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Digital Measures to Decipher Forest Fires a Comparative Study of the Moroccan and American Experiences

Driss Abbadi

Department of Legal, Political and Economic Research, Interdisciplinary Faculty of Taza, University of Sidi Mohamed Ben Abdel Allah, Fez, Morocco.

ABSTRACT

Objectives: The study analyzed the digital measures in forest fire management in Morocco and the United States, comparing of the fire management methods in each country. The goal was to enhance the policies and strategies used in Morocco and to further integrate the Moroccan approach with the American experience.

Methods: The study relied on the descriptive-analytical approach to describe the digital measures adopted in both Morocco and the United States for extinguishing forest fires. The comparative approach was also used to compare the experiences of both countries in combating forest fires and explore how Morocco can benefit from American expertise.

Results: The study results indicate that both Morocco and the United States use digital technology for early detection of forest fires. However, Morocco faces challenges such as funding shortages, inadequate technical infrastructure, and the need for firefighter training. Meanwhile, the U.S. employs advanced technologies, including satellites, drones, and ground-based thermal sensors, and benefits from integrated information management systems and artificial intelligence. Despite this, the U.S. also encounters challenges related to coordinating efforts among different agencies. In comparison, the U.S. has significantly higher levels of funding and technical support, allowing for the use of more advanced technologies. Therefore, Morocco could benefit from the American experience in several ways, including improving technical infrastructure, training firefighting teams, using integrated information management systems, and exchanging expertise and knowledge..

Conclusions: These results reflect the importance of digital technology in enhancing the effectiveness of forest fire response and highlight Morocco's potential to benefit from the United States' experience to address this environmental issue more effectively.

Keywords: Digital measures, forest fires, Moroccan experiences, American experiences

Introduction

Fires are a major environmental event that significantly impacts a large portion of terrestrial ecosystems worldwide across various regions and biomes. The severity and frequency of fire seasons are expected to increase globally by the end of the century, particularly in northern latitudes (Arshad et al., 2022). Forests worldwide are likely to face increasing threats from fires, and Morocco's forests are no exception. Statistics since 1960 indicate that Morocco experiences approximately 300 forest fires

annually, affecting an average area of 3,000 hectares, with considerable variability between years and a noticeable increase in fire occurrences since the mid-1990s. Although the annual area affected by fires may seem small compared to other countries in the region, the impact of forest fires in Morocco remains significant due to the country's highly variable forest cover, arid climate, challenges of climate change, and constraints that make it extremely difficult to rehabilitate degraded areas (Food and Agriculture Organisation, n.d.).

The United States also experiences numerous forest fires, recording an average of more than 182,000 forest fires annually, or nearly 300 fires per million acres (404,690 hectares). Approximately two-thirds of these fires, about 700 fires per million acres (1,730 per million hectares), occur in the South. Meanwhile, on the Pacific Coast, in Northwestern states like Oregon and Washington alone, which contain about 40% of the country's total harvestable timber, there are only 3,815 forest fires annually. The severity of these fires varies greatly, from simple surface fires that can be easily extinguished to disasters that challenge all control measures. Examples of the latter type include the Peshtigo Fire in northeastern Wisconsin in 1871, which destroyed over a million acres (404,690 hectares) and resulted in the death of 1,500 people, and the Tillamook Burn, one of Oregon's most beautiful forests, in 1933, which destroyed around 10 billion board feet (45,300,000 cubic meters) of timber, just 4 billion board feet (18,120,000 cubic meters) less than the total U.S. production that year. More recently, in 1947, fires swept through 240,000 acres (97,128 hectares) of forest, destroyed 800 homes in Maine, and severely impacted countless residents. Fortunately, such fires are rare, but their possibility underscores the importance of establishing well-trained and well-organized protection units (Lindenmuth, A. W., Jr., & Nelson, R. M., n.d.).

Due to this danger, forest rangers, owners, managers, and all those involved in forest management and protection have been seriously concerned for many years with fire control, either through preventive measures or rapid extinguishment. These concerns have significantly driven the study and development of fire-fighting technologies and equipment (Lindenmuth, A. W., Jr., & Nelson, R. M., n.d.). The United States and Morocco rely on the development of digital technology to decode forest fires, using satellite data and artificial intelligence techniques. Therefore, this study seeks to compare the Moroccan and American experiences in using digital measures, highlighting how Morocco can benefit from American expertise in predicting and combating fires. This comparison is essential for understanding how to improve forest fire management strategies in Morocco within different environmental contexts.

Significance of the Study

The topic "Digital Measures to Decipher Forest Fires: A Comparative Study Between the Moroccan and American Experiences" is both vital and significant. This study aims to provide a comparative framework to understand how digital technology can be effectively used in combating forest fires, contributing to better protection of the environment and human lives. Additionally, the study enhances opportunities for international collaboration and knowledge exchange, as comparing the digital strategies of both countries offers a valuable opportunity for cooperation in this field. By analyzing these strategies, the study can identify best practices and adapt them to suit local conditions in Morocco.

Research Problem

Forest fires represent one of the most significant environmental challenges faced by many countries worldwide due to the substantial damage they cause to the environment, economy, and society. As the

frequency and intensity of these fires increase due to escalating climate changes, it has become necessary to adopt advanced and effective strategies to combat them and mitigate their negative impacts. In this context, digital technology plays a crucial role in enhancing early detection capabilities, rapid response, and fire management.

Both Morocco and the United States have made notable advancements in using digital technologies to combat forest fires. While the American experience relies on advanced technologies and extensive networks of sensors and satellites, Morocco is striving to adopt these technologies in ways that align with its local environment and available resources.

The research problem of this study lies in understanding the differences and similarities between the Moroccan and American experiences in using digital measures to combat forest fires, and how Morocco can benefit from the American experience to improve its strategies in this field.

Research Questions

- What digital measures are used in combating forest fires in Morocco and the United States?
- How do these measures differ between the two countries in terms of technology, effectiveness, and application?
- What challenges do Morocco and the United States face in implementing these technologies?
- What lessons can be learned from the American experience, and how can they be applied to combat forest fires in Morocco?

Study Objectives

The study aims to analyze the digital measures used in combating forest fires in Morocco and the United States, compare the effectiveness of these measures, and identify the innovations and challenges associated with them. It also seeks to provide recommendations for improving Morocco's forest fire management strategies based on lessons learned from the American experience.

Study Significance

The significance of this study lies in offering in-depth insights into the use of digital technology in combating forest fires in Morocco, while also drawing from the American experience. This contributes to enhancing Moroccan policies and strategies to address this serious environmental issue.

Research Methodology

Political science research often requires more than one scientific approach to ensure the quality of the results obtained. In this regard, the study will rely on the descriptive-analytical method to describe in detail the digital measures for combating forest fires in both Morocco and the United States and to explain how these measures work and the steps involved. The study will also employ the comparative method to compare the approaches and identify the differences and similarities between the two experiences, drawing conclusions on how to improve or adapt Morocco's digital fire management measures based on the results derived from the comparison.

Section One: Digital Measures to Decipher Forest Fires in Morocco and the United States and Their Challenges

Forests worldwide face increasing threats from forest fires, exacerbated by climate change and human

activities. In this context, "digital measures" emerge as a modern and effective tool in combating these fires by enhancing monitoring, prediction, and rapid response capabilities.

This section of the study aims to review the digital measures used in both Morocco and the United States to combat forest fires and analyze their effectiveness in reducing human, material, and environmental losses. Despite the significant benefits of these technologies, there are challenges in their implementation. Therefore, this study sheds light on these challenges and discusses how to overcome them to enhance the effectiveness of digital measures in combating forest fires, both in Morocco and the United States.

First: Digital Measures to Decipher Forest Fires in Morocco and Their Challenges

The Moroccan government's concern for the risks of natural disasters, including forest fires, stems from the high-level directives of King Mohammed VI, which have been expressed on numerous occasions. One such instance is the Seventh Conference of the Parties to the United Nations Framework Convention on Climate Change, held in Marrakech in November 2001. In his message to the participants at COP 7, His Majesty perfectly encapsulated this concern: "Convinced that responsibility stems from awareness, I invite you to this collective reflection: Must we always wait for terrible tragedies to recognize our responsibility to protect the common heritage of humanity, which is the Earth, and for commercial interests to again heed the voice of human ecology? As for Morocco, it does not resign itself to this inevitability and ensures, to the extent of its capabilities, the full assumption of state responsibilities" (l'Agence Nationale des Eaux et Forêts, 2023, p. 16).

Forest fires in Morocco pose a significant environmental threat, leading to the destruction of forests, the loss of biodiversity, and negatively impacting local communities that rely on these natural resources. However, in recent years, digital technologies have become a crucial tool in combating these fires, offering advanced methods for more accurate and rapid monitoring and analysis of fire outbreaks. Morocco has increasingly begun to rely on these digital technologies to enhance its capacity to respond to forest fires. Among these measures:

Satellite Monitoring System: Morocco utilizes satellites to monitor forests and detect changes in vegetation cover and temperature, employing technologies such as the "Sentinel" satellite. The country primarily relies on data from satellites operated by international agencies, including the European "Copernicus" program and NASA satellites like "Landsat," to monitor the environment and manage forest fires. This data aids in predicting high-risk areas and providing early warnings. The technology allows for:

Forest Dynamics Monitoring: By using remote spatial sensing, Morocco can better manage its natural spaces, particularly in identifying and planning for logging and reforestation activities, monitoring the development of forest areas, and assessing the surfaces of different types of extinct forests.

Forest Fire Management: Remote sensing images enable the following:

Risk Mapping: Local-level risk mapping (from 1/100,000 to 1/50,000) based on thematic data cross-sections and meteorological data.

Burned Area Mapping: High-resolution satellite images (ranging from 50 cm to 20 meters) are used to map burned areas and assess damage.

High Temporal Monitoring: Monitoring burned areas at the national level with high temporal frequency using satellite data with low spatial resolution (ranging from 250 meters to one kilometer) (Agence

Spatiale Marocaine, 2023).

A tool developed in Morocco as part of the "Forest Fires" project under FORMA (Forest Monitoring for Action) designs and implements an experimental system for daily forest fire monitoring at the national level. This system primarily relies on the daily exploitation of low-resolution NOAA AVHRR images. This system allows for:

- Identifying Forest Areas at Risk: By globally and dynamically mapping sensitive areas prone to fire spread on a daily basis.
- Fire Monitoring: Detecting and characterizing large fire outbreaks in forest areas that occurred before the satellite passed overhead.
- Damage Assessment: Mapping large burned areas to evaluate the extent of damage (Agence Spatiale Marocaine, 2023).

Morocco also benefits from satellites that pass over its national territory daily, providing daily images. However, these are not sufficient for proactive fire management. Therefore, the Kingdom seeks to use small American satellites, which are densely deployed and provide continuous images and information around the clock. This approach will enable Morocco to improve fire tracking (Faouzi, 2024).

Geographic Information Systems (GIS): GIS is utilized to analyze geographical data and identify areas that require special attention. These systems assist in planning and resource management during emergencies. For instance, a group of Moroccan experts conducted a study on the Khizana forests (in the Chefchaouen province of Morocco). The assessment of fire risks in that forest using remote sensing and GIS led to the creation of a forest fire risk map by overlaying multiple layers of information derived from existing documents or collected in the field.

While the forest fire risk map itself is not a direct tool for combating fires, it enables forest management to establish an appropriate firefighting system and acquire the necessary equipment for more effective fire control. The map, resulting from various interactions within the applied model, was conceptualized and validated through the identification of reported fire locations and field observations. It was further validated through remote sensing by comparing NDVI (Normalized Difference Vegetation Index) indices from periodically captured satellite images. The NDVI index helps differentiate various land uses and detect areas affected by forest fires (Faleh et al., 2012).

The application of geomatics to assess forest fire risk also aids in decision-making for implementing a well-considered environmental management policy, particularly regarding fire prevention and control. It serves as an effective tool for prioritizing the establishment or maintenance of firefighting infrastructure and planning land areas at risk of fires. However, the scale of the fire that occurred in the Khizana forests in 2004 cannot be simply explained by the results provided by the locally applied model, which revealed its limitations due to not considering other factors. One of these factors is the restricted human influence (Faleh et al., 2012).

Despite these measures aimed at enhancing Morocco’s ability to manage and combat forest fires more effectively and rapidly, there are still challenges to address.

These challenges are as follows: Although the forest cover represents about 13% of Morocco's total area, it is primarily concentrated in mountainous regions inhabited by around 7 million people, equivalent to half of the rural population. Despite the significant biodiversity of these ecosystems, which play a crucial role in regulating water resources, enhancing resilience to climate change, and meeting energy and food needs, the forestry sector contributes approximately 1.5% to the GDP, amounting to

about 17 billion dirhams annually. The sector also provides between 8 to 10 million workdays, equivalent to 50,000 permanent jobs. Additionally, it supplies 30% of the national demand for construction and industrial wood, 17% of the national demand for fodder, and 4% of the global supply of cork oak (Economic, Social, and Environmental Council, 2024). Despite this importance, Morocco's forest ecosystems face ongoing degradation at a rate of approximately 17,000 hectares annually, due to various factors including the negative impacts of climate change and pressures from human activities. These pressures include a lack of offerings for eco-tourism, excessive firewood usage with an annual average of 3 million tons, and overgrazing at rates two to three times the productive capacity of the forest ecosystems, which hinders efforts to maintain sustainable forest cover (Economic, Social, and Environmental Council, 2024).

To address these challenges and enhance efforts over the past three decades, public authorities have developed the "Morocco Forests 2020-2030" strategy. This strategy aims to rehabilitate and restore forest ecosystems and sustainably valorize their resources. Although the preliminary evaluation of this strategy appears positive, it is still in its early stages, making it difficult to conduct an objective assessment of its results on forest cover (Economic, Social, and Environmental Council, 2024).

Second: Digital Measures for Forest Fire Management in the United States and Their Challenges

Modern digital measures for managing forest fires in the United States represent a significant advancement in the field of natural disaster management. These measures rely on advanced technologies to analyze the complex patterns associated with the outbreak and spread of forest fires. These digital tools contribute to improving prevention strategies and rapid response, enhancing the ability to protect environmental and human resources. Among the adopted measures are:

National Emergency Response Information System: The Science and Technology Directorate supports the U.S. Fire Administration (USFA) in researching and developing a new platform for information interaction and innovative data analysis known as the National Emergency Response Information System (NERIS). These activities are achieved through research and development grants awarded via the Science and Technology Directorate's broad agency announcement program. The directorate explores the feasibility of new concepts and innovative technical solutions to meet the needs of the U.S. Fire Administration. The work addresses the gap between the current Federal Fire Reporting and Incident Management System and the needs of the firefighting and emergency medical community in the country, aiming to provide actionable real-time information about local emergency incidents, as well as insights gained from aggregating regional and national data (US Department of Homeland Security, n.d.).

The United States has also developed a new device called FireGuard, which significantly assists National Guard members in California and Colorado in detecting and managing forest fires, leading to the saving of lives and property since the pilot program began in 2019. FireGuard relies on military satellites in collaboration with the National Fire Management Center and the U.S. Forest Service, and utilizes the Firefly capability of the National Geospatial-Intelligence Agency to detect forest fires, notify authorities, and provide valuable data to firefighting networks nationwide (National Guard Bureau, 2022).

Although FireGuard uses a similar algorithm to Firefly, it is refined and analyzed to provide unclassified information, according to Major Jan Bender, FireGuard team leader for the California National Guard. Bender noted that FireGuard enhances the overall situational awareness for wildfire partners by

providing initial fire detection and continuous assessments. He explained that FireGuard represents a significant shift in early wildfire detection in remote areas and at unusual times (National Guard Bureau, 2022).

The FireGuard program consists of two teams of intelligence analysts from the California and Colorado Air National Guard and Army National Guard, who use the Firefly algorithm to help interpret data from various sources, including satellite and drone imagery. The products generated by FireGuard are used to create aerial maps showing fire-affected areas and provide updates every 15 minutes to the firefighting community (National Guard Bureau, 2022).

In 2021, wildfires destroyed approximately 3,000 square miles in California, with FireGuard tools improving the capabilities of about 15,000 ground firefighters in detecting fire spread. Mike Morgan, Director of Fire Prevention and Control in Colorado, remarked that the ability to make decisions based on accurate and reliable information is crucial for saving lives and property during rapidly spreading wildfires (National Guard Bureau, 2022).

During the Marshall Fire in Boulder County, Colorado, in 2021, which destroyed over 6,000 acres, strong winds prevented manned aircraft from flying. The FireGuard team provided the only available information during the first eight hours, aiding in the evacuation of approximately 35,000 people. Morgan noted that the information provided by FireGuard was critical, as situational awareness would have been severely compromised without it. Peter Widmar, head of the intelligence unit in the Colorado Fire Prevention and Control Department, explained that FireGuard generated over 47,000 geographic products for more than 3,500 fires across the United States over the past two years. Colonel William DeBroff, Chief of Staff for the Colorado National Guard, stated that FireGuard has become an integral part of their operations, providing early wildfire detection on a national level, which was previously unavailable (National Guard Bureau, 2022).

Artificial Intelligence System in Firefighting in the U.S: With changing landscapes and the threat to homes and communities from wildfires in the U.S., particularly in California, firefighters faced more than 5,500 wildfires in 2024, burning a total area of 830,000 acres, according to Cal Fire. These fires destroyed over 1,200 buildings and resulted in one civilian death, officials reported. The 2024 "Park" fire, which became the fourth largest wildfire in California's history, forced firefighting agencies to use massive resources, including artificial intelligence, as noted by Brian Spear, CEO of Technosylva. Spear added that artificial intelligence is used to predict fire spread and track resources to ensure their coordination and efficient use (Sarnoff, L., 2024).

A new ally has emerged for fire agencies: artificial intelligence. The use of artificial intelligence technology in both prevention and response has become a cornerstone of wildfire management efforts in the U.S., according to Philip Seelig, head of the Fire Intelligence Division at the California Department of Forestry and Fire Protection. Seelig told ABC News, "Staff at all emergency command centers across the state monitor cameras through the ALERTCalifornia network and receive AI notifications about the likelihood of wildfires on a daily basis" (Sarnoff, L., 2024).

This AI is known as the "camera quilt," consisting of over 1,080 high-resolution, movable, and zoomable cameras spread across the state. This system, based at the University of California, San Diego, provides 24-hour monitoring of rural areas using near-infrared night vision to detect and monitor active wildfires. According to Seelig, this camera-based system has been successful for the California Department of Forestry and Fire Protection, noting that the automated system is faster than making a 911 call. In 2023, TIME magazine recognized California's use of AI for wildfire detection as "Best

Invention" of the year. Governor Gavin Newsom stated in a press release at the time, "California fights fires smartly, combining advanced technology with world-class firefighting power to better protect our communities" (Sarnoff, L., 2024).

When a wildfire is detected, emergency command staff run fire spread predictions and simulations through another AI system to understand the potential impacts of the fire, according to Seelig. The California Department of Forestry and Fire Protection (Cal Fire) has been using Technosylva, a company specializing in wildfire science and technology, since 2019. The AI system analyzes predictions based on past fire patterns, weather patterns, and vegetation types to provide context and a potential map of how the initial fire might spread. Brian Speer told ABC News, "We have revolutionized fire models; by using machine learning with AI, you can enhance situational awareness and accelerate decision-making to seconds rather than minutes or hours." The Technosylva system also integrates satellite and weather station data to model fire behavior and predict potential fire locations. According to Speer, this allows agencies to allocate resources more effectively, implement preventive measures in high-risk areas, and prepare for potential fires with greater accuracy (Sarnoff, L., 2024).

However, the application of these measures faces numerous challenges, requiring careful study and the development of effective strategies to overcome obstacles that may impede achieving the desired goals. These challenges include:

Firstly, climate change is one of the most prominent factors exacerbating the intensity and severity of wildfires. Studies have shown that rising temperatures and changing precipitation patterns contribute to increased drought, making forests more prone to ignition (Westerling, 2016). According to a report from NASA's Climate Change Center, increased temperatures and prolonged droughts lead to higher frequency and intensity of wildfires (NASA, 2021).

Secondly, fire management faces challenges in adapting to logistical and financial difficulties. Suppression operations require teams of specialists and heavy equipment, which can be costly and hard to procure, especially in remote areas (Jolly et al., 2015). Studies indicate that many agencies responsible for fire management struggle with shortages of financial and human resources needed to handle large fires (Calkin et al., 2014).

Thirdly, urban expansion plays a significant role in complicating firefighting efforts. With growing population and expanding urban areas into forested regions, evacuation and intervention efforts become more complex and hazardous (Radeloff et al., 2018). This expansion creates a "wildland-urban interface" where built areas meet forests, increasing the likelihood of fire ignition and spread.

Therefore, effective management of wildfires in the U.S. requires multifaceted strategies that include improving fire prediction, increasing funding for fire management, and coordinating urban expansion efforts with forest management plans (Steelman & McCaffrey, 2013).

Section 2: Comparison Between Moroccan and American Experiences in Forest Fire Management and How Morocco Can Benefit from Them

The section "Comparison Between Moroccan and American Experiences in Forest Fire Management" is a crucial focus for understanding how to improve strategies for addressing these increasing natural disasters. The United States is a leading country in employing advanced technology for fire management, including artificial intelligence, drones, and sophisticated digital systems. In contrast, Morocco is making promising strides in this area, relying on satellite data and early warning systems.

This study aims to compare the Moroccan and American experiences in terms of the digital tools and

strategies used, with a focus on the lessons learned that Morocco could adopt to enhance its capabilities in managing forest fires. By analyzing the American experience, Morocco can benefit from best practices in monitoring, prediction, and response, and adapt them to its local conditions and available resources.

First: Comparison of Digital Technologies Used in the Two Countries

Forest fires are significant environmental threats affecting vast areas worldwide, including Morocco and the United States. Digital technologies are crucial tools in managing and combating these fires, playing a vital role in monitoring, predicting, and preventing them. This article aims to compare the digital methods used in Morocco and the United States, analyzing their effectiveness and impacts.

Digital Technologies in Morocco : In Morocco, various digital technologies are employed for monitoring and managing forest fires. Moroccan authorities primarily rely on satellite data, such as that available through NASA's Fire Information for Resource Management System (FIRMS). This data provides crucial information on active fire locations, aiding in rapid response and coordination efforts (NASA, 2021).

Additionally, Morocco uses Geographic Information Systems (GIS) to analyze environmental data, create fire risk maps, and develop fire prevention strategies. Although fire risk maps are not a direct tool for fighting fires, they assist forest management professionals in establishing effective fire-fighting systems and acquiring appropriate equipment for more efficient fire management (Faleh et al., 2012).

The application of geomatics for assessing fire risk aids in decision-making for a well-considered environmental management policy, particularly in fire prevention and control. This application is also an effective tool for prioritizing the creation and maintenance of fire-fighting infrastructure and organizing lands prone to fire risks.

Digital Technologies in the United States: In the United States, advanced technologies are employed in forest fire management, including satellites, manned and unmanned aircraft, and Geographic Information Systems (GIS). The U.S. utilizes a wide range of satellites for fire monitoring, including programs such as: Moderate Resolution Imaging Spectroradiometer (MODIS), and Visible Infrared Imaging Radiometer Suite (VIIRS) (Schoennagel et al., 2017)

These satellites provide accurate information about current fires, weather conditions, and drought levels, which helps in predicting the location and spread of fires.

Furthermore, researchers at the University of Southern California (USC) have developed a new method for accurately predicting the spread of wildfires. By combining satellite imagery with artificial intelligence, their model offers a potential breakthrough in wildfire management and emergency response. The USC model uses satellite data to track the progress of a fire in real-time, then feeds this information into an advanced computational algorithm that can accurately predict the potential path, intensity, and growth rate of the fire. This study comes at a time when California and much of the Western U.S. are experiencing an increasingly severe wildfire season, with several fires burning across the state, including the "Lake Fire," which is the largest wildfire in the state in 2024, having destroyed over 38,000 acres in Santa Barbara County. Brian Shadi, a Ph.D. student in the Department of Aerospace and Mechanical Engineering at USC's Viterbi School of Engineering and the lead author of the study, said: "This model represents a significant advance in our ability to combat wildfires. By providing more accurate and timely data, our tool enhances the efforts of firefighters and evacuation teams battling wildfires on the front lines(Nina Raffio,2024).

Researchers began collecting historical data on wildfires from high-resolution satellite images. By carefully studying the behavior of previous fires, they were able to track how each fire started, spread, and was eventually contained. Their comprehensive analyses revealed patterns influenced by various factors such as weather, fuel (like trees and shrubs), and terrain. They then trained an AI-powered computer model known as the Conditional Wasserstein Generative Adversarial Network (cWGAN) to simulate how these factors affect the evolution of wildfires over time. They taught the model to recognize patterns in satellite images that matched how fires spread in their model. Subsequently, they tested the cWGAN model on real wildfires that occurred in California between 2020 and 2022 to assess its accuracy in predicting fire spread. According to Asad Oberai, Hughes Professor and Professor of Aerospace and Mechanical Engineering at USC Viterbi School of Engineering and co-author of the study: 'By studying how previous fires behaved, we can create a model that predicts how future fires will spread' (Nina Raffio, 2024).

Comparison between Morocco and the United States: The United States is characterized by its diverse digital technologies used in wildfire management, including the use of various satellites and AI models. While Morocco primarily relies on data from the FIRMS program and GIS systems, the United States focuses on integrating data from multiple sources such as satellites, manned, and unmanned aircraft.

The comparison between Morocco and the United States indicates that both countries use advanced digital technologies for wildfire management, but there are differences in the scope and diversity of these technologies. The United States has a broader range of digital technologies, while Morocco could benefit from deeper integration of AI technologies into its current systems. This difference in technologies reflects how each country adapts to the unique environmental challenges it faces and highlights the importance of knowledge and technology exchange between countries to improve global wildfire management strategies.

Second: How Morocco Can Benefit from the American Experience

Wildfires are an increasing concern globally, impacting ecosystems, economies, and human safety. Morocco, due to the diversity of its forested regions, faces growing challenges in fire management. By studying and adopting the American experience in wildfire management, Morocco can enhance its own fire management strategies. This article explores how Morocco can benefit from the United States' approach to wildfire management.

The American Approach to Wildfire Management: The United States has developed a comprehensive wildfire management strategy, refined through extensive experience and research. Key aspects of this approach include:

- **Advanced Technology:** American wildfire management utilizes advanced technologies such as satellite monitoring, drones, and predictive modeling to detect and manage fires (U.S. Forest Service, 2023). These tools aid in early detection and efficient resource allocation.
- **Firefighting Infrastructure:** The United States has established robust firefighting infrastructure, including specialized equipment and trained personnel. Agencies such as the U.S. Forest Service and the Federal Emergency Management Agency (FEMA) play critical roles in coordinating responses (FEMA, 2023).
- **Community Engagement:** Public education and community involvement are essential components of American wildfire management. Programs like Firewise aim to educate residents about fire safety

and prevention, promoting proactive measures (National Fire Protection Association, 2022).

- **Research and Innovation:** Investment in research is a cornerstone of American wildfire management. This includes studying fire behavior, the impact of climate change, and developing new fire suppression technologies (Fire Research Division, 2023).
- **Agency Coordination:** Effective wildfire management in the United States involves cooperation among local, state, and federal agencies. This coordination ensures a unified approach to fire response and recovery (National Interagency Fire Center, 2023).

Applying American Practices to the Moroccan Experience:

- **Adopting Advanced Technology:** Morocco could benefit from applying technologies used in the United States. For example, satellite imagery and drones can be used to monitor forest health and provide
  early detection of fires. This technological adoption could enhance Morocco's ability to respond effectively to fire threats (U.S. Forest Service, 2023).
- **Developing Firefighting Infrastructure:** Investing in modern firefighting equipment and establishing specialized units will improve Morocco's response capabilities. Training programs for personnel and developing a national fire management infrastructure can enhance operational effectiveness (FEMA,2023).
- **Enhancing Community Engagement:** Introducing community education programs similar to the Firewise program in Morocco could raise awareness about fire safety. Public workshops, educational campaigns, and fire drills will encourage communities to adopt preventive measures and be better prepared (National Fire Protection Association, 2022).
- **Promoting Research and Innovation:** Collaborating with international research institutions can provide Morocco with valuable insights into new fire prevention technologies and strategies. Understanding local fire behavior and environmental impacts will help tailor these innovations to Morocco's specific needs (Fire Research Division, 2023).
- **Improving Agency Coordination:** Establishing a comprehensive national strategy that includes coordination among various organizations can improve fire management in Morocco. Defining clear roles and communication channels will streamline responses and enhance overall effectiveness (National Interagency Fire Center, 2023).

By adopting practices from the American experience in wildfire management, Morocco can significantly improve its strategies. Implementing advanced technologies, investing in infrastructure, enhancing community engagement, supporting research and innovation, and improving inter-agency coordination are crucial steps in strengthening Morocco's ability to effectively manage and mitigate wildfires.

Conclusion

In conclusion, the comparative study of Moroccan and American approaches to digital wildfire management highlights the significance of modern technology in enhancing strategies for combating such disasters. While the United States offers an advanced model with the use of artificial intelligence and drones for fire monitoring and management, Morocco is increasingly benefiting from satellite technologies and early warning systems.

This comparison underscores the significant opportunities Morocco can gain by adopting and adapting best American practices to its local needs. By doing so, Morocco can improve its capabilities in fire

prevention and response, contributing to the protection of its environment and preservation of natural resources.

Investing in digital technology and developing the necessary infrastructure represent a crucial step toward a safer and more sustainable future for forests in Morocco and around the world.

Research Results

From the results of this research, it is evident that:

- Under the current climate changes, the frequency and intensity of forest fires are increasing globally. These fires have a direct impact on the environment, biodiversity, and people. Morocco and the United States are good examples for studying this issue due to their ongoing exposure to forest fires;
- **Digital technology as a tool for prevention and response:** Adopting digital measures such as using satellites, drones, and artificial intelligence can significantly improve the ability to monitor fires, predict their occurrence, and respond quickly to limit their spread. Comparing the Moroccan and American experiences can provide insights into how to improve these tools and use them efficiently;
- **Conservation of natural resources:** Forest fires have significant economic and social impacts, including the destruction of natural resources. Digital measures can contribute to protecting these resources and reducing losses, thereby enhancing environmental sustainability;
- **Future challenges and opportunities:** Analyzing the Moroccan and American experiences can help identify current challenges faced by countries in combating forest fires using digital technology. It can also contribute to developing new strategies to capitalize on the opportunities offered by technological advancements;

This study provides an important comparative framework for understanding how to leverage digital technology in combating forest fires, thereby achieving better protection for the environment and people.

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