"Optimising Plant-Based and Technological Measures to Reduce Wildfire Risk in Sulaymaniyah Mountains"

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ABSTRACT:

Mountain wildfires are an increasing concern in many parts of the world, including the rural mountainous areas surrounding Sulaymaniyah in Iraq's Kurdistan Region. A recent study shed light on the main causes of these fires, the associated risks, and strategies to mitigate them, with a focus on the local environmental and social context.

The researcher employed a combination of methods to gather data, including satellite imagery, field observations, interviews with community members and local officials, as well as a review of scientific literature and government documents. The findings revealed that both natural factors, such as drought, extreme heat, and lightning and human activities, including illegal land burning and lack of environmental awareness, contribute to the escalation of wildfires.

The study also highlighted that limited local firefighting capabilities and low levels of public awareness further increase the risk. Several practical measures were recommended, such as developing early warning systems, enhancing community participation through awareness campaigns, enforcing relevant policies more strictly, and promoting the planting of native fire-resistant vegetation in vulnerable areas.

In conclusion, while it is difficult to eliminate mountain wildfires, the study asserts that their frequency and impact can be significantly reduced through a combination of technology, community engagement, and strong local leadership. It further recommends segmenting target audiences based on cultural values and socioeconomic status, in alignment with effective community engagement models, to develop more tailored and impactful wildfire management strategies in Sulaymaniyah and similar regions.

Keywords: Mountain Fires, Sulaymaniyah, Fire Prevention, Wildfire Risk, GIS, Community Engagement, Climate Impact.

1. INTRODUCTION

Mountain fires, also known as wildfires or forest fires, are serious environmental problems that directly affect ecosystems, local populations, and various economic activities across different parts of the world. In recent years, there has been a significant increase in the frequency and intensity of these fires due to the interaction of human factors, ecological imbalances, and accelerating climate change. Rural and mountainous areas, especially in the Middle East, are particularly vulnerable to these fires because of dry climates, prolonged droughts, and poor management of natural resources and land.

The danger of these fires lies in their rapid spread, which threatens biodiversity and creates major challenges for local communities and the authorities responsible for managing them.

Despite the growing global interest in wildfire management, traditional and local practices such as cultural burning remain largely underutilised, despite extensive evidence demonstrating their effectiveness in enhancing ecological balance and increasing the resilience of natural systems to fires, as documented in regions like Australia and California. Utilising this inherited knowledge can contribute to sustainable, locally based solutions that complement modern interventions for wildfire prevention and response.

Consider the Sulaymaniyah Governorate within the Iraqi Kurdistan Region. Rich in biodiversity and with stunning mountains,

this area is known. But because of the dry summers, mountainous terrain, and rising human activity from farming and recreation, the mountains surrounding Sulaymaniyah City run a great risk of wildfires. Although these areas offer advantages including tourism, farming, and cultural legacy, the increasing mountain fires jeopardise all that. This scenario emphasises the urgent need of having efficient fire safety plans tailored to the particular requirements of the area.

Sadly, the way fires are now handled in Sulaymaniyah's mountainous periphery is not very successful. Most efforts are reactive and disjointed; thus, they are more about managing fires as they arise than they are about preventing them first of all. Previous fire events have revealed that our capacity to stop these fires, give early warnings, and increase community awareness suffers from major gaps. This study aims to address the critical issue of the lack of a localized and comprehensive strategy for managing mountain fires in the Sulaymaniyah region. It seeks to identify and analyze the main causes and patterns of mountain fires in the surrounding areas, evaluate the effectiveness of current fire prevention and response measures, and propose practical, evidence-based strategies for reducing the risks associated with these fires. The research employs a combination of field observations, interviews with local stakeholders, and Geographic Information Systems (GIS) analysis to achieve these objectives.

Focusing specifically on certain mountainous regions near Sulaymaniyah City as a case study, the study highlights broader challenges related to wildfires in the area. Its ultimate goal is to develop recommendations that are well-suited to the local institutional, social, and environmental contexts. A distinctive aspect of this study is the incorporation of traditional burning practices by actively engaging local knowledge holders and practitioners throughout both the planning and implementation stages. Additionally, the research explores innovative economic tools, such as parametric insurance and incentive

programs, to help sustain fire prevention efforts over time.

The study also emphasizes the importance of segmenting target audiences and designing culturally relevant awareness campaigns to effectively communicate fire prevention messages. It advocates for establishing collaborative governance frameworks that include local stakeholders as co-designers of prevention strategies, ensuring their meaningful participation. Ethical considerations are addressed by involving communities in decision-making processes, with interventions guided by local cultural values to enhance acceptance and long-term success.

Overall, this study plays a vital role in improving preparedness and response systems, promoting sustainable land and forest management, and fostering cooperation among government agencies, civil society, and local communities in the Sulaymaniyah region.

Environmental legislators and practitioners will find great value in the knowledge acquired by this research. This knowledge will help them to increase resilience and minimise the negative effects of mountain fires in Kurdistan and comparable areas. The problem is big, but we can make progress in safeguarding the environment and the communities that rely on it if we address the underlying causes and create a well-thought-out plan. Developing a safer and more proactive approach to managing our natural resources is more important than merely reacting to fires. If we wish to maintain the splendour and advantages of these mountainous areas for future generations, this is an essential step.

2. LITERATURE REVIEW

2.1. Global causes and impacts of mountain fires: Mountain fires are among the most significant natural threats facing countries worldwide, whether developed or developing. These fires often result from a combination of climatic factors such as prolonged droughts,

rising temperatures, and low humidity, alongside human activities like deforestation, burning agricultural waste, improper disposal of flammable materials, and urban expansion near forested areas.

While many wildfire management efforts rely heavily on technical and regulatory strategies, global studies clearly emphasise the importance of integrating local communities and stakeholders into these processes. Community involvement plays a crucial role in raising awareness, enhancing prevention, and enabling rapid response to fire incidents, making it an indispensable element of any successful fire management plan.

Moreover, engaging local populations empowers them to apply sustainable traditional practices—such as cultural burning—that have proven effective in reducing fire risks and preserving biodiversity. Collaboration between authorities and communities fosters the development of flexible solutions that can adapt to climate change and evolving environmental challenges. Therefore, community participation should be a fundamental component of every national and local strategy to combat mountain and forest fires.

2.2.. The damage caused by these fires is significant. They can wipe out vast forest areas, lead to soil erosion, release a lot of carbon into the atmosphere, and destroy homes for countless animals. Beyond the harm to the environment, mountain fires also have serious effects on people's lives and economies. They can force communities to evacuate, ruin infrastructure, and disrupt local businesses that depend on agriculture, forestry, or tourism. It's clear that addressing mountain fires requires understanding both the environmental and societal impacts they create (Xu&You, 2022).

2.3. Preventive Strategies in Similar Geographic and Climatic Areas: In regions with climates and terrains similar to those of Sulaymaniyah, such as parts of Southern Europe, the Mediterranean Basin, and arid areas of the Middle East, a variety of strategies have been implemented to prevent wildfires. Among the most common is controlled burning, which helps reduce excessive vegetation that could fuel fires. Firebreak construction is also critical, serving as a physical barrier to slow or stop the spread of flames. In addition, early detection and warning systems can alert communities before fires escalate. Public education and awareness campaigns about fire safety represent another vital component of wildfire prevention.

Moreover, modern technologies have significantly enhanced fire prevention approaches. Tools such as satellite monitoring and risk mapping using Geographic Information Systems (GIS) have improved the ability to predict wildfire threats and respond effectively. Experts also emphasize the importance of community engagement in fire risk management. When local populations are trained and actively involved, solutions tend to be more effective, context-specific, and sustainable.

However, while the literature presents a broad range of global practices, it often lacks a coherent synthesis of how these strategies interact or could be integrated into unified, field-applicable frameworks. There is a pressing need to consolidate successful experiences into adaptable and holistic approaches that consider local environmental, institutional, and social dynamics—ultimately enabling the development of more effective and resilient wildfire prevention systems (Gachelin et al., 2018).

2.4. Concepts and strategies for mountain fire prevention: global causes and impacts. A major environmental problem is mountain fires, especially in hilly or mountainous areas. These wildfires have the potential to endanger residents, wildlife, and

economic resources. The difficult terrain and erratic weather patterns make it difficult to control these fires. According to recent studies, wildfire incidents have increased globally, primarily as a result of changes in land use and climate change. (Flannigan et al., 2009).

These fires can start from natural events, like lightning or extreme weather, as well as from human activities such as careless burning, clearing land for farming, or other accidental fires. The impact on the environment is significant; we see a loss of biodiversity, worsening air quality due to smoke, and soil erosion, which can harm ecosystems for years to come (Keeley, 2017; Liu et al., 2015). From an economic perspective, mountain fires put a heavy financial burden on those managing natural resources and those tasked with fighting the fires. On a community level, these fires can displace people from their homes, lead to health risks, and cause damage to important infrastructure (Turner et al., 2019).

Mountains have certain ecological characteristics that affect how fires behave. They often host a variety of plant species, some of which are fire-adapted, meaning they've evolved to thrive in environments prone to fire. However, some of these plants also produce flammable substances that can make fires more intense. The steep slopes found in mountainous areas can cause fires to spread quickly, especially since heat rises and winds can carry flames along, especially during dry seasons (Bowman & Perry, 2018). Weather conditions also play a crucial role. Long periods of drought, increased temperatures, and low humidity make it easier for fires to ignite and spread quickly. Strong winds can further accelerate the rate at which fires expand, making them even harder to manage (Gill, Stephens, & Cary, 2013). Tackling mountain fires requires understanding their causes and effects,

from environmental damage to economic challenges, to develop effective prevention strategies (Bradstock, 2010). We must work together to protect these precious ecosystems and the communities that depend on them (Krawchuk et al., 2009).

On a global scale, the frequency and intensity of mountain wildfires have been increasing, driven primarily by warming climates and altered precipitation patterns (Flannigan et al., 2009; Westerling, 2016). Studies from Mediterranean regions, western North America, and parts of Asia report notable increases in wildfire incidents and severity correlating with these climatic trends (Moritz et al., 2013; Abatzoglou & Williams, 2016). In the Kurdistan region, particularly near Sulaymaniyah's mountainous periphery, recurrent wildfires have escalated due to a combination of climatic variability and intensified human activities such as livestock grazing and uncontrolled burning of agricultural lands (Ahmed&Hassan, 2020; Kurdistan Regional Government, 2022).

2.5. Integrated Strategies for Wildfire Prevention and Management in Mountainous Regions: To really tackle wildfire prevention in mountainous areas, we need a well-rounded plan. This means combining good environmental practices, getting the community involved, using new technologies, and having strong policies in place. Research shows that when these strategies work together, they can greatly lower the chances of wildfires and lessen their impact, especially in places like the mountain ranges near Sulaymaniyah City.

- Fuel Management and Firebreaks: One of the fundamental strategies is the reduction of fuel loads through the creation of firebreaks, vegetation-cleared strips along ridges and valleys that limit fire spread (Finney, 2001; Agee, 1993). Prescribed

burns and mechanical thinning are also critical techniques used to decrease fuel accumulation (Fernandes&Botelho, 2003; Stephens et al., 2012). In steep and rugged terrain, these measures should be adapted to the slope and vegetation types for greater effectiveness (Keeley et al., 2009).

- Reforestation with Fire-Resistant Species: Reforestation in degraded or previously burned areas using native, fire-resistant species helps restore ecological balance and reduce flammable biomass. Species with thick bark or high moisture content can act as natural fire barriers (Bond & Keeley, 2005; Pausas & Fernández-Muñoz, 2012; Keeley, 2009).

- Early Warning Systems and Remote Sensing: The integration of Geographic Information Systems (GIS), satellite remote sensing, and fire danger rating systems has revolutionised fire monitoring and response efforts (Chuvieco et al., 2010; Dennison et al., 2014). These technologies allow for real-time risk assessment and rapid detection, especially in remote and inaccessible mountainous zones (Kumar et al., 2019). Predictive indices further support the strategic allocation of firefighting resources (Jolly et al., 2015).

- Community Education and Participation: Educating local communities about fire risks and prevention techniques is essential to reduce human-caused ignitions and foster preparedness (Xanthopoulos, 2006; McCaffrey, 2004). Community-based patrols, participatory management, and training programs build resilience and local capacity (Steelman&Burke, 2007; Gadgil et al., 1993; Malamud et al., 2018).

- Infrastructure and Accessibility: Improving access roads, water infrastructure, and firefighting logistics enhances the capacity for rapid response in case of an outbreak (Coppoletta et al., 2016; Penman et al., 2011). Strategically

placed lookout towers and monitoring stations increase situational awareness and response coordination (Graham et al., 2004).

- Legal and Regulatory Frameworks: Effective wildfire prevention requires the enforcement of laws against illegal burning and negligent practices (Moritz et al., 2014; Steelman&Burke, 2007). Clear regulations, supported by penalties and incentive-based policies, encourage responsible land stewardship (Keeley&Zedler, 2009; Calkin et al., 2015).

- Use of Modelling and Technology: Advancements in fire behavior modelling, risk assessment tools, and integration of real-time weather data improve forecasting and preventive planning (Dennison et al., 2007; Ruffault & Mouillot, 2015; Vega-Garcia et al., 2018).

- Socioeconomic Incentives: Financial and technical support programs for landowners can encourage fuel reduction and safer land management practices. Community-based incentives also promote collective action and engagement (Finney et al., 2011; Chapin et al., 2003).

- Ecosystem Restoration and Landscape Management: Restoring natural fire regimes through adaptive management helps maintain ecological integrity and minimize fire risks. Mosaic landscapes with varied vegetation structures interrupt fire pathways and enhance resistance (Pausas, 2015; Gill et al., 2013).

- Cross-Agency Coordination and Governance: Coordinated efforts between national, regional, and local authorities are vital for comprehensive wildfire strategy and emergency response. Multi-stakeholder platforms facilitate knowledge exchange and shared responsibilities (Steelman&Burke, 2007; Al-Mufti et al., 2019).

- Cultural and Behavioral Change: Understanding and addressing the social

and cultural drivers of fire use can improve prevention efforts. Tailoring awareness campaigns to local values increases community acceptance and engagement (Syphard et al., 2012; Moritz et al., 2014).

- Fire-Adapted Communities: Developing fire-resistant infrastructure, buffer zones, and evacuation plans within communities reduces vulnerability to fire hazards. Integrating fire prevention into local land-use planning enhances resilience (Coppoletta et al., 2016; Moritz et al., 2014).

- International Best Practices: Integrated fire management systems that combine prevention, suppression, and recovery have proven effective in Mediterranean and Australian mountain regions, offering valuable insights for similar terrains (Moreira et al., 2011; Keeley et al., 2009).

- Climate Adaptation Strategies: Long-term planning must incorporate climate adaptation by linking fire risk reduction to water resource management, forestry practices, and biodiversity conservation (Flannigan et al., 2013; Bowman et al., 2009).

- Research and Capacity Building: Ongoing research in fire ecology, technological innovation, and the social dynamics of fire is essential. Training and capacity building in fire science support sustainable prevention and management (Moritz et al., 2014; Chuvieco et al., 2010).

2.6. Structural design phase: Concentrate on developing the necessary frameworks to successfully prevent fires in mountainous regions during the structural design phase. Considering the distinct topography and ecology of the mountains close to Sulaymaniyah, this entails designing firebreaks, constructing access roads, establishing monitoring stations, and constructing community fire shelters.

Carefully mapping firebreaks—cleared areas intended to prevent fires from spreading is a significant portion of our work. When designing these barriers, we take into account things like vegetation types, wind patterns, and slopes. Our access routes facilitate firefighting teams' rapid arrival at their destination, which is essential for a prompt emergency response. To make sure we're closely monitoring any fire threats, we also consider the locations of watchtowers and monitoring stations. In order to facilitate coordination in the event of a fire, we concentrate on organising local volunteer organisations and firefighting units and clearly outlining their responsibilities and communication channels. We're also examining how contemporary technologies, such as remote sensing and GIS, can improve our monitoring capabilities. In general, this phase seeks to create a robust, encouraging framework that integrates technology, community engagement, and infrastructure, especially tailored to the difficulties presented by the Sulaymaniyah mountains (Nenadović & Milošević, 2022).

2.7. Planting design phase: The planting design phase is really important for managing wildfire risks and restoring the natural environment in the hilly areas around Sulaymaniyah. This phase focuses on carefully choosing where and what types of plants will go into these spaces to create a landscape that can withstand fires while also supporting local wildlife and keeping the soil stable. In this process, priority is given to native plants that can handle the local climate well and are less likely to catch fire quickly. These include plants that have high moisture content, produce little resin, and aren't prone to burning fast. The layouts for planting are thoughtfully designed to create green buffer zones in more vulnerable areas, like those close to homes, access roads,

and places that have burned before. Spacing between groups of plants is also intentionally planned. This helps avoid creating long paths of fuel that could let fires spread easily, whether horizontally or vertically. Overall, this careful approach aims to both protect the community from wildfires and ensure a healthier ecosystem for the future (Monroe et al., 2023).
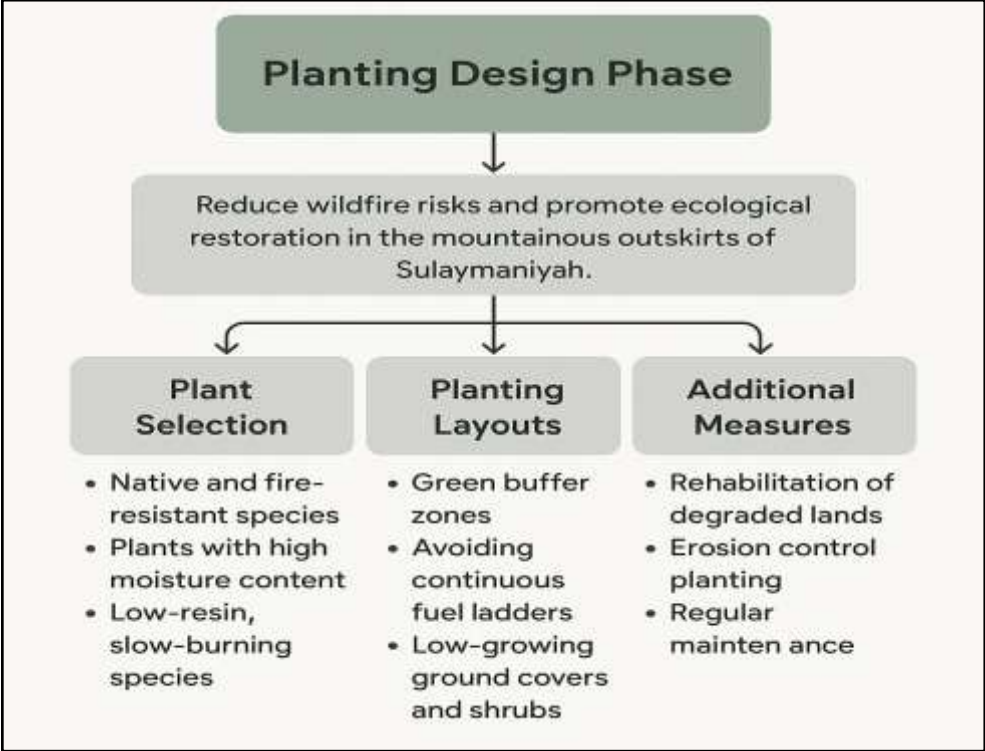

Diagram 1. Planting Design Phase for Fire-Resilient Landscapes in Mountainous Areas.

The table (1) outlines five key equations used in the planting design phase to reduce wildfire risk. First, $D = H/2$ is used to determine the spacing between shrubs, as reducing closeness reduces fire spread. Second, the flammability index (FI) is calculated using oil content, dry mass, and moisture; the lower it is, the safer the plants. Third, the width of the buffer zone is calculated based on the slope of the land using the equation $W = 10 + 0.5 \times S$; the greater the slope, the greater the required buffer width. Fourth, vegetation density in high-risk areas should be reduced to less than 1,000 trees per hectare to minimise fuel consumption. Finally, the fire spread index (FSI) is used to assess how quickly a fire will spread. It is based on fuel weight, wind speed, and the distribution factor; a value below 5 indicates low risk. These equations aim to create a fire-resistant and environmentally safe agricultural environment (Keane&Dickinson, 2022).

Table (1) Main Formulas for Vegetation Management and Fire Risk Reduction

Application Example	Equation	Element
If shrub height = 2 meters → spacing = 1 meter	$D = H / 2$	Spacing between shrubs
If oil = 10%, dry mass = 50 kg, moisture = 40% → FI = 1.5	$FI = (O + D) / M$	Plant Flammability Index
If slope = 20° → buffer width = 20 meters	$W = 10 + 0.5 \times S$	Green buffer zone width
Reduce from 3000 to less than 1000 trees per hectare in high-risk areas	<1000 trees/hectare	Target vegetation density
If W = 1.2, wind speed (V) = 5 m/s, fuel factor (F) = 0.8 → FSI = 4.8 (low fire risk)	$FSI = W \times V \times F$	Fire Spread Index (FSI)

Also plant fire-resistant shrubs and low-growing ground covers in buffer zone areas we've created that act to retard the spread of wildfires. This is designed to bring down the buildup of dry, flammable materials that may ignite. We can cut the spread of fire by throwing up these green barriers and saving woodlands and important buildings. To ensure these zones work well, it's important to select species that retain moisture and are less likely to ignite. We also spread plants surrounded by any continuous column of fuel that could carry a fire at top speed. Other than just planting new vegetation, restoring land that has been degraded by actions such as deforestation, poor land use, or overgrazing is a component of this mission. We prefer to replant these areas with native trees that are less vulnerable to fire. These trees have the capability of restoring critical environmental services, from moderating temperatures and providing habitat for local wildlife, to sequestering carbon from the atmosphere. We plant not just trees, but deep-rooted grasses that keep the ground moist, diminishing erosion and runoff. In order to restore the landscape and lower the likelihood of future wildfires, these actions are essential. An important aspect of this process is managing and preserving the vegetation. We do plan for the kind of maintenance that needs to take place (some of it is simply cutting back the overgrowth.) So that when there are fires, the area won't catch fire as easily or burn as quickly, AND the fires themselves, when they come, won't have tons of fuel to eat up. In order to make the best use of our resources, all of these activities are guided by local weather patterns and seasons. The planting design process follows the method, asking us to design for landscapes that are resilient, wisely structured, and ecologically and fire fire-appropriate. In leaning into fire safety, we're also increasing recreational opportunities, increasing the overall health and functionality of the ecosystem, and enhancing the beauty and quality of the landscape. Aside from the diminished risk of conflagration, a reasoned and maintained vegetative design fosters a sustainable and long-term love between humans and nature (Jenkins et al., 2019).
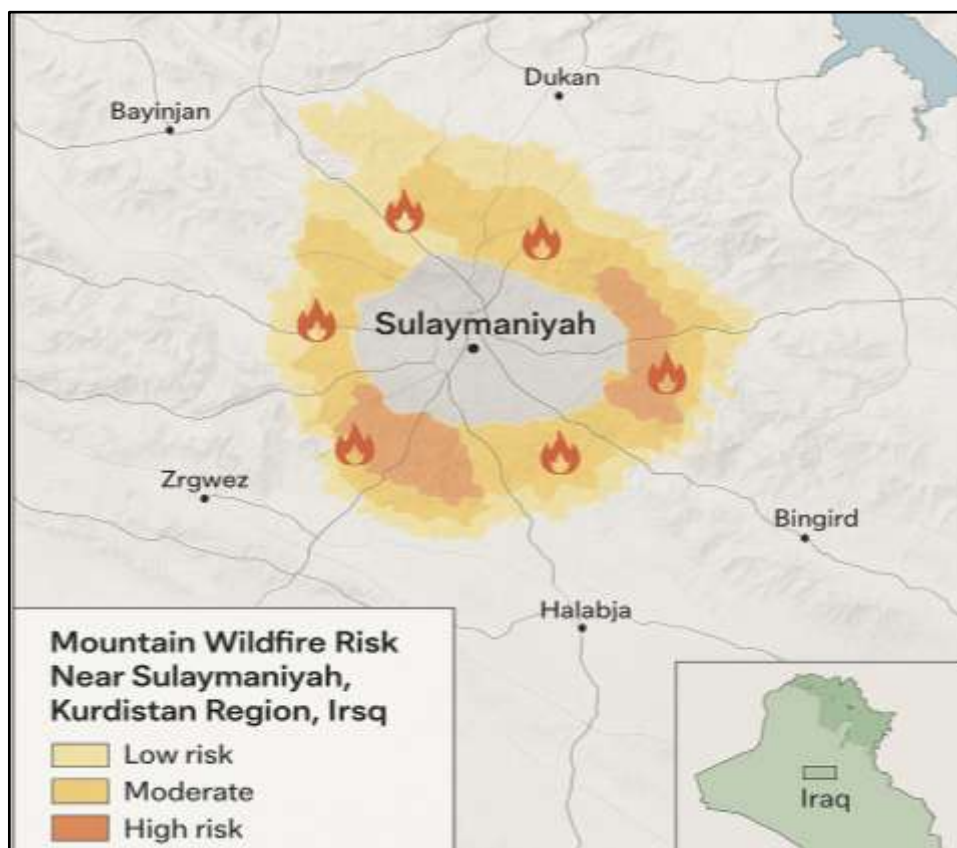
Maps 1. Mountain Wildfire Risk Zones in the Outlying Areas of Sulaymaniyah, Kurdistan Region, Iraq.

3. STUDY AREA DESCRIPTION:

3.1. Geographic and Ecological Overview of the Outlying Mountains of Sulaymaniyah: The Zagros Mountain range, which stretches from northeastern Iraq into western Iran, includes the mountains surrounding Sulaymaniyah. Their terrain is rugged, with steep peaks and gentle foothills, as well as high slopes. Grasslands, shrublands, and oak forests are among the various natural habitats found in the region. Numerous plant and animal species, some of which are rare or endangered, are supported by this variety. However, these mountains are also susceptible to wildfires, especially during dry seasons, due to their dense vegetation and the difficulty of accessing remote areas. This ecosystem is stunning yet challenging, and it poses some serious dangers. (Forti et al., 2021).

3.2. Climate Characteristics and Seasonal Risks: Sulaymaniyah lies within a semi-arid to Mediterranean climate zone, characterised by extremely hot and dry summers—often exceeding 40°C—and relatively cold, wet winters. Most rainfall occurs between November and April, leaving the months from June to September particularly dry and prone to low humidity levels (Rashid, 2024). These climatic conditions, combined with strong winds and widespread vegetation dryness, significantly increase the risk of mountain fires during summer. Studies also note a growing frequency and severity of droughts in recent years, further intensifying the fire threat in the region (Daham et al., 2018).

Beyond fire risk, these environmental conditions directly affect plant growth cycles and influence the selection of vegetation for restoration and fire prevention strategies. Poor species selection, especially those not adapted to

drought or that are highly flammable, can unintentionally increase fire hazards and hinder ecosystem recovery. Therefore, it is crucial to prioritise native, drought and fire-resistant plant species that can withstand local conditions and contribute to long-term sustainability.

Recommended species for the Sulaymaniyah region include:

- Quercus aegilops (local oak), known for its deep roots and high drought tolerance.
- Juniperus oxycedrus (juniper), a resilient tree adapted to dry, mountainous environments.
- Ziziphus spina-christi (Christ's thorn jujube), which tolerates extreme heat and is less flammable.
- Aromatic herbs like Thymus spp. (wild thyme) and Salvia officinalis (sage), which are well-suited to arid soils and help reduce erosion. Integrating these species into land and forest management plans enhances vegetation sustainability, reduces fire risk, and supports faster ecosystem recovery after disturbances. Any fire prevention or rehabilitation approach should therefore align with the region's evolving climate conditions and ecological realities (Daham et al., 2018).

3.3. Socioeconomic and Land-Use Profile: The mountains around Sulaymaniyah are home to several rural communities that mainly rely on agriculture, raising livestock, and some seasonal tourism to make a living. The land here is a mix of fields, orchards, grazing areas, and natural forests. Recently, though, more people moving to the area and unchecked tourism have put a lot of strain on these lands. People often burn leftover crops and graze animals too much, which harms the vegetation and raises the risk of fires. On top of that, there's not enough infrastructure or proper fire response systems in place, and many locals aren't very aware of environmental issues. All of these factors make it hard to manage the land sustainably and keep fires under control. It's a tough situation that needs attention for the well-being of the communities and the environment (Eklund et al., 2017).

3.4. Documented Wildfire Incidents in Sulaymaniyah Region: Real documented incidents involving mountain and large-area fires in the Sulaymaniyah region (Kurdistan), complete with key details and sources:

- Mount Goizha Wildfire (July 29, 2024): A major wildfire erupted around 3 AM on Sulaymaniyah's iconic Mount Goizha, spreading rapidly due to strong winds and burning approximately 200 dunams (~49 acres) of vegetation—including pine and other tree species. Civil Defense teams worked for several hours to extinguish the fire. Authorities are still investigating the cause (Civil Defense Directorate 2024)
- Sharazoor Plain Livestock Fire (June 9, 2024): A fire that began as a controlled shrub burn by farmers quickly grew out of control in the Sharazoor Plain (Hasil village), fueled by strong winds. The blaze killed roughly 300 livestock (sheep, goats, cattle) and spread across multiple villages before emergency teams subdued it (Ministry of Agriculture and Water Resources, 2024)
- Hawari Shar Park Lightning Fire (June 11, 2024): A lightning strike ignited vegetation in Hawari Shar Park's botanical garden, damaging about 12.3 acres of trees (oak, terebinth, hawthorn, Prunus microcarpa). Park authorities quickly quelled the fire using Civil Defence support. This incident underscored the natural ignition risks even in managed urban forest areas (Kurdistan Environment Board, 2024).
- Awagird Mountains Fire with Minefield Challenges (April 2025): A significant wildfire raged for over 24 hours in the Awagird Mountains (near

Erbil/Sulaymaniyah), sweeping through several villages. Firefighting efforts were severely hampered by the presence of landmines from past conflicts, making terrain inaccessible and dangerous.

- Galala & Sharbazher Wildfire (August 20, 2024): Suspected Turkish military airstrikes in the Galala and Qamish mountainous villages triggered a large wildfire in the Barzoot and Birani areas. Residents were urgently called to assist in firefighting efforts due to the terrain's difficulty and speed of the blaze (General Directorate of Meteorology and Seismology 2024)

While the study offers a comprehensive framework for wildfire prevention strategies in the Sulaymaniyah region particularly emphasising fire-adapted agricultural design and the use of predictive equations to reduce fire risk, there remains a clear need to adapt these models more closely to the local context. The successful implementation of such strategies depends on their alignment with the region's specific climatic and environmental conditions, including rainfall patterns, drought frequency, vegetation types, and soil characteristics.

Furthermore, the long-term sustainability and effectiveness of these prevention strategies are closely tied to the active involvement of local communities. Integrating indigenous knowledge, traditional land practices, and lived experiences can significantly enhance the practicality and cultural relevance of proposed solutions. Community members often possess nuanced insights into seasonal fire behaviours, resilient plant species, and historical mitigation approaches that can complement scientific methods.

Therefore, the study recommends extending the application of the proposed equations and strategies by incorporating localised environmental variables and promoting community co-participation in planning and implementation. This integrated approach not only ensures greater ecological accuracy but also builds trust and ownership among stakeholders, key elements for achieving resilient and sustainable wildfire prevention systems.

Table (2) Locations of documented mountain fires in the Sulaymaniyah region (2024-2025)

Date	Location	Cause/Trigger	Impact
29-Jul-24	Mount Goizha	Unknown (suspected negligence)	~49 acres burned
9-Jun-24	Sharazoor Plain	Human-caused (shrub burning + wind)	~300 livestock lost
11-Jun-24	Hawari Shar Park	Lightning strike	12.3 acres of the botanical garden were damaged
Apr-25	Awagird Mountains	Unknown; terrain with landmines	Fire lasted 24+ hours, hampered suppression
20-Aug-24	Galala & Sharbazher	Suspected airstrike-related ignition	Large wildfire; required local support
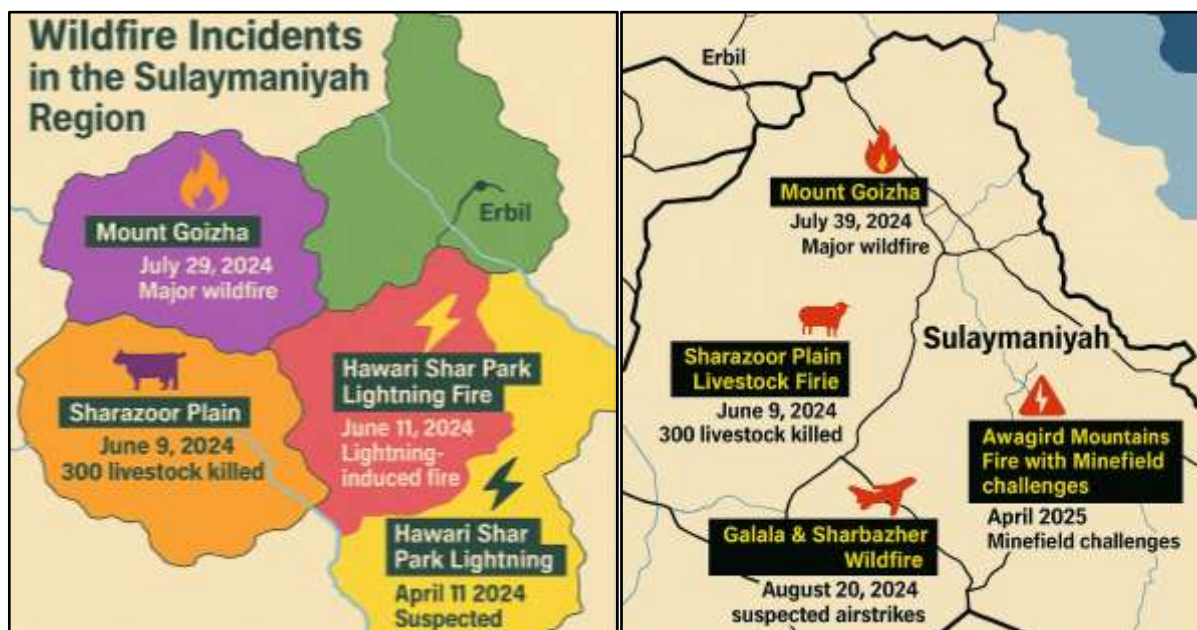
Maps 2&3. Wildfire Incidents by Region: Sulaymaniyah and Surrounding Areas (2024–2025)

These incidents in Sulaymaniyah and its surroundings highlight the dual nature of fire sources involving both natural elements (lightning, wind) and human-related causes (negligence, military activity) as well as the geological and infrastructural challenges that complicate firefighting efforts (e.g. rugged terrain, minefields). These real events provide valuable context and empirical grounding to inform prevention strategies tailored to the region.

4. METHODOLOGY

4.1. Research Design: This study adopts a case study research design focused on the mountainous outskirts of Sulaymaniyah, Kurdistan Region, Iraq. The approach is both qualitative and spatial, aiming to explore the causes of wildfires, assess current risk levels, and propose prevention strategies through environmental analysis and community-based evaluation. The research integrates landscape design principles, ecological planning, and fire risk mapping.

4.2. Data Sources and Sampling: Primary data were collected through field observations, structured interviews with residents, environmental officers, and firefighting personnel, as well as GPS-based site surveys. Secondary data was obtained from the Kurdistan Environmental Protection Agency (KEPA) reports, satellite imagery, and previous academic studies. Sampling focused on five fire-prone mountain sites around Sulaymaniyah, selected based on fire incident records from the last ten years.

4.3. Analytical Tools and Techniques: The study utilised GIS (Geographic Information Systems) and remote sensing tools to map fire-prone areas, analyse vegetation patterns, and assess terrain slope and accessibility. SWOT analysis was applied to identify strengths, weaknesses, opportunities, and threats in current prevention practices. Descriptive statistics were used to summarise survey responses, while spatial overlays were used to identify strategic firebreak zones and optimal planting zones.

4.4. Limitations: Some limitations affected the scope of this study. Access to remote or

steep mountainous areas was restricted due to safety and logistical constraints. In addition, limited historical fire data and incomplete vegetation records presented challenges in building a comprehensive long-term fire risk model. Seasonal

variations and unforeseen weather conditions may have also influenced field data accuracy. Despite these limitations, the study provides a valuable foundation for future fire prevention planning in the region.
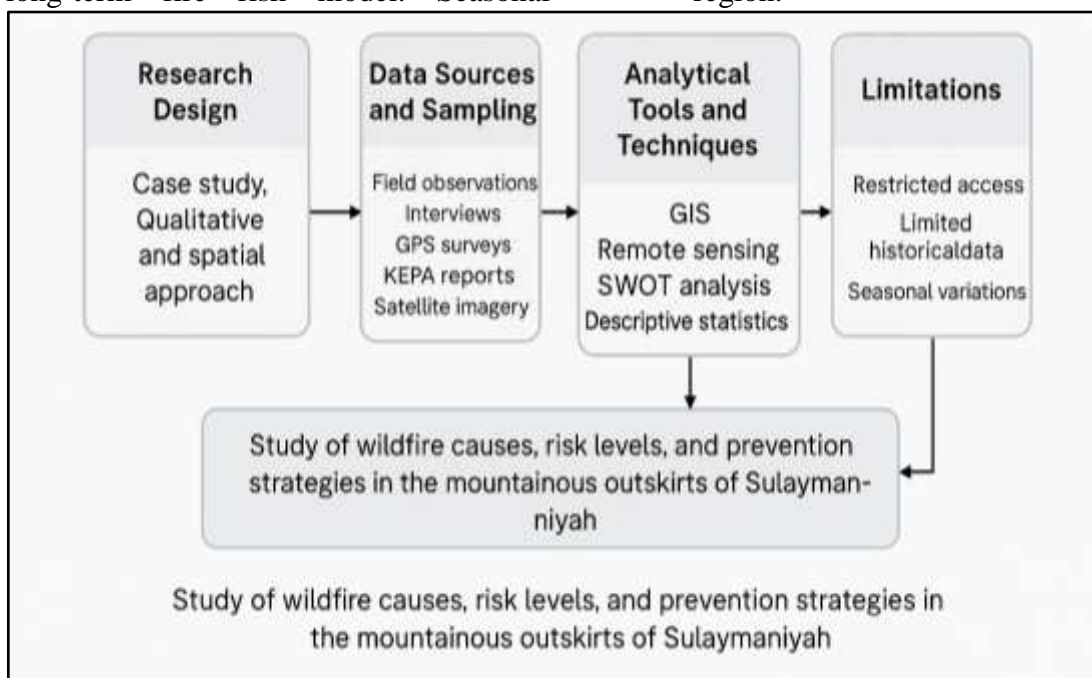
Diagrams 2. Integrated Methodology for Mountain Wildfire Prevention Research

5. CAUSES AND RISK FACTORS

5.1. Natural Causes: Natural factors play a significant role in the ignition and spread of mountain fires, including:

- Drought: Prolonged periods of low rainfall led to dry vegetation, increasing its flammability and facilitating rapid fire spread.
- Heatwaves: Extended high temperatures raise the likelihood of fires by drying out soils and plants, making conditions more prone to ignition.
- Lightning: Lightning strikes, especially during dry thunderstorms, are a common natural ignition source for wildfires in mountainous areas (Matin et al., 2017).

5.2. Human-Induced Causes: Human activities significantly contribute to the occurrence of mountain fires, such as:

- Agricultural Practices: Burning of crop residues or clearing land by fire without proper controls raises the risk of uncontrolled wildfires.
- Negligence: Careless actions like improperly extinguished campfires, discarded cigarette butts, and unmanaged recreational fires (Lovreglio et al., 2010).
- Arson: Deliberate ignition of fires, often motivated by vandalism, conflict, or other malicious intents.

5.3. Assessment of Risk Levels in Different Zones: Risk assessment separates the mountainous regions surrounding Sulaymaniyah into zones according to different fire risk levels that are established by variables like vegetation density, distance from populated areas, land use patterns, and data on previous fire incidents. High-risk areas are those

with arid climates and thick, dry vegetation.

There is a higher risk of fire in areas with a lot of agricultural activity or frequent human carelessness. Because of the possible risks to lives and property, areas close to urban or rural communities need extra attention. (Moazzeni et al., 2020).

6. CURRENT RESPONSE AND MANAGEMENT PRACTICES

6.1. Local Government Policies and Enforcement: To lessen the frequency and effects of mountain fires, the Sulaymaniyah local government has created a number of policies. These include land use rules, prohibitions on open burning during high-risk times of the year, and sanctions for carelessness or deliberate fire starting. However, because of scarce resources, difficult terrain, and the dispersed nature of rural populations, enforcement is still uneven. Although coordination between forestry departments, civil defence, and environmental agencies is getting better, it still needs to be strengthened to guarantee prompt and efficient responses (M. Harry et al., 2021).

6.2. Community Involvement and Awareness: In order to prevent and manage fires, community involvement is essential. To inform locals about fire hazards, safe farming methods, and emergency protocols, several awareness campaigns have been held. To equip communities with the information and resources they need for early detection and initial response, local NGOs and environmental groups host training sessions. Notwithstanding these initiatives, difficulties still exist because of disparities in literacy, cultural fire-related customs, and inadequate communication systems in isolated mountain communities (Makarabhirom et al., 2004).

6.3. Firefighting Resources and Early Warning Systems: Several volunteer brigades and a few professional fire units with basic firefighting equipment and vehicles make up the firefighting infrastructure in Sulaymaniyah's mountainous outskirts. However, insufficient equipment and accessibility problems make it difficult to effectively suppress large or quickly spreading fires. Authorities have started combining satellite monitoring, local reporting networks, and Geographic Information Systems (GIS) to enhance early detection and quickly spot fire outbreaks. Although they are still in their infancy, early warning systems and fire danger rating models have the potential to improve readiness and response times (Rahimi et al., 2019).

7. PROPOSED STRATEGIES FOR FIRE PREVENTION

7.1. Short-term and Long-term Strategies: Establishing firebreaks, stepping up patrols during high-risk times, and strengthening rapid response teams are examples of short-term strategies that concentrate on immediate actions. The goal of these initiatives is to lessen the likelihood of an ignition and put out any fires as soon as they start. Reforestation with fire-resistant species, sustainable land management, and urban planning that reduces fire hazards close to communities are all examples of long-term strategies. Both strategies necessitate ongoing assessment and modification in response to environmental shifts and monitoring findings.

7.2. Policy Recommendations: Policies should include incentives for landowners to adopt fire-safe practices, clear guidelines for controlled burns, and tougher enforcement of current regulations in order to improve fire prevention. Creating specialised wildfire management units and improving interagency coordination are also crucial.

To guarantee thorough risk reduction, policymakers should incorporate fire risk considerations into larger environmental and development planning frameworks.

7.3. Technological and Community-Based Approaches: Fire detection and monitoring capabilities can be significantly increased by implementing cutting-edge technologies like Geographic Information Systems (GIS), remote sensing, and early warning fire danger rating systems. By providing training and allowing them to participate in decision-making, community-based fire management also empowers locals. This strategy guarantees culturally relevant preventative measures and promotes stewardship of local resources.

7.4. Education and Awareness Campaigns: Reducing fires caused by humans requires ongoing education and awareness campaigns. To encourage safe practices and draw attention to the negative ecological and economic effects of wildfires, campaigns should target farmers, schools, and tourists. The impact and reach of messages can be increased by utilising local leaders, community workshops, and media platforms. To maximise effectiveness, awareness campaigns must be customised to the Sulaymaniyah region's linguistic and cultural context (Carreiras et al., 2014).

8. CASE COMPARISONS:

Several countries and regions have developed effective fire prevention strategies that can offer valuable lessons for Sulaymaniyah's mountainous outskirts:

8.1. California, USA: uses a combination of advanced technology, community engagement, and strict land-use policies. The state employs satellite-based fire detection systems, mandates defensible space around properties, and conducts regular controlled burns to manage fuel loads. Public education campaigns and fire preparedness drills are routine (Syphard et al., 2014)

8.2. Australia: The "FireWise" program focuses heavily on community participation and awareness. Residents are trained to prepare their homes and surroundings, while emergency services use predictive fire modelling and coordinated evacuation plans. Controlled burning and vegetation management are critical components.

8.3. Spain (Catalonia): employs integrated fire management combining GIS mapping, early warning systems, and rapid response teams. Strict regulations on agricultural burning and urban development in fire-prone zones help reduce fire risks. Collaboration between the government, local communities, and NGOs enhances prevention and recovery efforts. These examples demonstrate that a mix of technological tools, robust policies, and active community involvement is key to effective mountain fire prevention (McLennan & Handmer, 2012).

9. DISCUSSION AND CONCLUSION:

This study has provided a focused analysis of the rising threat posed by mountain fires in Sulaymaniyah's peripheral highlands. Through examining the geographic, climatic, and human dimensions of the problem, it became evident that the region's vulnerability is shaped by a combination of natural factors such as prolonged drought, increasing heatwaves, and lightning and human-induced causes, including unsupervised agricultural burning, negligence, and encroachment into forested areas. The findings underscore that while certain response mechanisms are present, such as basic fire brigades and initial community awareness efforts, the overall prevention and management system remains fragmented, under-resourced, and reactive rather than proactive. Furthermore, topographical challenges, a lack of advanced

detection technologies, and limited institutional coordination further exacerbate the risks.
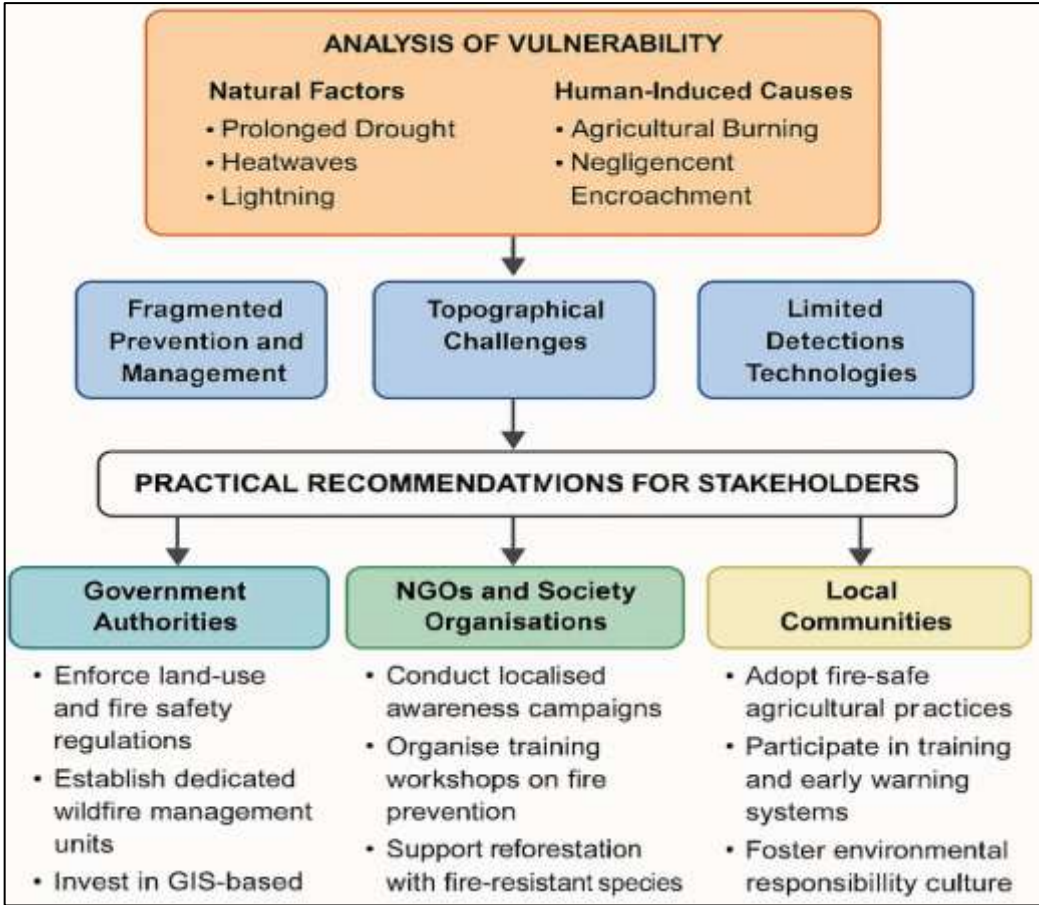

Diagram 3. Stakeholder Recommendations for Mountain Fire Prevention in Sulaymaniyah

9.1. Practical Recommendations for Stakeholders: To mitigate the increasing risks of mountain wildfires and establish a flexible, context-specific prevention framework tailored to the geographic and environmental conditions of Sulaymaniyah, the following practical recommendations are proposed:

1. Government Authorities

- Enforce land-use and fire safety regulations more strictly, especially during peak fire seasons. Deploy regular inspection teams in high-risk zones and apply fines for violations.
- Establish specialized wildfire management units within the civil defense and environmental directorates, equipped with all-terrain vehicles, drones for aerial surveillance, and trained personnel.
- Invest in early warning systems using satellite monitoring, thermal sensors, and GIS-based fire risk mapping to support real-time response.
- Develop and maintain an interactive digital fire-risk map, updated monthly with indicators such as drought, vegetation density, and historical fire data—accessible to both authorities and the public via a mobile app.
- Integrate wildfire prevention into national rural development and environmental policies, providing financial incentives (e.g., subsidies or tax breaks) to farmers who implement fire-safe practices.

2. NGOs and Civil Society Organizations

- Organize local awareness campaigns targeting rural populations and schools, using culturally relevant materials and local dialects.
- Conduct field-based training workshops on safe land clearing, early fire detection, emergency response, and use of basic firefighting tools.
- Launch reforestation and landscape restoration projects using native fire-resistant species like (*Quercus aegilops*, *Juniperus oxycedrus*, and *Ziziphus spina-christi*).
- Serve as liaisons between local communities and government agencies, ensuring that prevention strategies are inclusive and community-informed.
- Create small community-based funding schemes for acquiring basic fire prevention tools (e.g., water pumps, portable hoses, protective gear).

3. Local Communities
- Adopt fire-safe agricultural practices, including avoiding open burning during drought seasons and applying traditional, controlled composting methods instead.
- Participate in training programs, reporting systems, and early warning initiatives to strengthen local readiness.
- Form volunteer fire-watch committees in each rural village or mountainous settlement to conduct regular inspections, clear firebreaks, and assist during emergencies.
- Promote a culture of environmental responsibility and alertness, particularly during high-risk summer months, through schools, mosques, and community events.
- Engage in seasonal collective cleanup days to remove dry vegetation and debris from agricultural plots and forests.

4. Policy and Legislation
- Update national environmental laws to explicitly address mountain wildfire management, defining responsibilities, penalties, and coordination mechanisms across ministries.
- Incorporate fire risk reduction in national climate change adaptation and disaster risk management frameworks.
- Require environmental safety plans for all tourism and agriculture-related projects in mountainous areas as a condition for licensing.

5. Education and Academia
- Integrate wildfire education into middle and high school curricula, using hands-on projects, seasonal observations, and interactive field activities.
- Support universities in conducting applied research on wildfire dynamics, native vegetation restoration, and GIS-based risk modeling.
- Train local journalists and media professionals on responsible wildfire reporting to avoid misinformation or panic and encourage community action.

6. Financing and Innovation
- Establish a national wildfire prevention fund, supported by public and private sectors, to finance community-based projects and technology deployment.
- Introduce climate risk insurance and incentive programs for landowners who implement sustainable and fire-resilient practices.
- Develop mobile apps for farmers and residents that allow real-time fire alerts, reporting, and access to resources like weather forecasts and emergency contacts.

7. Regional and International Cooperation
- Leverage successful international experiences in mountain wildfire management (e.g., Spain, Greece,

Turkey) through knowledge exchange programs and technical partnerships.

- Invite international experts for joint training exercises with local emergency teams and develop localized operational manuals.
- Establish a regional center for wildfire monitoring and analysis in northern Iraq, connected with global data sources and able to advise policy makers with timely and detailed risk assessments.

9.2. Areas for Future Research

Given the increasing frequency and severity of wildfires in the region, future research should explore:

- The long-term ecological effects of repeated fires on mountain biodiversity and soil health.
- The integration of indigenous knowledge in fire management and its effectiveness.
- The impacts of climate change on regional fire patterns using localized climatic models.
- The development of customized fire risk prediction tools and resource allocation strategies tailored to the Kurdistan region.

By implementing the recommended strategies and expanding research efforts, this case study offers a foundation for developing a comprehensive, multi-stakeholder approach to wildfire prevention in Sulaymaniyah, an approach that is scientifically informed, technologically supported, and community-driven.

Their collective efforts made this study possible.

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