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Raising the Efficiency of Fire Management Using Analytic Hierarchy Process in Syrian Coastal Region Forests

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Abstract:

Natural forests are a precious wealth and a source of true identity that contribute to the preservation of important sites of natural heritage with the possibility of benefiting from them over generations. They are an inexhaustible wealth if they are well managed, organized and protected, the vegetation has a vital role in maintaining the environmental balance and improving the environment and public health, in addition to its economic, protective, aesthetic, recreational, social and educational benefits.

Most of these sites have recently been affected by natural disasters, especially fires that swept across large areas of western Syria and covered a large area from the coastal region to the central region. The losses they suffered appear to be large and extended over vast areas, in addition to the deterioration of the environmental and ecological systems and their imbalance within the region, due to climate change, which combines strong winds with high temperatures.

The study aims to choose the best strategy to increase the efficiency of fire management in Syrian Coast Region forests, taking into account the Sustainable Development Goals (SDGs), using Analytic Hierarchy Method (AHP). Deducing the main and secondary criteria necessary to build the decision matrix and developing final strategies to work according to it, based on references and previous studies in the field of research.

Key Words: The Forest, The Fires, The Fire Management, Sustainable Development Goals (Sdgs), Analytic Hierarchy Method (AHP).

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رفع كفاءة إدارة الحرائق باستخدام طريقة التحليل الهرمي في غابات إقليم الساحل السوري

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الملخص:

الغابات الطبيعية ثروة ثمينة ومصدر للهوية الحقيقية التي تسهم في صيانة المواقع الهامة من التراث الطبيعي مع إمكانية الاستفادة منها على مر الأجيال، فهي ثروة لا تنضب إذا أحسن إدارتها وتنظيمها وحمايتها، وللغطاء النباتي فيها دور حيوي في المحافظة على التوازن البيئي وتحسين البيئة والصحة العامة إضافة لفوائدها الاقتصادية والوقائية والجمالية والترويحية الاجتماعية والتعليمية.

تأثرت في الآونة الأخيرة معظم هذه المواقع بالكوارث الطبيعية، خاصة الحرائق التي اجتاحت مناطقاً واسعةً من غربي سوريا وغطت مساحة كبيرة من المنطقة الساحلية وصولاً للوسطى، وتبدو الخسائر التي تعرضت لها كبيرة وممتدة على مساحات شاسعة إضافة إلى تدهور النظم البيئية والإيكولوجية واختلال توازنها ضمن الإقليم، وذلك بسبب التغيير المناخي الذي يجمع قوة الرياح مع ارتفاع درجات الحرارة.

تهدف الدراسة إلى اختيار أفضل استراتيجية من أجل رفع كفاءة إدارة الحريق في غابات إقليم الساحل السوري مع مراعاة أهداف التنمية المستدامة، باستخدام طريقة التحليل الهرمي **(AHP)**. استنتاج المعايير الرئيسية والثانوية اللازمة للوصول إلى بناء مصفوفة القرار ووضع الاستراتيجيات النهائية للعمل وفقها، بناء على المراجع والدراسات السابقة في مجال البحث.

الكلمات المفتاحية: الغابات، الحرائق، إدارة الحرائق، أهداف التنمية المستدامة، طريقة التحليل الهرمي (AHP).

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1 .Introduction:

With the increasing severity of extreme natural phenomena, fire forest has become a serious threat to the environment and the communities living in these areas, coastal forests are important environments that require effective management to combat fires. Managing fire forest is a complex challenge that requires effective coordination between local authorities and parties concerned with preserving the environment and the safety of citizens. The coastal region is located in the northwest of Syria to the east of the Mediterranean Sea, with an area of 4180 km2 distributed between the governorates of Latakia in the north and Tartous in the south. The forest wealth in Syria is one of the most important natural resources and its area is approximately half a million hectares, of which 233 thousand hectares are natural forests and the rest are artificial afforestation, meaning that the area of forested lands is equivalent to 2.5% of the total area of the country. Acicular forests and broad-leaf forests are the predominant forests in the coastal region, as Acicular forests occupy an area of 384.76 km2, equivalent to 31.66% of the area of the region, while broad-leaf forests are estimated at an area of 229.21 km2, equivalent to 18.86 km2 of the entire area (Al-Abd et al., 2018). Also, 60% of the forest area is severely degraded due to fires, overgrazing and cutting down forests for agriculture, so a large part of the natural forests has been transformed into secondary plant communities of little Economic value. (UNEP, 2000).

With climate change and upcoming challenges, it is essential to adopt modern methods for monitoring and combating fire forest. Choosing the appropriate methodology is crucial to preserving this vital environment. This methodology should include a comprehensive analysis of the fire risk and identify the optimal strategies to reduce this risk and increase the effectiveness of the response when it occurs.

Many consider the preparation of fire forest risk maps as one of the first steps to avoid catastrophic and destructive incidents in these forests. The term fire risk refers to the probability of a forest fire based on the basic factors of fires (Bachmann et al., 2001, 28). The basic factors for drawing these maps, as mentioned by Chuvico and Congalton in 1989, are understanding the behavior of forest fires and understanding the factors that affect this behavior, and studying the factors that contribute to making the environment vulnerable to forest fires. Accordingly, we can propose an appropriate methodology for forest fire risk that contributes to deducing and drawing appropriate maps, which in turn helps forest experts prevent or reduce the risks of setting fires within forests and take appropriate measures during the fire season (Al-Abd et al., 2018).

Research problem:

The problem is represented in the following questions:

Do the management models used achieve the required efficiency in decision-making in reducing the risks of forest fires؟

To what extent is the conceptual model of the decision support tool developed؟

Research objectives:

The main objective is to develop a new strategy to improve the efficiency of fire management in Syrian coastal forests, in addition to complementary and sub-objectives, which are:

−Deducing the necessary criteria and linking them to fire management objectives.

−Developing a decision support tool that contributes to reducing fire risks, enhancing fire prevention, and reducing negative impacts.

2. Literature Review:

Some global studies have shown that strategic planning can help improve fire management in protected areas and natural forests, including: Catalonia, Spain:

Catalonia is located in the far north-east of the Iberian Peninsula and comprises 32,113 km2 of the Autonomous Community of Catalonia (north-east Spain). Catalonia is administratively divided into 948 municipalities, which are grouped judicially into 42 provinces and 4 provinces.

Forest fires continue to cause significant losses of social, economic and natural values in Mediterranean areas where human activities cause fires and at the same time have the highest negative impacts, and such "megafires" are expected to increase due to climate change and the increase in fuel quantities and their continuity. Some strategies have also proven to be largely ineffective during extreme fire weather conditions, and represent significant financial expenditures in Spain (15–20 million euros per year), and result in human losses, in terms of injuries and loss of life (56.3 injuries per year and 3.5 deaths per year on average from 1996 to 2010) (Alcasena et al., 2016). The study aimed to develop a broader mix of fire management objectives based on fire systems, human values and land use, highlighting where alternative and integrated strategies provide a long-term solution to better coexist with fire.

Wildfire management strategy in Catalonia:

To explore how the current approach to wildfire can be extended to consider other fire management strategies, the current study combined simulation modelling outputs with land use patterns, valuable assets, and historical ignition data to map specific fire management objectives. To illustrate the framework, this study was conducted in Catalonia (northeastern Spain), a fire-prone Mediterranean region where extreme events have caused significant losses over the past decades.

Alcasena 2019 identified four key wildfire management objectives and used these objectives to prioritize and rank management options at the municipal level according to spatially explicit quantitative metrics:

- Create fire-resistant landscapes.
- Restore the culture of prescribed fire.
- Support safe and effective fire response.
- Create fire-adapted human communities.

To map these specific targets, input data were used to model landscape-matched fires (topography, surface fuels, and forest canopy metrics), fire weather conditions (fuel moisture content and wind scenarios in the wildfire season), and an ignition probability grid derived from historical ignition locations. Topography, surface fuels, and canopy metric point grids were compiled into the landscape file. Using a surface fire spread model, to account for incoming fires, the following maps are presented:

Fire intensity map by cause:

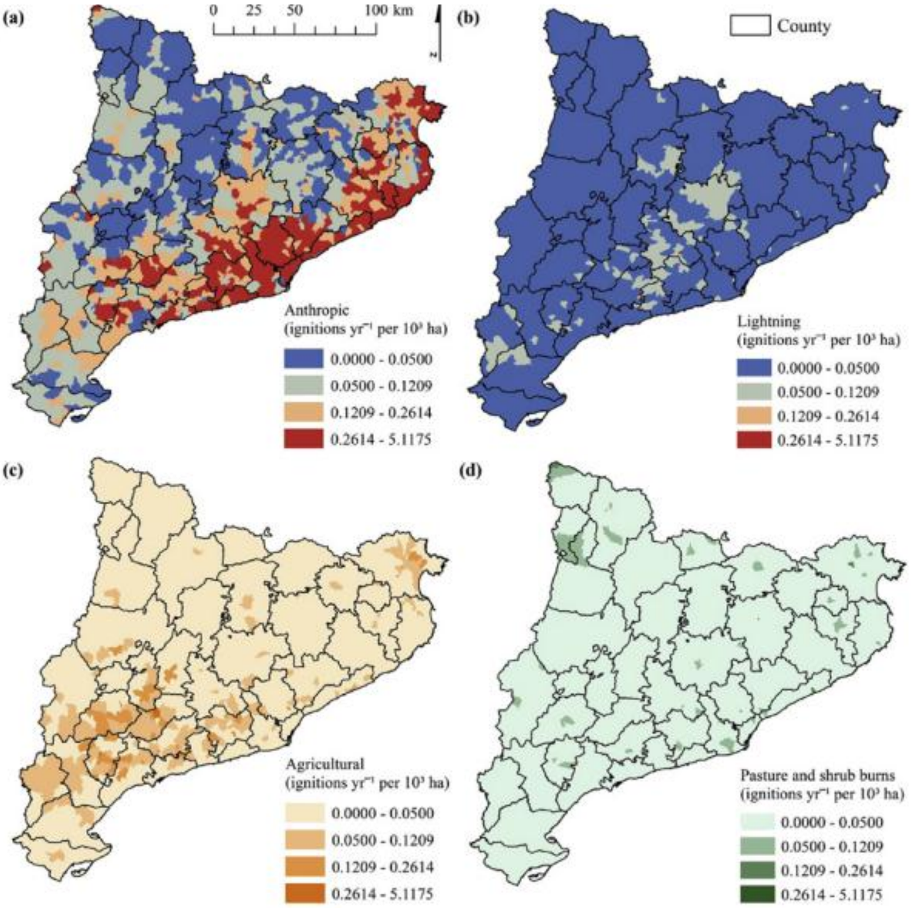

Figure 1. Fire intensity map by cause - Source: (Alcasena et al., 2019, 310)

Conditional flame length map and high intensity annual burn probability map:

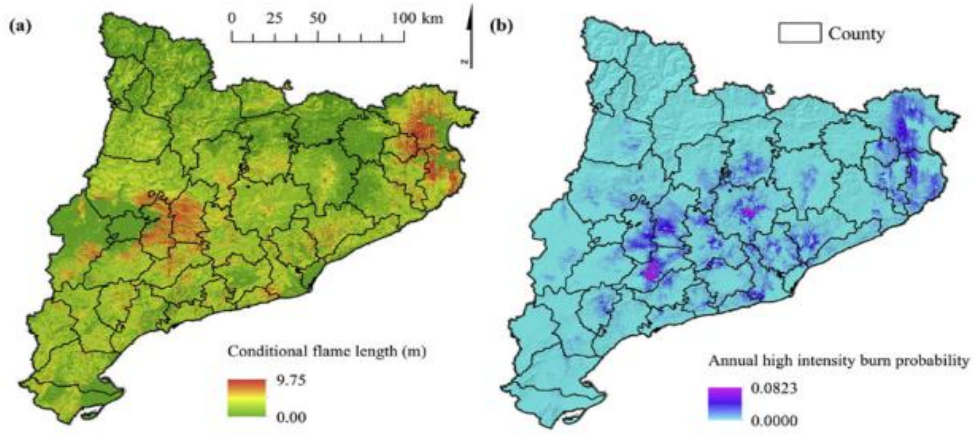

Figure 2. Map of conditional flame length and annual high-intensity burning probability - Source: (Alcasena et al., 2019, 31

Fire exchange and transmission map:

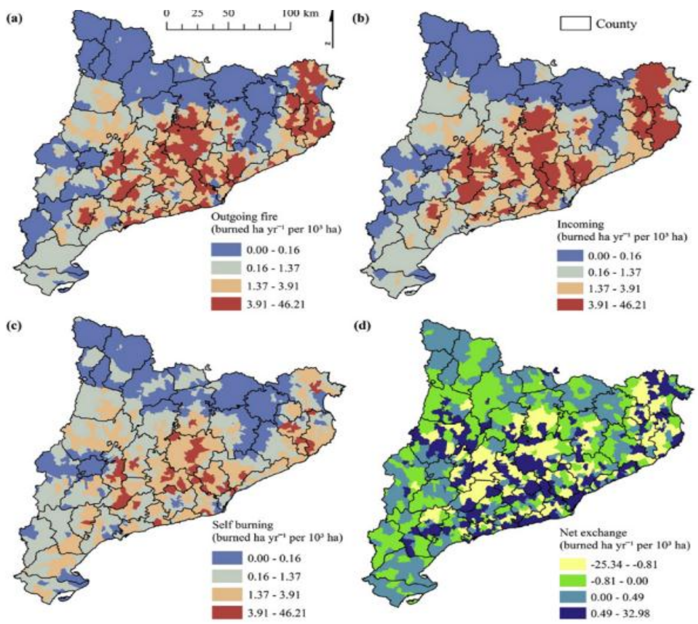

Figure 3. Fire exchange and transmission

Source: (Alcasena et al., 2019, 312)

Fire spread map for buildings and industrial sites:

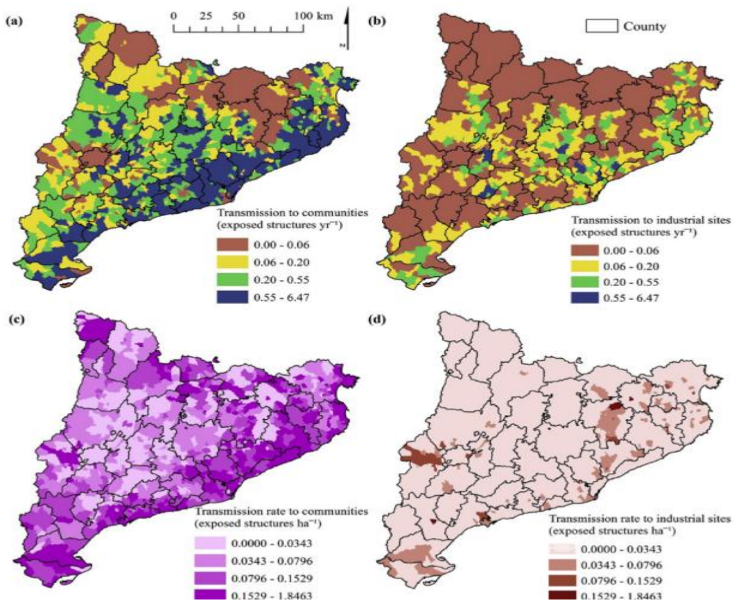

Figure 4. Fire transmission map for buildings and industrial sites

Source: (Alcasena et al., 2019, 313)

Extract maps based on the strategy:

The strategy used simulation modeling outputs to analyze wildfire risk in a series of key causal factors: (a) fire source municipalities, (b) significant fire exchange between municipalities, (c) wildfire risk in forests in dominant fire paths, and (d) overall exposure to densely developed communities.

After analyzing the previous maps, maps are extracted that are based on the four objectives of the wildfire management strategy in the study area. The results of these efforts are presented in a set of priority maps in order to transform the results into useful and direct results for implementing the wildfire management strategy.

The following mechanism was adopted in this study:

Historical fire data + fire spread modeling + asset value + land cover = priority maps.

3.Material & Methods:

In order to produce appropriate maps for fire management, a methodology was worked on, consisting of three elements as follows:

− Determinants:

Work is done within a basic determinant, which are the Sustainable Development Goals (SDGs) where the study takes into account:

Goal 3 Good health and well-being Target D: Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks.

Goal 13 Climate Action Target 1: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries

Target 2: Integrate climate change measures into national policies, strategies and planning.

Target 3: Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.

Goal 15 Life on Land Target 1: By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements.

Target 2: By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally.

Target 4: By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development.

Target 5: Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species.

- Basic stages:

To develop the treatment methodology, three main objectives were identified that contribute to improving the efficiency of fire management in nature reserves, identify opportunities to reduce the risk of forest fires, and describe the challenges facing forest fire management, which are managing ignition caused by human activities, managing vegetation cover, responding to forest fires effectively and efficiently, and protecting homes and communities at risk (Alcasena et al., 2019). These objectives are:

- Objective One: Create fire-resistant landscapes.
- Objective Two: Support safe and effective response when fires occur.
- Objective Three: Create human communities adapted to fires.

We extract executive programs that set spatial priorities that focus on achieving these objectives:

- Executive Program One: Fire prevention.
- Executive Program Two: Fuel Management.
- Executive Program Three: Response Planning.
- Executive Program Four: Community Engagement.

By achieving these objectives and their executive programs, forest fire management can be enhanced, which contributes to preserving the environment and ensuring its sustainability.

The implementation programs are linked to the basic evaluation criteria through data collection and analysis (as in Catalonia), and interviews with experts in forest fire management, in order to extract spatial priorities focused on achieving fire management objectives.

Figure 5. Linking executive programs with criteria –

Source: Prepared by the researcher based on theoretical literature

After deducing the criteria necessary for preparing fire management maps, we apply these criteria to the study area (the coastal region), and we have the following maps:

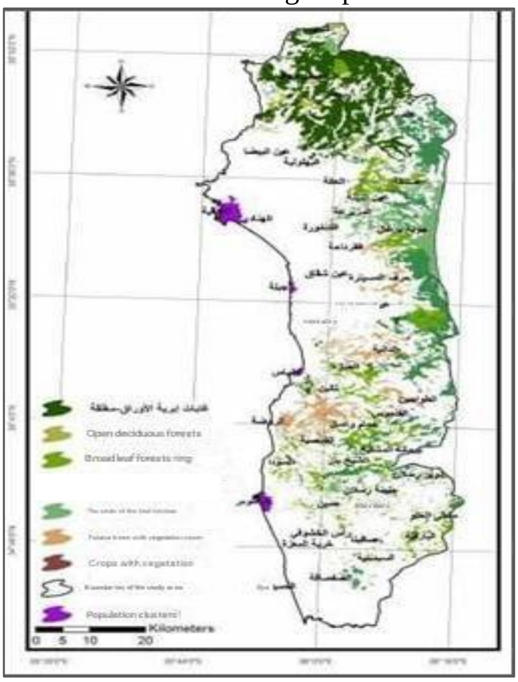

Figure 6. Coastal forest map

(Source: General Authority for Remote Sensing in Syria)

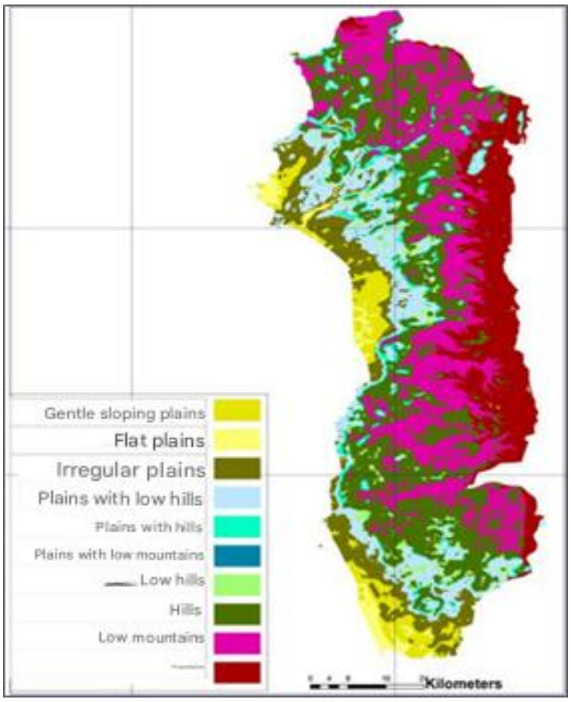

Figure 7. Map of landforms in regional coast

(Source: General Company for Engineering Studies in Syria)

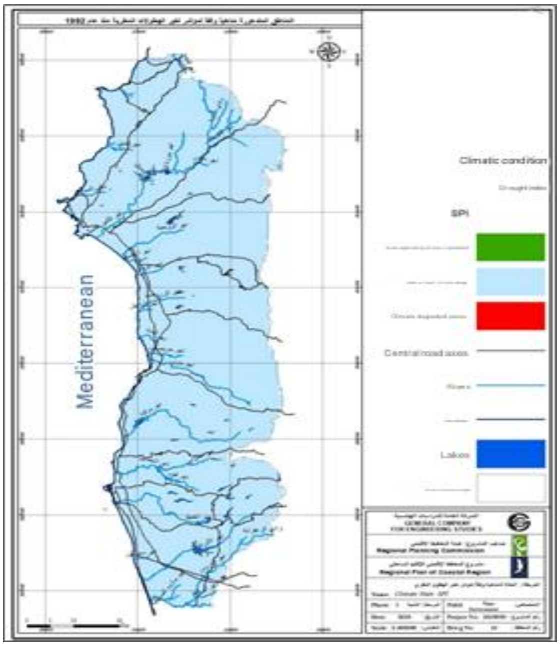

Figure 8. Climate map

(Source: General Company for Engineering Studies in Syria)

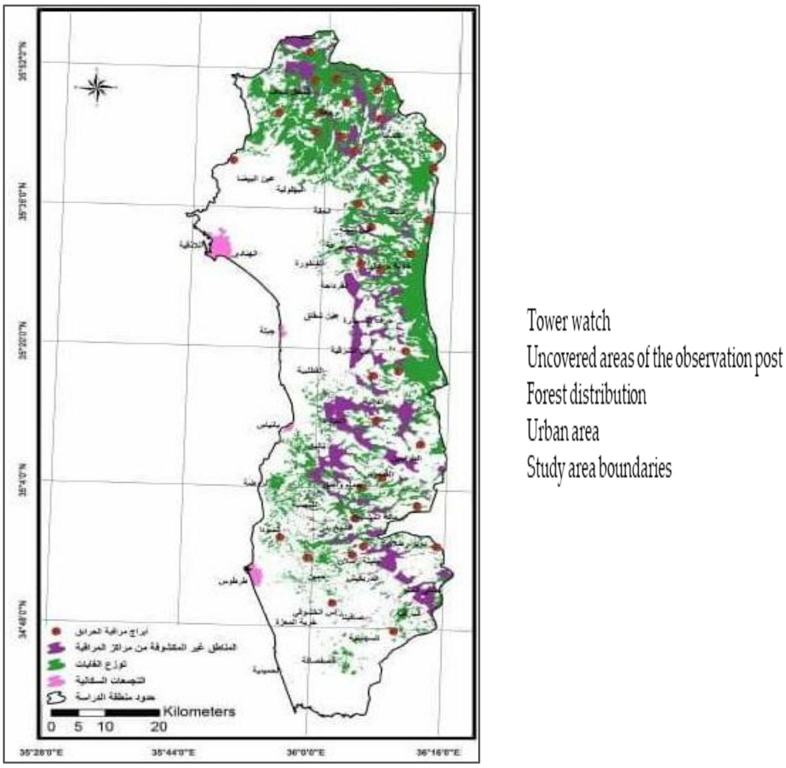

Figure 9. Map of the visibility range of forest fire observation towers
(Source: General Authority for Remote Sensing in Syria)

−**Tools:** Analytic Hierarchy Method (AHP).

Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method that enables the user to arrive at a range of preferences derived from a set of alternatives. Alternatives are determined based on the scale developed by Saaty in 1980, which includes the relationship between a set of criteria and a set of alternatives in a hierarchical form, as each criterion has a set of alternatives that can be compared pairwise with the other criterion, and these alternatives are measured on a special scale developed by Saaty, ranging from 1 to 9.

[illegible]	Degree of importance
Little importance	1
Medium importance	3
Great importance	5
Very great importance	7
Absolute importance	9
Interstitial degrees between provisions	Grades (2,4,6,8)

Table 1. Ordinal scale of importance using AHP method

Paired comparison matrix: It is a matrix for comparing each pair of criteria in terms of the importance scale. It is used to extrapolate weights and calculate the degree of stability of judgments (level of logic of weights).

Level of stability of judgments: Saaty set a consistency ratio of 0.1 (10%) as a criterion for judging the level of stability of judgments in the matrix. The less the consistency value is 0.1, the closer the judgments in the matrix are to stability.

4. Result & Discussion:

To use the APH decision tool, we link the criteria we have derived to wildfire management objectives. These objectives help prioritize and rank management options at the municipal level according to spatially explicit quantitative measures (figure 5).

After linking the executive programs to the criteria, the AHP decision support tool is used to weight these criteria, then enter them into the ArcGIS program to extract spatial maps, according to the following steps (figure 10):

- Defining the goal of each executive program.
- Preparing the criteria in the form of Raster Layers and re-standardizing them.
- Determining alternatives: Alternatives are determined based on the scale developed by Saaty in 1980 (table 1).

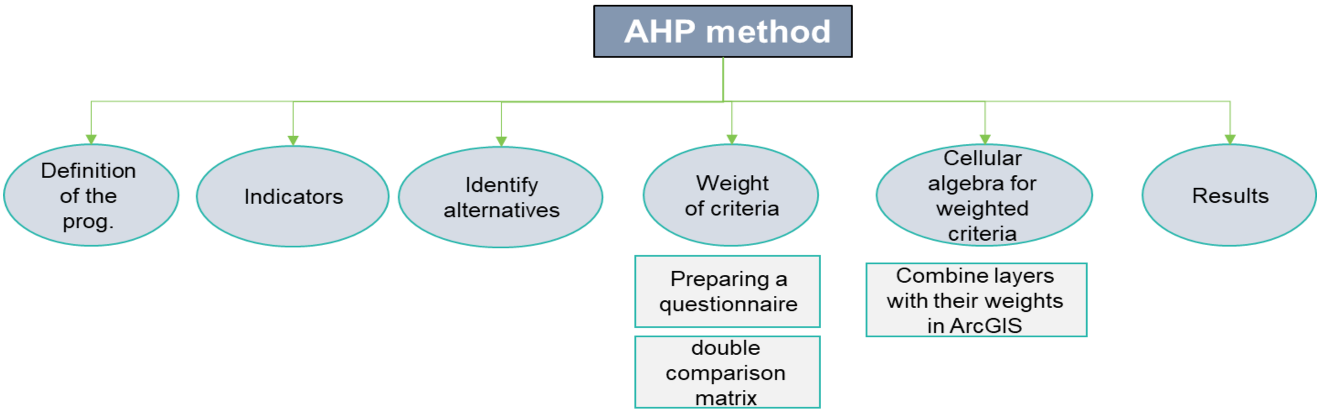

Figure 10. AHP decision support tool in ArcGIS

−Weighing the criteria: The criteria are weighed through the following stages:

•Preparing a questionnaire for a purposive sample: This questionnaire is intended for experts specialized in the research topic.

•Unpacking the questionnaire: After obtaining the questionnaire results, the following equation is applied:

The weighted average of the sample responses to the single criterion=

Sum (number of responses for each alternative x value of the alternative) / sample size.

•Correcting the weighted average value to an integer on the AHP scale.

•Building a pairwise comparison matrix: It is a matrix for comparing each pair of criteria in terms of the importance scale. It is used to extrapolate the weights and calculate the degree of stability of the judgments (level of logic of the weights).

•Calculating the level of stability of the judgments: Saaty set a consistency ratio of 0.1 to judge the level of stability of the judgments in the matrix. The less the consistency value is 0.1, the closer the judgments in the matrix are to stability and non-contradiction. However, when the consistency ratio crosses the value of 0.1, the judgments will be rejected and repeated again from the beginning at the questionnaire stage.

•One of the most important software that supports the construction of the pairwise comparison matrix is the AHP Online System platform. Through the platform, the level of consistency of judgments can be calculated, as the consistency value must be less than 0.1. (Al-Dahhak et Darwish, 2023)

−Algebra of cell layers for weighted criteria: collecting layers with their weights in the ArcGIS program.

−Extracting results: spatial priority maps for executive programs.

5.Discussion:

1. The AHP method provides a suitable mechanism for solving multi-criteria decision-making problems, as it helps in optimally employing spatial analyses in fire management.
2. Adopting a new weighting methodology and proving the validity of the weighting ratios assumed in the study based on the algorithm, where it was found that the consistency ratio is less than or equal to 0.1.
3. Determining the priorities of budget allocations in prevention and advance planning programs, where the forest monitoring platform can benefit from the results of the decision support tool.
4. This method is an added value in preparing regional studies, and the basic results of this study help stakeholders and forest managers who deal with policy making and strategic planning.
5. Contributing to strengthening community action programs aimed at preventing or mitigating forest fire disasters.
6. Working within and taking into account the determinants of the sustainable development goals.

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