

AI and Satellite data for Natural Crisis Prevention: A Regional Fire Risk Diagnosis in Pleven Province, Bulgaria

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Abstract

The increasing severity of wildfires calls for data-driven regional strategies for prevention and early intervention. This paper presents a diagnostic approach that combines artificial intelligence (AI), satellite data (mainly from Copernicus/Sentinel), and machine learning to assess and forecast wildfire risk in Pleven Province, Bulgaria. The study focuses on two key dimensions of regional diagnostics: geographic location and natural landscape. It introduces a Potential Fire Risk Index (PFRI), built from satellite-based indicators such as NDVI, NDMI, Land Surface Temperature (LST), Fire Weather Index (FWI), and dry forest biomass density (DBDI). Using five years of data, the model identifies spatial patterns of vegetation stress and soil moisture deficit, providing early insights into high-risk zones. The findings highlight potential wildfire hotspots beyond the 2024 events and offer evidence-based recommendations for prevention policies, including AI-powered early warning systems. This study demonstrates how advanced geospatial technologies can support sustainable territorial governance in climate-sensitive regions.

Keywords: Artificial Intelligence, Wildfire Risk, Satellite Monitoring, Pleven Province, Dry Biomass, NDVI, Regional Diagnostics, Fire Prediction

JEL classification: R58

Paper type: Research article

Received: 10 June 2025

Accepted: 9 July 2025

DOI: 10.54820/entrenova-2025-0075

Citation: Mihaylov, M. (2025). AI and Satellite data for Natural Crisis Prevention: A Regional Fire Risk Diagnosis in Pleven Province, Bulgaria. ENTRENOVA - ENTERprise REsearch InNOVation, 11(1), <https://doi.org/10.54820/entrenova-2025-0075>.

Introduction

Today, society faces serious challenges related to rapid climate change and its consequences for the natural environment and human life. Droughts, high temperatures, and frequent fires are no longer rare—they are a reality that is changing the way of life in many regions of Bulgaria. These processes affect not only nature but also economic activity, human security, and the sustainable development of communities. One of the regions where these problems are particularly severe is Pleven. Here, climatic features and human activity create conditions that make the territory especially vulnerable to ecological risks. For economists specializing in regional diagnostics, understanding these processes is not just an academic interest but a key element in developing strategies for sustainable development and improving quality of life. Regional diagnostics begin with defining the geographical characteristics of the territory—its borders, natural features, and landscape. These parameters form the basis for analysing the social, economic, and ecological processes that shape regional development. In the case of Pleven, studying climate change and its consequences is particularly important because it reveals the connection between natural conditions and economic activity. Droughts, changes in vegetation, and increasing fires directly impact agriculture, forestry, and the safety of the population. These problems are not just ecological—they affect the region's economic stability by reducing land productivity, increasing prevention and recovery costs, and creating tension in local communities.

Studying these processes is crucial because it allows the identification of vulnerable areas and the proposal of measures to overcome them. Modern technologies, such as satellite observations and big data analysis, make it possible to accurately map risk areas and predict future crises. For example, satellite imagery and special indicators of vegetation and soil moisture can determine where the fire risk is highest and how to reduce it. This is not just a matter of scientific precision but also of practical benefit for local authorities and economic actors who need reliable tools for decision-making. This study focuses on changes in the Pleven region over the period 2015–2025—a time when climate change is felt most strongly. The analysis of vegetation, soil moisture, and temperature changes reveals not only the scale of the problem but also the possibilities for its resolution. The study does not limit itself to stating facts but offers concrete solutions: restoring irrigation systems, reforestation with resilient species, creating early warning systems, and training local communities in sustainable practices. These measures not only reduce the risk of disasters but also create conditions for more sustainable economic development. In this sense, the work is valuable not only for scientists but also for practitioners—regional administrations, economic organizations, and local communities. It shows how regional diagnostics, supported by modern methods, can become a powerful tool for overcoming climate challenges. In a changing climate, such studies are not just useful—they are necessary for the future of regions and the people who live in them. An overview of IPTV network architecture

IPTV, Internet Protocol television, is a technology that delivers television services over IP networks rather than via satellite or cable. The IPTV industry relies on Internet Protocol Television (IPTV) technology to deliver television programs and other video content to users over the internet. This approach offers users flexible access to media content and enables service providers to manage delivery more efficiently (Lee et al., 2020). A key aspect of this industry is the design and analysis of the underlying IPTV core network architecture, which is essential to providing high-quality, reliable service to customers. To ensure efficient performance, this network must offer sufficient capacity (measured in bits per second), low latency, and minimal congestion (Zhou & Li, 2019). This

capacity is typically measured in bits per second (bps), and the capacity requirements vary based on factors such as the number of users, the type of content, and the time of access. Congestion in this network can lead to delays, buffering, and degradation in video quality. Depending on the service provider's network architecture (Figure 1), there are two main IPTV deployment architectures: centralized and distributed. In a centralized IPTV architecture, all the IPTV services are hosted and managed from a central location, typically a data center. In contrast, a distributed IPTV architecture leverages multiple smaller data centers or edge nodes located closer to end users. This approach can improve the overall reliability of the IPTV service by distributing the load across multiple locations, reducing the risk of a single point of failure. A distributed architecture can also improve end-user quality of service by reducing the distance between the content source and the viewer, thereby reducing latency and improving the overall user experience.

1. Climate and Ecological Challenges in Pleven Region: Context, Goals, and Methodology

This study focuses on a detailed analysis of changes in vegetation activity, moisture content, and thermal stress in the Pleven region over the decade 2015–2025, with the main goal of identifying and mapping areas with increased fire risk. According to the **EVANDE** technical report, "moisture in fuel is usually absorbed, making it more flammable. That is why regions with high sun exposure and temperatures usually experience more fires" (Burlando, 2016). The choice of Pleven as a research area is not accidental but is motivated by the region's specific climatic and geographical features, which make it one of the most vulnerable territories in Bulgaria to climate change challenges. In recent years, the region has faced increasingly frequent droughts, extreme temperatures, and a growing number of forest fires, threatening both natural ecosystems and agricultural lands and settlements. The situation was particularly dramatic in 2024 when prolonged droughts, the accumulation of dry vegetation, and individual fires in agricultural and forest areas demonstrated the need for modern approaches to fire risk prevention and management.

Climate change, which manifests globally, is expressed locally through increased drought and thermal stress on vegetation, turning the region into a critical zone for observation and the application of innovative solutions. In this context, the study not only analyses existing risks but also offers practical tools for regional administrations, local municipalities, and the scientific community, who are tasked with developing effective strategies to protect the territory and population.

Preventing crises caused by forest fires using new technologies and big data is not new. The GRASS GIS system is a powerful open geospatial platform that works with raster and vector data, terrain models, ecosystems, hydrology, data management, and imagery. It has applications in both the public and private sectors, especially in environmental organizations (Tsenkov, 2019). This study aims to explore how satellite data can support forest fire prevention at the regional level. An important aspect is the use of mathematical models, artificial intelligence, and new technologies for forecasting. The main methodological framework of the study is based on the integration of modern satellite technologies and remote sensing systems, which allow for rapid, accurate, and spatially detailed environmental assessments. A central element of the methodology is the use of satellite data from the Copernicus program, particularly the Sentinel-2 mission, which provides high-resolution images (up to 10 meters), crucial for spectral bands. This resolution is key because it allows detailed analysis not only of vast territories but also of individual agricultural plots, forest masses,

and even suburban areas. This creates opportunities to identify local features that might remain hidden when using lower-resolution data.

In addition to satellite data, meteorological indicators and forecasts provided by the European Forest Fire Information System (EFFIS) are integrated, contributing to the creation of a complex, multi-layered model for fire risk assessment. The system uses a harmonized methodology and provides 10-day forecasts for EU territories. The study integrates the system, which provides daily fire danger maps and historical data on burned areas. Combining different sources of information not only increases the accuracy of the analysis but also gives it practical direction, making it a valuable tool for planning and decision-making by local authorities. An important advantage of the methodological approach is the possibility of comparative analysis of data from two different periods—2015 and 2025. This allows not only the identification of current problem areas but also the tracking of dynamic changes over time related to climate change and human activity. For example, comparing satellite images from the two periods reveals changes in vegetation cover, soil moisture, and thermal stress, which are key factors in fire risk assessment. Thus, the study does not limit itself to a static picture but provides a dynamic risk assessment, which is extremely important for developing long-term prevention strategies. Three main indices widely recognized in the scientific community and used in global environmental monitoring programs were employed: **NDVI (Normalized Difference Vegetation Index)**, **NDMI (Normalized Difference Moisture Index)**, and **Moisture Index (MI)**. These indices were chosen for their ability to provide quantitative assessments of key parameters related to fire risk, such as vegetation activity, moisture content, and thermal stress.

NDVI (Normalized Difference Vegetation Index)

The NDVI index was developed in the 1970s by John Rouse and a team at Texas A&M University in collaboration with NASA as the first attempt to quantitatively measure vegetation activity through satellite observations. It quickly found application in agriculture for yield forecasting and later became a key tool in global climate and sustainable development monitoring programs. NDVI measures the ratio between reflected light in the near-infrared spectrum (NIR), characteristic of healthy vegetation, and absorbed light in the red spectrum (RED), associated with photosynthesis.

$$\text{NDVI} = \frac{\text{NIR} + \text{RED}}{\text{NIR} - \text{RED}}$$

- **NIR (Near Infrared, ~0.7–1.1 μm)**: This range of electromagnetic radiation is strongly reflected by healthy, well-developed vegetation. Satellite sensors record how much of this energy returns to them. The healthier and more lush the vegetation, the higher the NIR reflection.
- **RED (Red spectrum, ~0.6–0.7 μm)**: This is the zone of the spectrum that plants absorb during photosynthesis to produce energy. When vegetation is healthy and actively photosynthesizing, it absorbs most of the red light, leading to low reflection values. In stressed or dry vegetation, absorption decreases, and red light reflection increases.
- **Numerator (NIR - RED)**: The difference shows the contrast between strong infrared reflection and red absorption—a key indicator of vegetation vitality.
- **Denominator (NIR + RED)**: Normalization through the sum removes the influence of external factors such as differences in lighting, shadows, and atmospheric conditions, making the values comparable across different places and times.

The formula uses spectral data extracted from satellite platforms, which are free and accessible for almost any point on Earth, such as Sentinel or Landsat. High NDVI values (+0.6 to +1) indicate dense, healthy vegetation, while low or negative values signal poor vegetation, bare soil, or urbanized areas. Today, NDVI is a global standard used by organizations like FAO, UNEP, and NASA MODIS for land use monitoring, drought assessment, and fire risk forecasting. In this study, NDVI was used to identify areas with reduced vegetation activity that are more vulnerable to fires.

NDMI (Normalized Difference Moisture Index)

The NDMI index was introduced by Bo-Cai Gao in 1996 as a method for assessing vegetation moisture through satellite data. It is now a proven indicator of water content and leaf mass. Initially used in ecological and agricultural studies, NDMI is today an important indicator of fire danger, especially in the context of increasing droughts and fires. It compares the near-infrared spectrum (NIR), which reflects vegetation structure, with the shortwave infrared spectrum (SWIR), which is sensitive to water content in leaves. Positive NDMI values indicate well-hydrated vegetation, while low values indicate dry, easily flammable vegetation. NDMI is used in monitoring systems by NASA, ESA, and EFFIS to detect critical fire-prone zones. In this study, NDMI was used to assess vegetation moisture and identify areas with increased fire risk due to lack of moisture.

$$\text{NDMI} = \frac{\text{NIR} + \text{SWIR}}{\text{NIR} - \text{SWIR}}$$

Moisture Index

The Moisture Index is a more recently developed index that combines information from different spectral channels and is widely used in countries like the USA, Australia, and Portugal for drought and fire management. It is integrated into early warning systems and helps farmers and forest services take preventive measures. The index measures the ratio between the green spectrum (GREEN), associated with chlorophyll content, and the near-infrared spectrum (NIR), which reflects water content and vegetation structure. Positive Moisture Index values indicate the presence of moisture and active photosynthesis, while negative values indicate dry soil and degrading vegetation. In this study, the Moisture Index was used as a unifying tool to compare and correlate data from 2015 and 2025 more comprehensively. It combines NDVI (an indicator of vegetation health) and NDMI (an indicator of moisture) to create a more complete picture of drought dynamics, moisture, and fire risk in the Pleven region.

The study methodology includes several key stages that ensure the accuracy and reliability of the results. Initially, satellite data from Sentinel-2 for the two reference periods—2015 and 2025—were extracted. Then, the NDVI, NDMI, and Moisture Index were calculated and visualized using specialized software such as QGIS and Google Earth Engine. This allows the creation of detailed maps illustrating changes in vegetation activity, moisture, and thermal stress in the region. The results were spatially analyzed to identify zones with critical changes that correlate with increasing fire risk. The maps also include measurements of **LST (Land Surface Temperature)**, another established index for remote fire risk assessments.

In the next step, the results were compared with historical fire data provided by EFFIS. This verification is crucial as it allows the reliability of the methodology to be assessed and the practical value of the indices used to be demonstrated. For example, comparing fire risk maps with real fire data from 2024 confirmed that the

identified critical zones coincide with the areas where the most fires were recorded. This evidence of the methodology's accuracy makes it a reliable tool for predicting future risks. The final stage of the methodology involves developing recommendations for innovative strategies to reduce fire risk. These strategies include integrating artificial intelligence for real-time data analysis and personalized solutions based on satellite observations, aimed at regional administrations and local communities. The proposals focus on improving fire prevention and risk management in the Pleven region, considering its specific climatic and geographical features. Thus, the study not only provides a scientific basis for understanding fire risks but also offers practical tools for their management, making it particularly useful for local authorities and the scientific community.

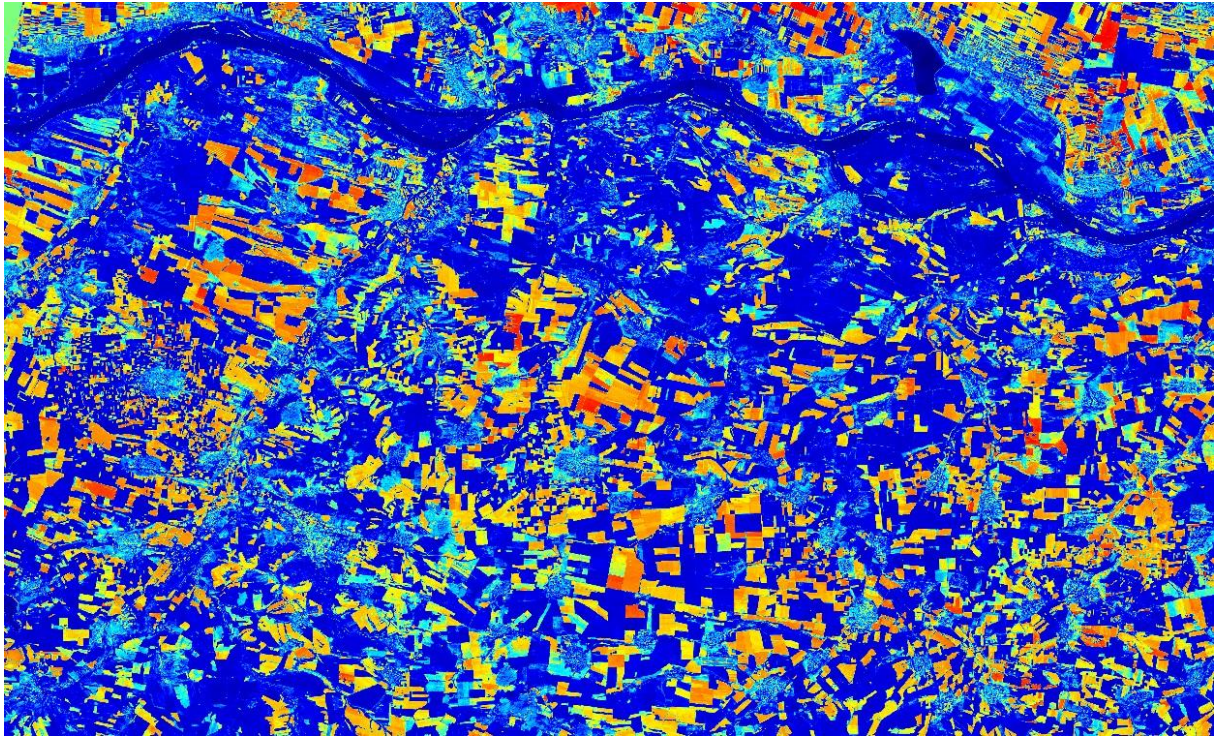
2. Dynamics of Changes in Vegetation Activity and Fire Risk in Critical Zones of Pleven Region: Analysis of Satellite Data for 2015–2025

Over the past decade, the Pleven region has witnessed significant changes in climate and environmental conditions that have seriously affected forest ecosystems. More and more plant species are becoming sick and dying, resulting in entire forest masses drying out. An example of this is the almost completely lost coniferous plantations near the village of Oresh. Structural problems—such as an inefficient irrigation system and unclear distribution of responsibilities among institutions (the Ministry of Agriculture through the Forest Executive Agency, the Ministry of Environment and Water, municipalities, mayoralities, and regional administration)—lead to a lack of coordinated monitoring of drought and the condition of forest species. While forest fires accounted for only 1% of all registered fires in the Pleven region in 2015, the situation in 2025 is fundamentally different—the increased frequency and scale of forest fires clearly show the deepening of climate risks. To analyse this dynamic, satellite data and indices for assessing vegetation and soil moisture were used, including **NDVI, NDMI, and Moisture Index**. NDVI allows tracking the biomass potential of vegetation by comparing reflection in the near-infrared spectrum and red light, while NDMI provides information on moisture in the leaf mass using the near and shortwave infrared spectrum. The Moisture Index integrates information on the condition of vegetation cover and soil, providing a comprehensive measure of the moisture balance and directly linking it to vegetation flammability and fire risk. Although NDVI and NDMI were used to identify trends and problem areas, it was the Moisture Index that allowed the results to be generalized and the overall state of the moisture regime to be derived, clearly emphasizing the transition from local ecological problems to a systemic risk for forest ecosystems and the safety of the population in the region.

In 2015, the Pleven region was still characterized by a relatively stable ecosystem. Satellite images show large areas in blue and green, indicating well-hydrated vegetation and soil (Figure 1). For example, in the Trastenik area, NDVI reached a value of 0.65, reflecting dense and healthy vegetation, while NDMI was 0.35—a indicator of high moisture content. In the village of Izgrev, NDVI was 0.58 and NDMI was 0.30; this combination of values is typical for agricultural lands with a good water regime. Between the village of Oresh and the municipality of Levski, NDVI was 0.62 and NDMI was 0.32—numbers that also indicate stable conditions.

Figure 1

Soil moisture and dry vegetation in Pleven region in 2015



Source: Copernicus satellite

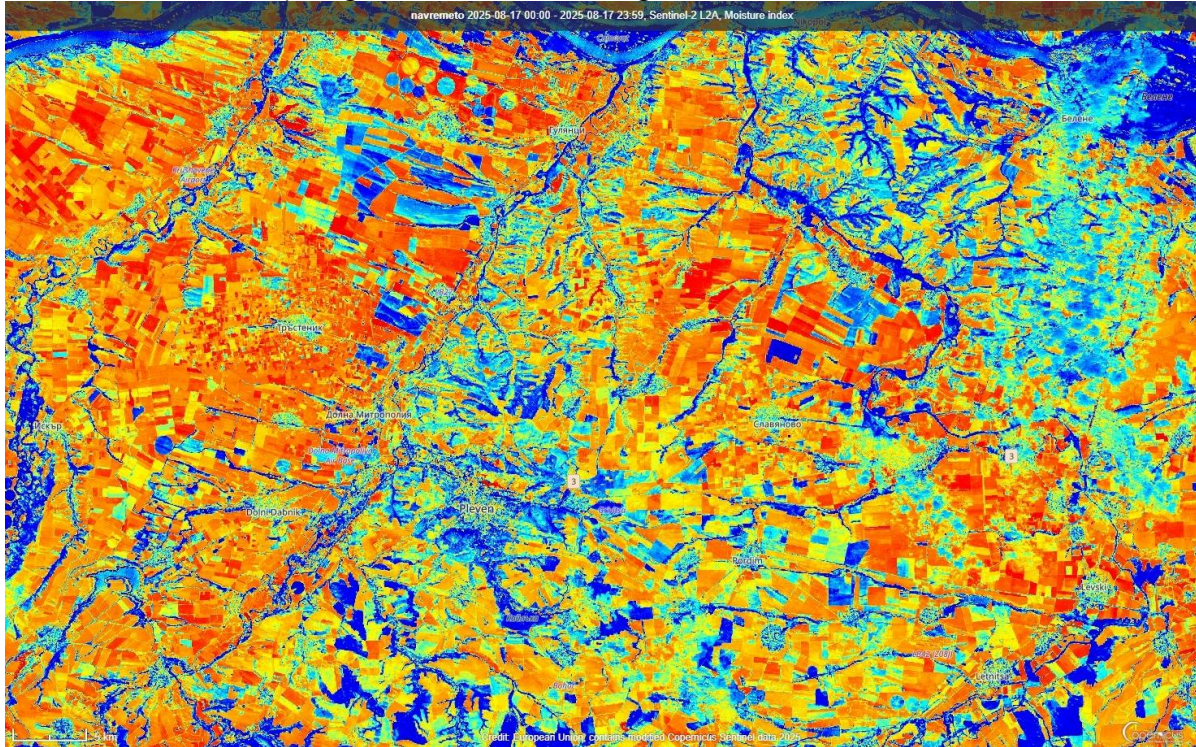
Despite these relatively high values, the 2015 images show initial signs of drying. In the southern and western parts of the region, orange-yellow spots appear, indicating decreasing soil moisture. These colour gradations are most visible in areas far from natural water sources and in regions with intensive agriculture without sufficient irrigation. Although the drought then seemed weak, it was the first sign that climatic conditions in the region were changing. Average summer temperatures began to rise, and rainfall became more unpredictable. Even at this stage, the zones around Trastenik and Izgrev were identified as more sensitive to drought: the yellowish tones on the map indicate decreasing soil moisture. Unfortunately, we do not have free access to older satellite images of the region to compare them with the current year's data. The initial analysis of satellite data for 2015 shows that the Pleven region was relatively stable: the Moisture Index gave high values, especially along the Danube valley and in the zones around Trastenik and between Oresh and Levski, where blue-green shades indicate well-hydrated vegetation. However, initial signs of drying are felt in the southern regions—where irrigation canals are already partially filled with silt or water flow has stopped.

By 2025, the situation had reversed. The maps are dominated by orange, red, and yellow spots, evidence of a sharp decline in moisture. NDVI and NDMI show that vegetation activity and moisture have decreased by 35–43% and 65–70%, respectively, in the three critical zones. Places that previously had dense vegetation are now marked by dry stubble, abandoned fields, and thinning forest masses (Figure 2). This trend is supported by climatic data—prolonged droughts combined with temperatures above 37–39°C dry out the soils and turn accumulated dead biomass into easily flammable material. Satellite images for this period show predominantly orange, red, and yellow zones where green and blue tones previously dominated. This is a clear visual indicator of a strong decrease in moisture in the soil and vegetation. NDVI in the Trastenik area dropped to 0.42, and NDMI to 0.12; in the village of Izgrev,

NDVI decreased to 0.33, and NDMI to 0.09; in the zone between Oresh and Levski, NDVI is 0.38, and NDMI is 0.10. These numbers show that the green biomass has thinned, and the moisture in the plants has dropped to almost critical levels.

Figure 2

Soil moisture and dry vegetation in Pleven region in 2025



Source: Copernicus satellite

Despite these relatively high values, the 2015 images show initial signs of drying. In the southern and western parts of the region, orange-yellow spots appear, indicating decreasing soil moisture. These color gradations are most visible in areas far from natural water sources and in regions with intensive agriculture without sufficient irrigation. Although the drought then seemed weak, it was the first sign that climatic conditions in the region were changing. Average summer temperatures began to rise, and rainfall became more unpredictable. Even at this stage, the zones around Trastenik and Izgrev were identified as more sensitive to drought: the yellowish tones on the map indicate decreasing soil moisture. Unfortunately, we do not have free access to older satellite images of the region to compare them with the current year's data. The initial analysis of satellite data for 2015 shows that the Pleven region was relatively stable: the Moisture Index gave high values, especially along the Danube valley and in the zones around Trastenik and between Oresh and Levski, where blue-green shades indicate well-hydrated vegetation. However, initial signs of drying are felt in the southern regions—where irrigation canals are already partially filled with silt or water flow has stopped.

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Drought is particularly severe in agricultural zones, where lack of irrigation and land abandonment lead to the accumulation of dry biomass. This is evident around the village of Izgrev, where about 70% of the moisture (according to NDMI) has been lost compared to 2015. In the Trastenik area, NDMI decreased by more than 65%, placing the zone in the "high fire risk" category. Between Oresh and Levski, where some lands have been abandoned, NDMI dropped by almost 69%. Here, thermal data (LST) show surface temperatures up to 39°C, which further increases stress on vegetation and makes plant material more flammable. Even the zones around watercourses, which in 2015 were "oases" of moisture, now appear lighter on the map, meaning they are also affected by drought.

The reasons for these changes are complex. Climate change is the main factor: in Northern Bulgaria (including the Pleven region), there is a trend toward longer summer periods without rainfall and rising average temperatures. These conditions lead to faster evaporation of moisture from the soil and plants. A second factor is the change in land use—decreasing cultivated areas, abandonment of irrigation canals, and partial deforestation. When agriculture is not actively managed, plant residues accumulate and dry out, creating potential fuel. This is compounded by anthropogenic influences such as unregulated use of water resources, lack of modern irrigation systems, and practices that do not account for the changing climate.

As a result of the long-term lack of maintenance in the Pleven region, the environment and agriculture are increasingly feeling the consequences of drought and infrastructure degradation. During socialism, canals were built here to transport water from the Danube, Osam, and Vit to agricultural masses, but since 2005, much of this system has collapsed—pipes and facilities have been left to decay or sold for scrap. This leads to "waterlessness" in the broad sense: during hot months, the soil dries out, and grain crops such as corn and sunflower are grown without irrigation, worsening yields. Water canals are silting up and being abandoned, and riverbeds are not being cleaned sufficiently. This disrupts the hydrological regime, leading to more spring floods and long periods of drought in summer. The lack of regular maintenance also creates conditions for the spread of invasive species. Along the Danube and Osam, alluvial forests are forming, which should act as "green buffers," but instead of local species—poplars, ash, alder—the aggressive *Amorpha fruticosa* (black locust) is spreading. This shrubby acacia was introduced as an ornamental plant but has now become a dominant species. It forms impenetrable, dense masses, retains sediments, and alters the flow of rivers. In spring, these dense "living dikes" obstruct the normal spread of water and cause floods, while in summer, they hinder water circulation, creating artificial swampy areas in some regions and draining moisture from others. Invasive species displace native trees and shrubs, which have deeper root systems and better ability to retain moisture, thus reducing the natural resilience of ecosystems to drought and fires. To improve landscape resilience, experts recommend reforestation with species that retain moisture longer and are more fire-resistant. Suitable plants include broad-leaved trees with thick bark and high moisture content in their tissues, such as some oaks and plane trees. A particularly indicative example is

the cork oak (*Quercus suber*), whose bark contains many air cells and burns slowly; these thermal properties make cork oaks a natural "fire-retardant" belt. The slow burning of the bark acts as a barrier, and when burning, it does not release strong smoke. Other species suitable for climatic conditions similar to Pleven's include ash, elm, and dogwood; they have powerful root systems that penetrate deep into the soil and can extract water from deeper layers, maintaining high moisture content in the tissues even during drought. Red berried shrubs such as hawthorn, rosehip, and cornel also retain moisture longer and are less flammable compared to coniferous species. Comprehensive measures to alleviate the problem include several directions. On one hand, it is necessary to restore and modernize the irrigation infrastructure: build new canals or wells, repair pumping stations, and regularly clean existing waterways. Rivers need to be reviewed more often—strengthen banks, remove invasive species, and restore natural riparian forests. Reforestation should focus on drought- and fire-resistant trees and shrubs adapted to the new climatic regime. The integration of new technologies—satellite monitoring, early warning systems, and algorithms that analyze fire and drought risk in real time—is also important. Training local communities in sustainable practices and introducing flexible irrigation solutions, such as drip irrigation and rainwater harvesting, are also part of the long-term strategy. Only a combination of infrastructural, ecological, and managerial measures can restore the balance of ecosystems and reduce fire risk in the Pleven region.

Predicting future drought and fire risk for 2026 requires predictive models. A simple linear regression approach, using the rate of NDMI decline over the past decade, suggests that moisture in the Trastenik area could decrease from 0.12 to about 0.097, in the village of Izgrev from 0.09 to about 0.069, and between Oresh and Levski from 0.10 to about 0.078. However, these values do not account for potential changes in precipitation or irrigation measures. Therefore, more complex methods based on artificial intelligence are more appropriate. Regression models and algorithms such as **Random Forest** analyze the relationships between the moisture index, temperatures, precipitation, and land use, deriving the influence of each factor on the final value. Neural networks—especially recurrent **LSTM**—allow the inclusion of time dependencies and cyclic climatic phenomena; they can "remember" periodic dry and wet years and predict how they will affect the moisture balance. Combined models (ensembles) that integrate the advantages of linear, tree-based, and neural approaches provide the most stable results because they average different forecasts, thus capturing both long-term trends and short-term anomalies.

Risk management recommendations must consider the local context. First, restoring the irrigation network—no matter how expensive—would return some balance to moisture levels. Where it is not possible to restore old canals, local solutions can be used: drip irrigation, micro-dams, or rainwater storage. Second, revising the beds of the Danube, Osam, and Vit, removing invasive *Amorpha fruticosa*, and restoring typical riparian habitats such as alder, ash, willow, and poplar would help achieve a more natural water regime—fewer spring floods and better water retention in summer. Third, renewing forest plantations with more drought-resistant species and creating firebreaks is important because old monoculture plantations of acacia and pine are proving unsuitable under the new climatic regime. Finally, introducing an early warning system that combines satellite data, ground observations, and predictive AI models could give local authorities a few days or weeks of lead time to react—limiting fire outbreaks, organizing irrigation, and warning the population.

These factors have consequences that affect not only natural ecosystems but also the economy and human security. Drought and high temperatures increase fire risk, which can destroy forests, agricultural crops, and infrastructure. The loss of biodiversity

is another serious consequence: some plant and animal species cannot adapt to drier conditions and disappear from the region. Economic losses are significant because reduced yields from agricultural lands and the destruction of forest resources directly affect the incomes of farmers and the local labor market. All this makes it important not only to understand the trends but also to develop adaptation strategies.

3. Recommendations for Management and Adaptation Measures

To make reliable forecasts for drought and fire risk, it is not enough to rely solely on historical trends. The climate in the Pleven region is changing rapidly, and the state of vegetation and soil moisture is subject to many local and global influences. Traditional linear extrapolations are useful because they show the general trend; for example, it was calculated that if the current rate of NDMI decline continues, moisture in the Trastenik area will drop from 0.12 to about 0.097, and a similar percentage decline is expected in Izgrev and the zone between Oresh and Levski. However, this approach does not account for the variability of precipitation, local effects of land use, and interactions between different factors. For example, a normal situation can be interrupted by a rainy month, and increasing irrigated areas or revising canals can change local dynamics. For this reason, modern practice is moving toward complex models that include a wide range of variables—climatic, biophysical, and anthropogenic.

The first important step is the integration of different data sources. Satellite images provide spatially detailed maps of vegetation activity and moisture in vegetation, combining soil and plant moisture. They allow spatial patterns to be discovered, such as the fact that in the most drought-affected zones, NDMI has dropped by 65–70% compared to 2015, and NDVI has decreased by about 35–43%, thinning the vegetation cover and increasing the likelihood of fires. It is important to add data on surface temperature (LST) to highlight hotspots, as well as data on topography, soil type, proximity to water sources, and human activity (e.g., the presence of roads, settlements, irrigation canals). Ground measurements—meteorological stations that measure precipitation, temperature, and air humidity, and sensor systems that monitor soil moisture at different depths—also contribute to more accurate forecasting. When all this data is combined into a spatial database, a multidimensional "portrait" of the Pleven region is obtained, which can be analyzed by different models.

Regression modeling is one of the classic approaches in predictive ecology. It seeks dependencies between a dependent variable (e.g., soil moisture level) and multiple independent variables (NDVI, NDMI, precipitation, temperature, elevation above sea level). Simple linear regressions provide general trends, but for complex systems like the ecosystems of Pleven, more advanced versions such as multiple linear regression, polynomial regression, and even logistic regression are applied when predicting the probability of a specific event, such as the occurrence of a fire. These models perform sensitivity analysis to see which factors have the strongest influence—for example, whether temperature is more critical than precipitation or whether the degree of irrigation can compensate for temporary droughts.

Machine learning builds on regression methods. Algorithms such as Random Forest and Gradient Boosting create an ensemble of "decision trees"—small models that explore different combinations of factors and determine how they affect the outcome. In Random Forest, each "tree" is trained on a random sample of data and analyzes a random subset of variables, reducing the risk of overfitting and providing more stable predictions. Such models can show, for example, that the combination of low NDMI, high LST, and proximity to abandoned agricultural lands increases fire risk more than each of these variables individually. Gradient Boosting, on the other hand,

creates sequential models that attempt to correct the errors of previous ones, thus approaching the nonlinear dependencies that ordinary regressions cannot capture. Neural networks, and more specifically recurrent networks (RNN and LSTM), are particularly useful when analyzing time series. LSTM models can "remember" how moisture and vegetation indices have changed over the years and discover cyclic patterns that depend on local climatic phenomena. For example, when trained on a 20-year series of NDVI, precipitation, and temperatures, LSTM can "understand" that after three dry years, a wetter period usually follows and integrate this knowledge into the forecast. Thus, if the model detects a sequence of droughts, it can predict whether 2026 will be a continuation of the drought or whether relief is likely. It is important to maintain these models with updated data, as climate change can alter cyclicity. Identifying risk zones is not limited to index forecasting; mapping the results is also necessary. In practice, this is done by combining predictive values in a GIS. Based on the distributions of NDVI, NDMI, and LST, pixels are classified into categories—such as "low," "medium," and "high" drought. When data on precipitation and temperatures is overlaid, the model can calculate the probability of fire for each cell. Layers such as "invasive species," "proximity to settlements," "irrigated areas," and "abandoned lands" are added. The resulting maps are analyzed to identify sequential "wedges"—areas that annually transition from normal to stressed states and back. These zones, where several risk factors overlap, are prioritized for intervention. For example, if the map shows that the northeastern part of a plot is subject to low NDVI and high temperature for three consecutive years, while the adjacent western sector retains its moisture, this northeastern corner will be declared "high risk."

Innovative technologies also allow the development of dynamic models that operate in real time. AI-based early warning systems use heterogeneous data—from meteorological forecasts and satellite images to information from local sensors—and process them through probability models. For example, if next week's forecast predicts high temperatures and strong winds, and the model notes that soil moisture is already low, the danger level automatically increases, and a signal can be sent to the fire and emergency safety service as well as to the municipality. They can activate local fire teams, restrict access to certain areas, or encourage farmers to perform preventive irrigation. Intelligent systems are also used in irrigation: sensors placed in fields measure soil moisture in real time. This data is sent to the cloud, where an AI algorithm compares the current value with the optimal one for the specific crop and growth phase; if the moisture is below the critical threshold, the system activates the irrigation system automatically. The same algorithm considers the precipitation forecast to avoid unnecessary irrigation.

It is important to note that modern models for risk prediction and mapping are not black boxes. Their results can be visualized in a user-friendly interface where the regional specialist or forest engineer sees maps with different color scales on their screen: red warns of critical risk, orange of moderate risk, and green of low risk. These maps can be updated daily or weekly and downloaded to a mobile phone. When data on planned interventions (e.g., where mechanical cleaning of dry biomass has taken place) is added to the map, their impact on risk can be assessed. This set of technologies—satellite monitoring, AI models, and dynamic mapping—must be combined with practical field actions. For example, when developing risk maps, it is important to conduct validation checks: teams can take soil samples in zones identified by the model as critical and confirm whether the moisture is indeed low. This process not only improves the accuracy of forecasts but also allows local people to participate in monitoring. Their feedback further "trains" the model, adapting it to the specific conditions of the region.

Satellite platforms and intelligent sensor systems enable detailed monitoring of vegetation, soil moisture, and surface temperature. Data on NDVI, NDMI, and Moisture Index can be updated with relatively high frequency, allowing critical drought zones to be detected long before visible damage occurs. When this data is combined with ground measurements of precipitation and temperatures and analyzed using artificial intelligence, predictive models are obtained that forecast how conditions will develop in the coming months or years. Simple linear models serve as a starting point, but in the real world, they are supplemented by more complex algorithms—**Random Forest**, **Gradient Boosting**, and recurrent neural networks (**LSTM**)—which can process large data arrays and capture nonlinear and cyclic dependencies. These models produce a risk map where each point is evaluated according to the probability of becoming the epicenter of a fire or severe drought. It changes dynamically, reflecting new meteorological conditions, changes in land use, and the effects of measures taken. In Spain and Portugal, similar systems are already used for fire management; fire risk indices calculated through artificial intelligence determine where the most resources should be sent. In Italy, drought prediction models are combined with economic data to predict how water deficits will affect different crops.

However, technologies alone are not enough. Nature is a complex and interconnected system in which small changes can have major consequences. Therefore, risk management must be based on an understanding of ecological processes and the use of natural regulation mechanisms. One of the most neglected but highly effective ways to reduce fire hazard is the use of small livestock. Controlled grazing by goats and sheep in forest areas is a proven tool for reducing fuel accumulation and fire risk. Goats and sheep can significantly limit the amount of dry forest and grass biomass that serves as fuel for fires. They feed on flammable shrubs and grasses, including *Amorpha*, and thus "mow" the understory in forests, creating natural firebreaks. In Spain and Portugal, sheep flocks are used purposefully to maintain buffer zones around villages—animals graze in strips 50–100 meters wide that separate forest plantations from agricultural and residential areas. Thus, if flames approach, there is not enough fuel for them to spread. In Bulgaria, there are also examples where goats released into forest masses with many hawthorns and dog roses reduced dry biomass by 40–50% in a single season. Additionally, livestock naturally fertilizes the soil and attracts insects such as beetles and ants, which aerate the soil and contribute to nutrient cycling. In some areas, larger animals—such as cattle or buffalo—are used to maintain wet zones and create ponds that act as natural fire buffers. Their heavy hooves trample the grass and create small water puddles where moisture is retained longer. Similar policies function in Andalusia, Spain, as part of the regional fire prevention policy.

Conclusion

The study of climate and ecological changes in the Pleven region reveals alarming trends that require immediate and coordinated action. Data from satellite observations and analysis of vegetation activity and soil moisture indices indicate a dramatic deterioration in the region's ecological condition over the period 2015–2025. The reduction of soil moisture by up to 70% in critical zones, the thinning of vegetation cover, and the increasing fire risk are not just ecological problems—they threaten economic stability, human security, and the sustainable development of communities. Particularly concerning is the state of irrigation infrastructure, whose degradation exacerbates the effects of climate change and creates conditions for frequent droughts and fires. These processes highlight the need for deep integration between scientific knowledge, technological innovations, and practical solutions. Without

coordinated action among institutions, local communities, and economic actors, risks will continue to deepen, with serious social and economic consequences.

One of the most significant conclusions is that effective solutions require a multidisciplinary approach. Modern technologies, such as satellite systems, geospatial analyses, and artificial intelligence, provide powerful tools for monitoring and predicting risks, but their effectiveness depends on the collaborative work of specialists from different fields. For example, combining data on groundwater with satellite moisture indices would allow more accurate mapping of water resources and the development of strategies to overcome water scarcity. Collaboration among geologists, hydrologists, agronomists, and climatologists would lead to the creation of sustainable agricultural and forest ecosystems capable of adapting to changing conditions. The introduction of innovations—such as restoring irrigation systems, using fire-resistant plant species, and creating early warning systems—shows that the region is ready to embrace technological progress as part of its development strategy. However, this requires not only scientific precision but also the active participation of local communities, who must be trained and motivated to apply sustainable practices. Ultimately, the sustainable future of the Pleven region depends on the ability of different specialists, institutions, and citizens to work together, combining traditions, innovations, and responsibility toward future generations.

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