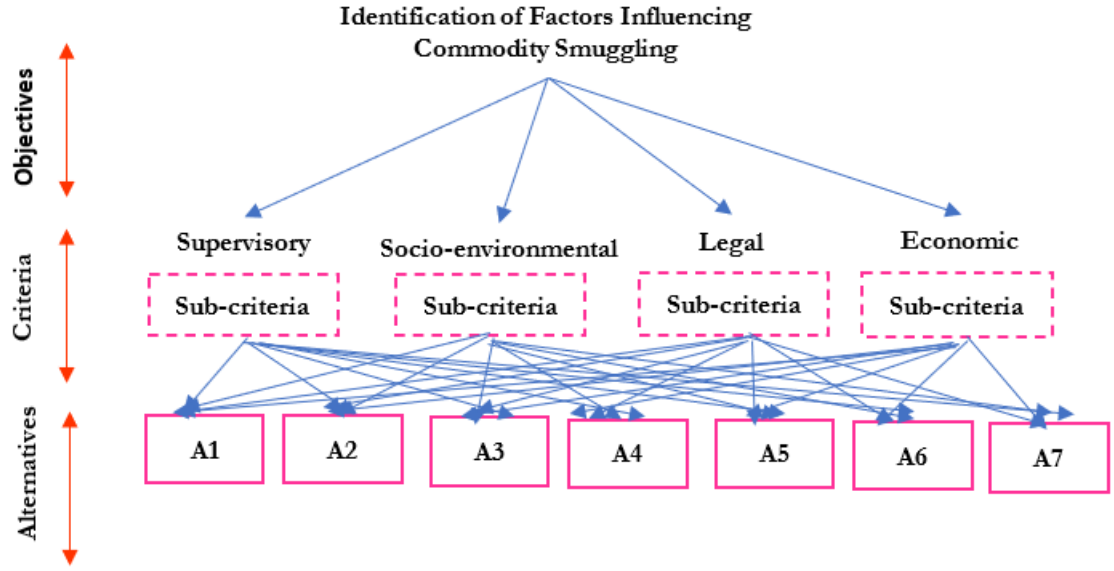

Fig. 1. Hierarchical structure of the problem.

Table 1. Factors influencing commodity smuggling in western mazandaran province.

Criteria	Economic	Legal	Socio-Environmental	Supervisory
Sub-criteria	High inflation	There was no wood cultivation	Lack of culture and education to support the forest	Weaknesses of managers in designing a deterrent strategy
	High unemployment rate	Weakness of current deterrent laws	Access to side roads for smuggling	Lack of specialized protection units
	Increase in wood import tariffs	Low deterrence penalty	Collaboration of employees with smugglers	Lack of surveillance hardware systems (CCTV)
	Low income of the forest fringe	Eliminate forest respiration		Lack of continuous monitoring of wood factories
	Low income of delinquent personnel			
	Rising wood prices			
	Increase wood products			

4 | Results and discussion

4.1 | Calculation of Weights and Selection of the Most Preferred Main Indicator

Based on the pairwise comparison scoring among the four main criteria (on a scale from 1 to 9), and according to the output of Expert Choice software, the pairwise comparison matrix of the main criteria is presented in *Fig. 2* (inconsistency rate: 0.08).

	Economic	Legal	Socio-envi	Monitoring
Economic		4.0	3.0	3.0
Legal			2.0	3.0
Socio-environmental				2.0
Monitoring	Incon: 0.08			

Fig. 2. AHP Pairwise comparison matrix for the main criteria.

The numbers in *Fig. 2* represent the priority of the row criteria relative to the corresponding column criteria. The values shown in red indicate the reverse situation, i.e., the priority of the column criteria over the row criteria. The *Fig. 3* illustrates the ranking and the calculated weights of the criteria.

Fig. 3. Ranking and weighting of the criteria.

Based on the weights obtained from the Analytical Hierarchy Process (AHP), the economic criterion, with a weight of 0.519, was identified as the most influential factor in the occurrence of timber smuggling in western Mazandaran. This weight is approximately twice the combined weight of the other three criteria, indicating that livelihood and financial motivations (such as unemployment, poverty, and lack of alternative income sources) are the primary drivers of this phenomenon, as shown in *Fig. 4*. The legal criterion ranks second with a weight of 0.228. Factors such as legal gaps, non-deterrent penalties, and lengthy judicial processes contribute significantly after economic factors. The socio-environmental criterion, with a weight of 0.152, is in third place, while the monitoring criterion, with a weight of 0.101, has the least influence among the four criteria. This ranking of criteria is also illustrated in *Fig. 4*.

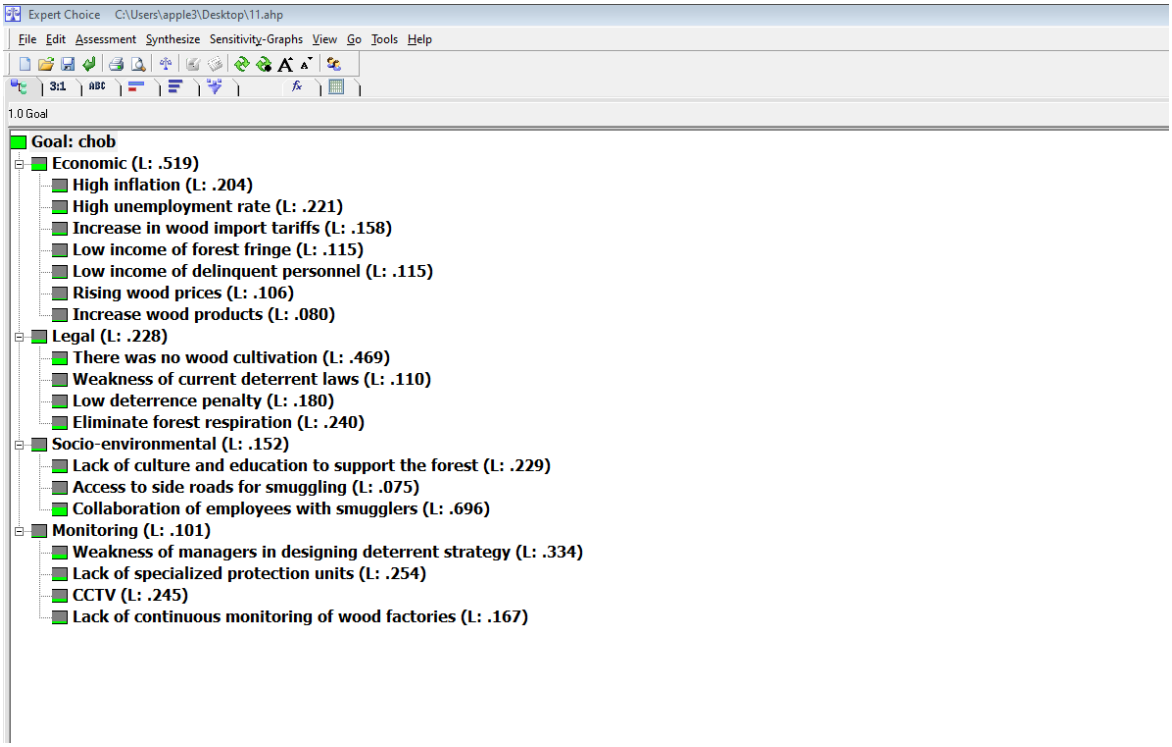

Fig. 4. Comparative weights and ranking of main criteria.

4.2 | Determination of the Priority of the "Economic Criterion"

The economic criterion itself is composed of four sub-criteria, and its pairwise comparison matrix is presented below (inconsistency rate: 0.09), as shown in *Fig. 5*.

	High inflati	High unem	Increase in	Low incom	Low incom	Rising woo	Increase w
High inflation		2.0	2.0	1.0	2.0	1.0	2.0
High unemployment rate			1.0	2.0	2.0	5.0	3.0
Increase in wood import tariffs				2.0	1.0	3.0	1.0
Low income of forest fringe					1.0	1.0	2.0
Low income of delinquent perso						2.0	1.0
Rising wood prices							3.0
Increase wood products	Incon: 0.09						

Fig. 5. Relative Importance of Economic Sub-Criteria.

Fig. 6 shows the ranking and the assigned weights of the criteria.

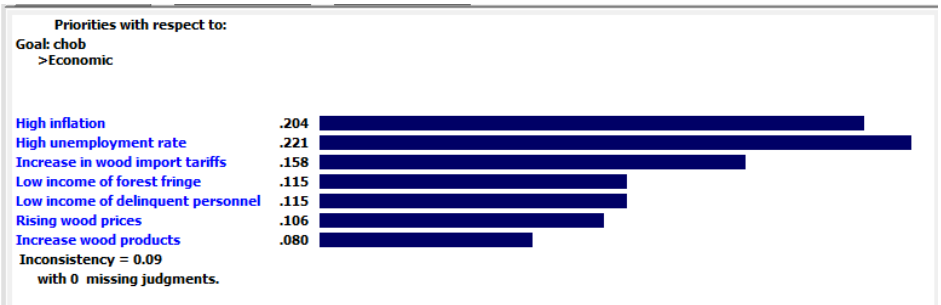

Fig. 6. Ranking and weights of the criteria.

Within the framework of the economic criterion, a set of factors exerting pressure on livelihoods and increasing the profitability of timber smuggling has been identified. High unemployment rates, particularly

among residents living in forest-edge areas, along with rising inflation, push individuals toward illegal activities to meet their basic living needs. In addition, the low income of forest fringe communities, as well as inadequate salaries for some personnel, makes them vulnerable to corruption and involvement in smuggling activities. On the other hand, the increase in timber import tariffs, rising domestic timber prices, and growing demand for wood products have significantly amplified the profitability of smuggling and intensified economic incentives. Accordingly, these seven sub-criteria collectively create the conditions for timber smuggling in western Mazandaran.

4.3 | Determination of the Preference of the "Legal Criterion"

The environmental criterion consists of four sub-criteria, and its pairwise comparison matrix is presented as follows (inconsistency rate: 0.09), as shown in *Fig. 7*.

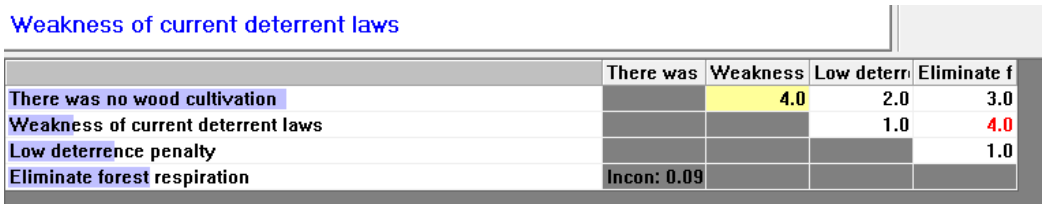

Fig. 7. Ranking and Weights of the Criteria.

Fig. 8 shows the ranking of the criteria and their assigned weights:

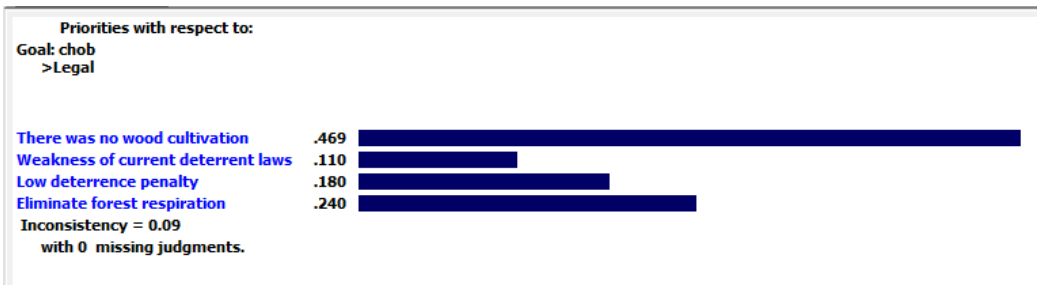

Fig. 8. Ranking of the criteria and their assigned weights.

Therefore, the criteria are ranked in order of priority (importance) as follows: Within the legal indicator framework, four main sub-criteria have been identified, highlighting the inefficiency of the legal and regulatory system in controlling timber smuggling. The most important factor is the absence of timber cultivation, meaning the lack of industrial and economic programs for wood production outside natural forests, which increases harvesting pressure on pristine forests and creates conditions conducive to smuggling. In the second rank is the removal of forest rest periods (the suspension of harvesting cycles and natural regeneration), which disrupts ecological balance and intensifies incentives for illegal logging. Additionally, low penalties and the absence of effective deterrence make the cost of committing the crime negligible compared to the profits from smuggling. Finally, the weakness of existing deterrent laws indicates that even current regulations lack the necessary coherence and effectiveness to combat smuggling networks, as shown in *Fig. 7*. In summary, these factors show that structural gaps in the legal system and forest policymaking are as influential in the emergence of smuggling as economic problems.

4.4 | Determining the Priority of Criteria in the "Socio-environmental Index"

The socio-environmental index itself consists of five sub-criteria, and its pairwise comparison matrix is presented below (consistency ratio: 0.07), as shown in *Fig. 9*.

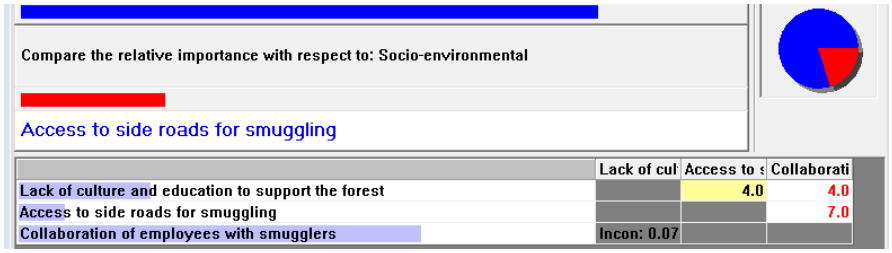

Fig. 9. Priority of criteria in the socio-environmental index.

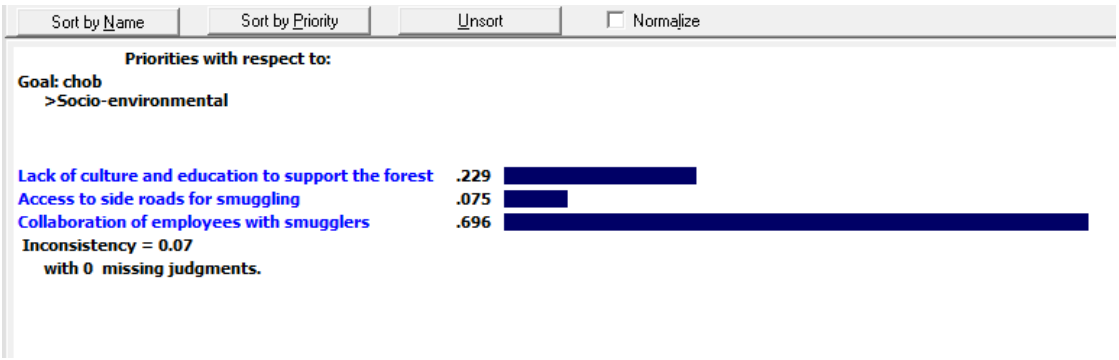

Fig. 10. Ranking and the assigned weights of the criteria.

Based on *Fig. 10* and within the socio-environmental index framework, three sub-criteria have been identified, mainly related to human and infrastructural factors. The most important factor is collusion between employees and smugglers, indicating that internal corruption and the infiltration of smuggling networks into protection and administrative personnel constitute the greatest obstacle to controlling timber smuggling. In the second rank is the lack of environmental culture and forest conservation education. Weak environmental awareness and the failure to institutionalize the value of natural resource protection among local communities lead to public indifference toward the consequences of forest destruction. The least important factor in this index is the accessibility of secondary roads for smuggling activities. Although the existence of infiltration routes and hidden paths facilitates smuggling operations, their impact is relatively lower compared to the other two factors (employee corruption and cultural weakness). In summary, internal betrayal by responsible personnel and the lack of a conservation-oriented culture among the public form the main foundation of timber smuggling from a socio-environmental perspective.

4.5 | Determining the Priority of Criteria for the "Monitoring Index"

The monitoring index consists of four sub-criteria, and its pairwise comparison matrix is presented below (consistency ratio: 0.09), as shown in *Fig. 11*.

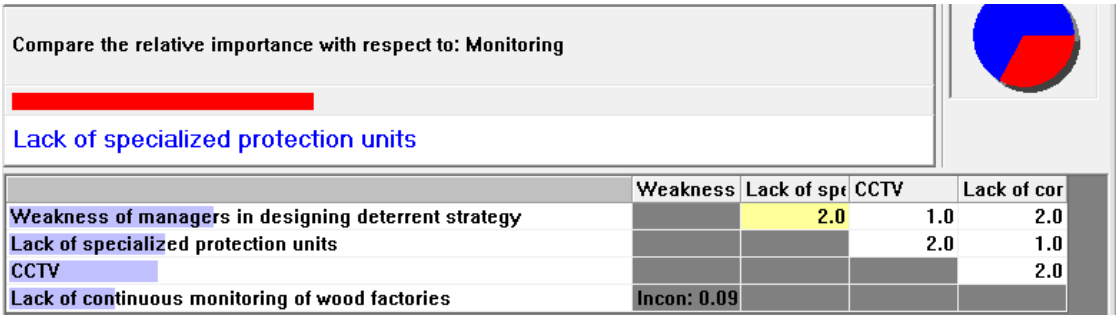

Fig. 11. Comparison of relative importance with respect to the monitoring index.

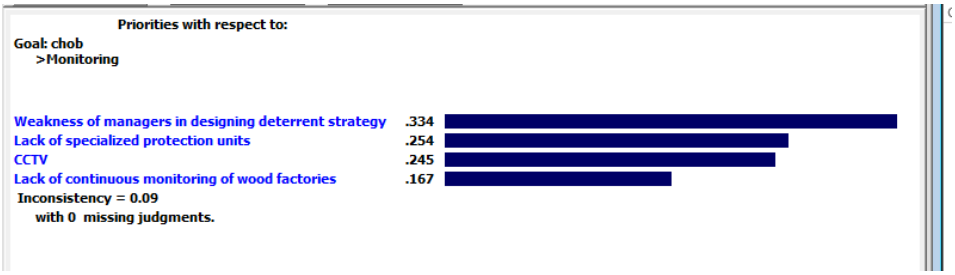

Fig. 12. Ranking and the assigned weights of the criteria.

Within the monitoring index framework, four main sub-criteria have been identified, all of which stem from the inefficiency of the management and control system over smuggling-related processes. The most important factor is managers' weakness in designing deterrent strategies; in other words, the absence of effective and strategic planning at higher managerial levels hinders systematic prevention and control of smuggling. In the second rank is the shortage of specialized protection units. Protective forces are insufficient in terms of number, training, and equipment, and therefore cannot effectively monitor extensive forest areas. Furthermore, the lack of hardware-based monitoring systems (such as CCTV cameras, drones, and remote sensing platforms) results in many illegal activities remaining undetected and undocumented. Finally, the absence of continuous supervision over wood-processing factories indicates that the final link in the smuggling chain, the conversion and sale of illegal timber, is not properly controlled. In summary, weaknesses in management, a shortage of specialized human resources, a lack of advanced monitoring equipment, and neglect of oversight in processing industries constitute the four main pillars of inefficiency in the monitoring system in Western Mazandaran.

4.6 | Determining the Priority of All Criteria

The overall criteria comprise 17 indicators, with a consistency ratio of 0.09. *Fig.13* shows the ranking and the assigned weights of the criteria.

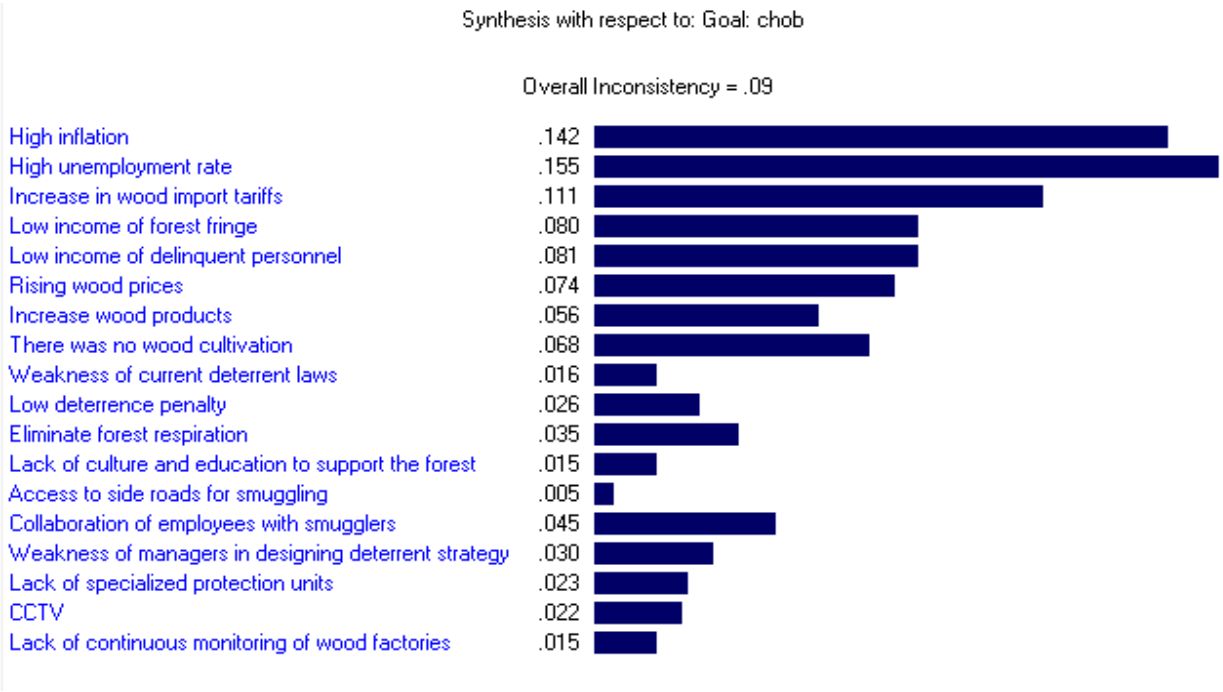

Fig. 13. Priority of all criteria.

Based on the final prioritization of all 18 sub-criteria, it becomes clear that economic factors are prominently ranked at the top. The most important sub-criterion overall is the high unemployment rate (weight: 0.155), followed by high inflation (0.142). In third place is the increase in timber import tariffs (0.111), indicating the influence of trade policies on smuggling activities. Next, the low income of offenders (0.081) and the low income of forest-edge residents (0.080) are ranked consecutively. Among the non-economic factors, the absence of timber cultivation (0.068) is the most important. Notably, monitoring-related and socio-environmental sub-criteria, such as employee collusion (0.045), managerial weakness (0.030), and shortage of protection units (0.023), are ranked lower, while access to secondary roads (0.005) has the lowest weight. In summary, unemployment, inflation, and import tariffs are the three main drivers of timber smuggling in western Mazandaran, while other factors have significantly less influence.

4.7 | Analysis Using the DEMATEL Technique

The DEMATEL (Decision-Making Trial and Evaluation Laboratory) technique is an effective multi-criteria decision-making method used to identify causal relationships among factors within a complex system. Unlike methods such as AHP, which focus solely on prioritization based on weighting, DEMATEL is also capable of determining both the direction and intensity of influence that each factor exerts on others. In the present study, the DEMATEL technique was used to rank the main criteria (economic, legal, socio-environmental, and regulatory). The main objective is to identify which of these criteria act as causes (influencing factors) and which act as effects (influenced factors) in the occurrence of timber smuggling in Western Mazandaran. Accordingly, by constructing the direct-relation matrix and calculating the indices D (level of influence), R (level of being influenced), D+R (overall interaction), and D−R (causal direction), the final ranking of the criteria was carried out based on their systemic roles. The results of this analysis are presented in *Table 2*.

Table 2. Results of the DEMATEL technique.

Factors Obtained From Factor Analysis	Row Sum	Column Sum	Row And Column Sums	Difference Between Row And Column Sums
	D	R	R+D	R-D
Economic	3.120	3.477	6.597	-0.357
Legal	2.813	3.408	6.222	-0.595
Socio-Environmental	2.804	3.073	5.877	-0.270
Monitoring	2.799	0.965	3.763	1.834

The results obtained from the DEMATEL analysis indicate that, in terms of influence (D), the economic criterion has the highest rank with a coefficient of 3.120, followed by the legal (2.813), socio-environmental (2.804), and regulatory (2.799) criteria, respectively. On the other hand, in terms of influence received (R), the economic criterion also shows the highest level of dependence on other factors with a coefficient of 3.477, followed by the legal (3.408), socio-environmental (3.073), and regulatory (0.965) criteria. An examination of the horizontal vector (D+R), which represents the overall interaction of each factor with the system, indicates that the economic criterion has the highest value and thus the greatest level of interaction, while the regulatory criterion has the lowest value, reflecting the weakest interaction with other factors. Regarding the vertical vector (D−R), which determines the degree of causality or effect, the results show that only the regulatory criterion has a positive value (D−R > 0). Therefore, this criterion is identified as a causal (driving and influential) variable. In contrast, the three criteria, economic, legal, and socio-environmental, have negative D−R values and are considered effect (dependent) variables influenced by other factors. Finally, in the Cartesian coordinate system, the horizontal axis represents (D+R) and the vertical axis represents (D−R), and the position of each of the four criteria is determined in the diagram based on these two coordinates, as shown in *Fig. 14*.

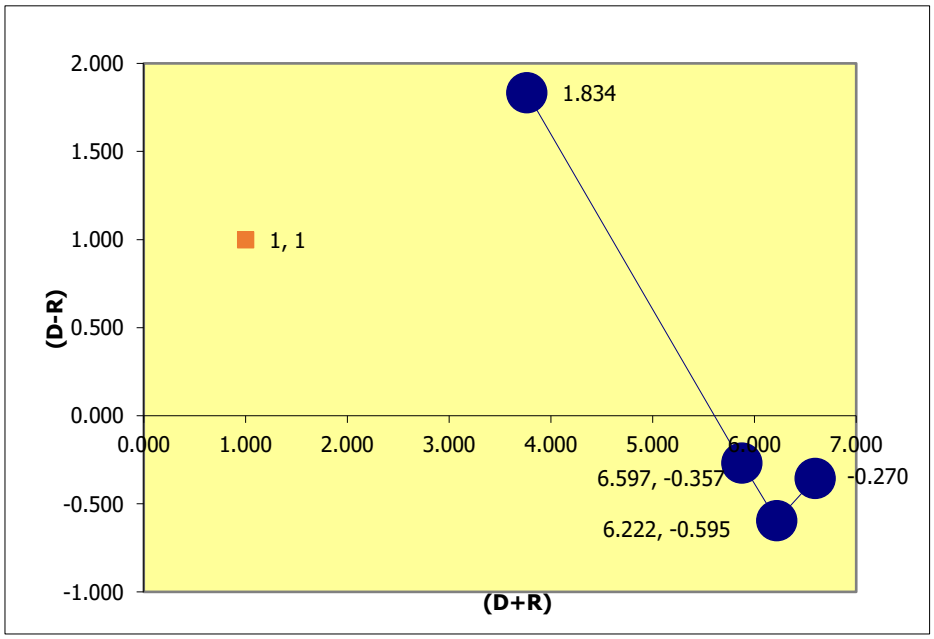

Fig. 14. Cause–Effect positioning of criteria in the DEMATEL framework.

Also, using the DEMATEL technique, the prioritization of factors influencing timber smuggling is summarized in *Table 3*.

Table 3. Prioritization of factors.

Factors Obtained From the DEMATEL Analysis	Row and Column Sums
	R+D
Economic	6.597
Legal	6.222
Socio-environmental	5.877
Monitoring	3.763

The DEMATEL output for the (D+R) index, which represents the overall level of interaction of each criterion with the others, shows that the economic criterion, with a value of 6.597, has the highest level of interaction. These findings means that this criterion both exerts the greatest influence on others and is also the most influenced by them. It is followed by the legal criterion with a value of 6.222, which ranks second. The socio-environmental criterion, with a value of 5.877, is in third place. Finally, the supervisory criterion, with a value of 3.763, has the lowest level of interaction with the other factors, indicating that it operates relatively more independently and its systemic interactions are lower than those of the other three criteria. In other words, economic, legal, and socio-environmental factors are interconnected in a complex network, whereas the supervisory factor plays a more separate role.

5 | Conclusion and Policy Recommendations

The findings obtained from both the AHP and DEMATEL methods consistently show that, among the four main criteria (economic, legal, socio-environmental, and supervisory), economic factors have the most significant impact on timber smuggling in western Mazandaran by a considerable margin. Among these, "high unemployment rate" and "inflation" are identified as the most important sub-criteria, indicating that the root of this phenomenon lies in structural poverty, lack of stable employment, and livelihood pressures faced by communities living near forest areas. The second-ranking legal factors, particularly "lack of timber cultivation (plantation forestry)" and the "removal of forest rest periods", suggest that the shortage of legally supplied timber in the market pushes demand toward illegal logging and smuggling. However, the most important analytical finding of the study, derived from the DEMATEL technique, is the identification of the supervisory factor as a "hidden cause." Although it had the lowest direct weight in the prioritization results, it functions as a causal variable in the cause-effect relationships, intensifying other factors. In other words, weaknesses in strategic management, shortages of specialized protection units, and the lack of modern monitoring tools create a context in which economic incentives and legal gaps are easily translated into smuggling activities.

Furthermore, the high weight of "collusion of employees with smugglers" within the socio-environmental criterion reflects a form of systemic micro-corruption, which itself is a consequence of weak internal supervision and insufficient wages and benefits. Therefore, strategies to combat timber smuggling in western Mazandaran must be designed at two levels: at the immediate level, it is recommended to update fines in line with inflation, create temporary employment programs for local communities in forest protection, and install smart surveillance cameras at critical checkpoints. At the structural level, developing contract-based timber cultivation with rural communities, designing a hybrid monitoring system (specialized personnel combined with drones), and reforming the forest rest policy toward scientific and participatory utilization are essential. Overall, without addressing the underlying economic roots and without reforming the supervisory system, particularly combating corruption and strengthening managerial capacity, any isolated or purely enforcement-based measures will not only be ineffective but may also intensify tensions between local communities and conservation institutions.

Authors' Contributions

R. R.: Writing-original draft, Methodology, Data Curation, Conceptualization, Software, and Visualization, and Validation. The author has read and agreed to the published version of the manuscript.

Data Availability

The data is available on request from the corresponding author.

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There are no competing interests to declare.

Consent for Publication

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The author confirms that this research did not involve human participants or animal subjects.

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