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Forest fires: consider preventive measures, not just reactive ones

Abstract

Fire results from the interaction between an ignition source and landscape vegetation; meteorological variables and the nature of the fuel influence the ignition of fires. The meteorological variables to consider include temperature, wind speed and direction, relative humidity, solar radiation incidence, and atmospheric stability. Rising temperatures during the hot, dry season lead to lower relative humidity, affecting the moisture content of dry fuels and increasing their flammability. Wind speed promotes the spread of flames; the most dangerous situations are accompanied by strong, dry winds. Fuel—specifically, the chemical composition of the vegetation—determines its energy content and flammability; the moisture content of both live and dead fuel is significant, particularly from May to October, the dry season characterized by a lack of precipitation. If the fire encounters conditions favorable to its spread, it sweeps across vast areas, inflicting severe damage on vegetation, wildlife, and the soil, and causing ecological, economic, and social losses. Data on meteorological al variables were obtained from SENAMHI stations. The analysis of fire incidence utilized fire data from INDECI, as well as the physical evidence method to reconstruct the progression of a forest fire and classify its cause. Finally, a predictive fire model was applied to the vegetation cover, taking into account the interaction between physical and climatic factors. The report indicates that over 95% of the causes are anthropogenic, and recommendations—such as the early detection of at-risk areas and public policy measures—are outlined. Wildfires destroy vast areas of vegetation, acting as a primary driver of habitat and ecosystem fragmentation while contributing to deforestation, erosion, and desertification.

Keywords: vegetation cover, irradiation, prevention, scrub, pyrophytic

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Introduction

According to INDECI,[1] it is estimated that the majority of forest fires in Peru are of anthropogenic origin, as one of the main causes is related to activities such as clearing land for farmland and burning pastures. During the period under analysis, these forest fires affected 93,365.80 hectares and destroyed 94,239.90 hectares of vegetation cover; in total, 187,805.40 hectares of cropland were affected.

According to SERFOR reports (Forest Fire Prevention and Risk Reduction Plan for 2019–2022), there were 587 forest fires during the 2012–2016 period, with the department of Cusco reporting the highest number of forest fires, at 130 incidents; followed by the departments of Puno and Apurímac.

According to studies by CENEPRED[2] and INDECI,[3] Cusco presents forest fire risk scenarios classified as very high risk. Likewise, it was found that, for the region, most fires occur between July and October. This data is associated with the dry season, when fire is used in agricultural practices and land-use changes (Figure 1) (Table 1).[4,5]

Table 1 Average monthly maximum, minimum, and mean temperatures (23-year averages: 1993–2018)

MES	$T_{máx}$ (°C)	T_{min} (°C)	T_{med} (°C)	Precipitación (mm)
January	19.1	7	13	138.8
February	19.1	6.9	13.1	116.1
March	19.4	6.5	12.9	99.6
April	19.9	3.9	11.4	47.3
May	20.2	0.8	10.1	7.0
June	19.1	-1.7	9.1	2.7
July	19.7	-2	8.5	4.4
August	20.2	0.1	10.1	7.2
September	20.1	3	11.8	21.7
October	21	5	12.9	50.4
November	21.2	6	12.1	70.3
December	20	6.5	12	105.7
Annual average	19.9	3.5	11.4	671.2 Total Annual

Source: SENAMHI, K'ayra Weather Station, Cusco. 2020.

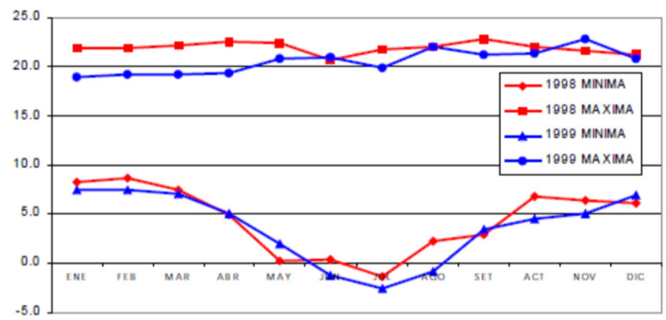


Figure 1 Average temperatures recorded for Cusco.

Source: SENAMHI, K'ayra Weather Station, Cusco. 2010.

Analysis of the climate data presented by SENAMHI over a significant 23-year period indicates that the lowest temperatures are recorded from April through September, and the highest temperatures from August through December; the driest months span May through August, with intermediate months such as April, September, October, and November; the rest of the year is rainy.

Methodology

Information on meteorological variables—primarily temperature, relative humidity, and precipitation—was obtained from weather stations managed by SENAMHI in the Cusco Region. To analyze the incidence of fires, their cumulative duration, the number of simultaneous fires, and the size of the burned areas, fire data from the General Statistics on Forest Fires, provided by CENEPRED,[2] were used. In addition, the physical evidence method was used;[6–9] this investigative technique allows for the reconstruction of a forest fire's progression by studying the fire's behavior, ultimately determining its point of origin and, once identified, classifying the cause that triggered it. In this way, it will be possible to definitively dispel popular myths, which have traditionally linked the origin of wildfires to various motives—a practice that, in addition to misleading the public, has undermined the basis for many of the preventive measures undertaken, rendering them ineffective.

Finally, a predictive model for wildfires based on vegetation cover was used, which involves developing a methodology that accounts for the interaction between physical and climatic factors,[10] from a geospatial perspective, taking into account meteorological and fuel variables that help explain fire behavior,[11] along with socioeconomic factors (land use); in this regard, variables have been identified and analyzed that serve as inputs for the predictive model, based on the identification of variables that define the local characteristics inherent to a fire. The predictive model must be applicable to any situation within the national or regional territory; for this reason, priority must be given to variables that provide information for the entire analyzed scenario. Accordingly, we have chosen to work with meteorological data related to precipitation, temperature, wind, and relative humidity, along with physical variables such as slope, fuel type, vegetation cover, and biomass.

Results

Variables involved in a fire.

The most important variables required for prevention are as follows:

Territorial factors:

a. **Fuel (vegetation cover)**. The type of vegetation determines the intensity of the fire; this intrinsic characteristic of vegetation confers a certain degree of likelihood that it will ignite, spread, and sustain the fire; this is known as combustibility.[12] The abundance of vegetation is one of the key variables to consider; among the hazard variables is the predominant fuel type, which is linked to pre-existing plant biomass. This variable is classified based on vegetation cover, and the hazard level increases as the fuel becomes more prone to rapid ignition—as is the case with grasses, crops, shrubs, and pastures.

b. **Slope**. When a fire breaks out, it spreads more readily on steep slopes, where the flames come closer to the fuel and propagate the fire through radiation, convection, and contact with preheated, dry vegetation; in turn, the terrain's morphology interacts with environmental conditions such as winds and solar heating to either promote or retard the fire.[13,14] The level of natural vulnerability is directly proportional to the slope of the terrain.

Climatic factors: Fires are usually preceded by periods of water scarcity. Areas particularly susceptible to wildfires are those with a dry season and high temperatures. Furthermore, fires can be exacerbated by strong winds, which help spread the fire over large areas.[15]

a. **Climate**: SENAMHI generates information corresponding to Peru's climate classification map, based on the Thornthwaite climate classification system.[16] The information covers precipitation, temperature, sunshine duration, winds, the distribution of rainfall throughout the year, and average relative humidity; these variables are categorized as required by the precipitation and temperature model.[17]

b. **Winds**: Rapid fire spread is associated with wind, especially on steep slopes, where local convective updrafts (air heated by the terrain) originate; consequently, the fire tends to rise rapidly, increasing its spread rate toward unburned fuel and causing its rapid ignition.[14,18]

c. **Solar radiation**: The intensity of solar radiation is greatest when the Earth's surface is perpendicular to the sun's rays. The angle of incidence on the surface varies with the time of year, the time of day, and latitude.[19] Vegetation serving as fuel will be drier, causing the fire to advance more rapidly.[20] On an annual basis, the areas with the highest incidence and irradiation of solar energy in the Cusco region are mainly located in the southern sector, where 6.0 to 6.5 kWh/m^2 of solar radiation, while areas with low solar radiation values are found in the north and are primarily in the department's Amazonian region, with values ranging from 4.5 to 5.0 kWh/m².[21]

d. **Potential evapotranspiration**: This is one of the variables in natural hazard analysis that also has a high degree of influence. According to SENAMHI,[22] evapotranspiration is approximately 830 mm/year for the Andean region of Cusco and exceeds 1,200 mm/year for the regional Amazon. The hazard level is directly proportional to the values of potential evapotranspiration.

e. **Monthly cumulative precipitation**: This is one of the variables in natural hazard analysis with a high influence value.

f. **Maximum temperatura**: The influence value is high. Areas with higher temperatures will be directly proportional to the hazard posed by this factor.

These climatic factors are generated by SENAMHI; therefore, the data is readily available and freely accessible, leading to the conclusion that the key to controlling a fire and reducing the damage and public alarm it causes is prevention.

Prevention measures to be considered

Measures or actions implemented through regulations or initiatives to prevent or reduce the destructive impact of wildfires must include:

1) Technical studies,
2) Engineering,
3) Formulation and Dissemination,
4) Legal Framework
5) Modeling and Forecasting.

The prevention strategy must take into account various variables: analysis of hot spots, meteorological conditions, fire occurrence statistics (recurrence, impact, affected area, etc.), topography, identification of vulnerable areas, and institutional strengthening to develop capabilities in forest fire prevention and risk reduction. Given that there is a latent risk of a fire breaking out, a prevention program must be implemented to ensure the availability of the human resources (trained personnel), materials (specialized equipment), and organizational resources (planning) necessary to address such an eventuality; the following should be considered:

Vegetation ecosystems susceptible to burning:

a. Shrubland

An ecosystem sensitive to fire due to its dry conditions and abundance of combustible material; fire causes death, fragmentation, degradation, and possible disappearance of these ecosystems. This vegetation cover constitutes an important resource because it serves to protect watersheds and provide firewood and medicinal plants to the community (Figures 2A-2D).

b. Andean or montane forests (cloud forests, relict Podocarpus and Polylepis forests, dry forests in inter-Andean valleys) have a very low response to fires; they do not regenerate easily and have difficulty returning to their original conditions (low resilience); they are plant communities not adapted to fire (Figures 3A and 3B).

c. Savanna vegetation

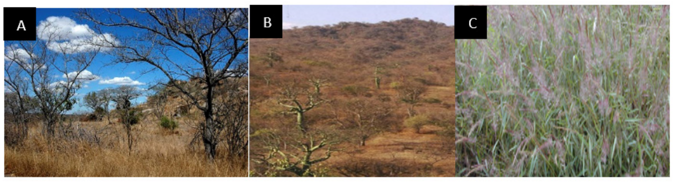
Characterized by a tree-shrub layer with sparse tree canopy cover, either due to small trees or low tree density. During the dry season, it is highly combustible and burns easily (Figures 4A-4C).

d. The Andean grassland. During the dry season (April–November), it has low relative humidity, temperatures above 22°C, strong winds, and high flammability; therefore, it is susceptible to fires (Figures 5A and 5B).

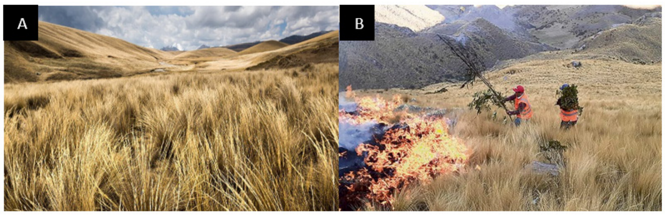
e. Plantations of exotic species, such as eucalyptus (*Eucalyptus globulus*) and pine (*Pinus radiata*), are found at elevations up to 3,800 meters above sea level. These species are pyrophilic because they contain volatile oils (in the case of eucalyptus) and resins (in the case of pine); they accumulate litter that is slow to decompose, facilitating the spread of wildfires (Figures 6A and 6B).

Figures 2A-2D Thorny scrubland is an ecosystem highly vulnerable to fire. It must be identified and georeferenced for use in prevention efforts.

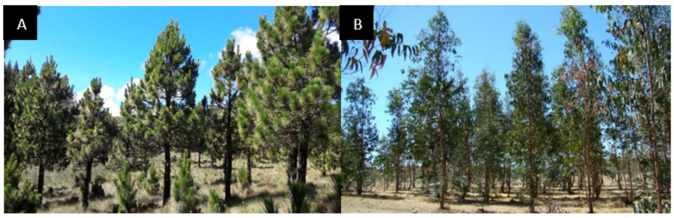
Figures 3A and 3B Montane forests, because they are residual, and thorny scrub, because it is highly combustible, deserve special attention in fire prevention efforts.



Figures 4A-4C Savanna vegetation consists of Wilka (*Piptademia spp*.); Pisonay (*Erithrina spp*.); Palo santo (*Triplaris sp*.); Mot'e mot'e (*Citharexylum sp*.); Huarango (*Acacia huarango*); P'ispita (*Acalypha sp*.); Chamba (*Mimosa sp*.); and algarrobo (*Prosopis pallida*). During the dry season, this vegetation is highly combustible. It is important to consider the introduced grass with a high content of essential oils and resins: Gordura grass (*Melinis minutiflora*). Location is important for prevention.



Figures 5A and 5B The Andean grassland consists of various grasses that, during the dry season, serve as highly flammable fuel. Geolocation is of utmost importance in prevention efforts.



Figures 6A and 6B Plantations with pyrophilic exotic species (Pinus, Eucalyptus) contain essential oils and resins that promote the spread of fire.

Prevention measures:

a. Identification of high-risk áreas: It is important to have information on the most vulnerable zones, and these should be prioritized for the implementation of relevant prevention measures;[23] the georeferencing of ecosystems by competent authorities such as SERFOR, regional and local governments, and sectors such as agriculture and others is of vital importance.

To categorize the types of risks that typically arise, the framework known as Karl Lewinsking's Traffic Light System—transcribed below—should be used, as it includes various preventive actions. To determine high-risk areas, factors such as the number of fires that have occurred and their recurrence, the volume of people, uncontrolled access, activities carried out by visitors, and sites where crop residue and dry material accumulate are considered (Table 2).

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Table 2 Karl Lewinsking's traffic light system

Description	Low risk	Medium risk	High risk	Very high risk
Temperature	Up to 25 °C	Up to 30 °C	30 °C to 36 °C	Above 36 °C
Relative humidity	Up to 50%	Up to 40%	Less than 20%	Below 10%
Wind wind	0 to 10 km/h	10 to 20 km/h	Above 20 km/h	Over 30 km/h
Vegetation (fuel)	Semi-humid	Dry	Dry or very dry	Very dry
Clear	Cloudy	Cloudy to partly cloudy	Sunny to partly cloudy	Sunny
Status	Favorable	Pre-alert	Alert	Alarm
Traffic Light	Green	Yellow	Red	Critical red situation
Actions	Monitoring Normal	Monitoring and detection measures detection Constant	Intensive monitoring and measures in all critical areas	Monitoring and constant with emergency services
	Routine	Permanent	Surveillance Permanent	Extreme surveillance
	Prevention of ROUTINE	Prevention CONSTANT	Prevention URGENT	Prevention EXTREME

Source: FAO, 2007.

It should be noted that most of the information required to use the Lewinsking traffic light system can be provided by SENAMHI.

b. **Construction of firebreaks:** These are paths that every afforestation and reforestation project must include; they prevent fire from consuming all vegetation and act as a barrier to stop the fire from spreading; furthermore, they allow access for vehicles and machinery used for fire control (Figures 7A and 7B).[24]

c. **Construction of fire reservoirs**: Field infrastructure must include the construction of reservoirs to store water for supplying vehicles used to control fires during fire events (Figures 8A and 8B).

d. **Public policies to be implemented:** Many countries have implemented policies, legislation, and emergency measures to control and combat both wildfires and air pollution, as well as to minimize their consequences.[25]

With the proper information, forest fires can be predicted, which would allow for the design and implementation of efficient prevention strategies and measures. It is essential to raise awareness about forest fire prevention as a way to avert a potential forest fire, rather than incurring the costs and potential human and material losses associated with fighting a full-blown forest fire.

Figure 7A and 7B The construction of firebreaks is important in any afforestation and reforestation project.

Figures 8A and 8B Forest fire control infrastructure must include the construction of reservoirs to supply water to firefighting vehicles.

The objectives of these policies are:

1) To prevent and control fires;
2) To protect public health and safety during these events;
3) Prohibit open fires;
4) To introduce and implement guidelines and standards on air quality;
5) Strengthen the control of emissions from mobile and stationary sources;
6) Strengthen the capacities of the relevant agencies; and
7) Strengthen cooperation and support among the agencies involved.

e. **Early detection:** This aims to detect, locate, and report the presence of a fire while it is still in its early stages. This requires constant monitoring of all areas and an adequate communication system among the departments responsible for personnel safety.

Competencies and responsibilities:

a. **National Forestry and Wildlife Service (SERFOR). Competent authority.**

The Fire Risk Prevention and Reduction Plan (Executive Directorate Resolution No. 284-2018-MINAGRI-SERFOR-DE)[26] includes, among other aspects:

1) An assessment of the causes and environmental impacts of forest fires and pests.
2) Strategies and mechanisms for coordination, supervision, and control.
3) Implementation of a system for the prevention and control of forest fires and pests in critical areas.
4) Education campaigns for the prevention and control of forest fires and pests.
5) Annual work plan.
6) Follow-up, evaluation, and monitoring (Figures 9A–9D).

This Forest Fire Prevention and Risk Reduction Plan, approved for the 2019–2022 period, grants SERFOR significant authority as the governing body for forest and wildlife management.

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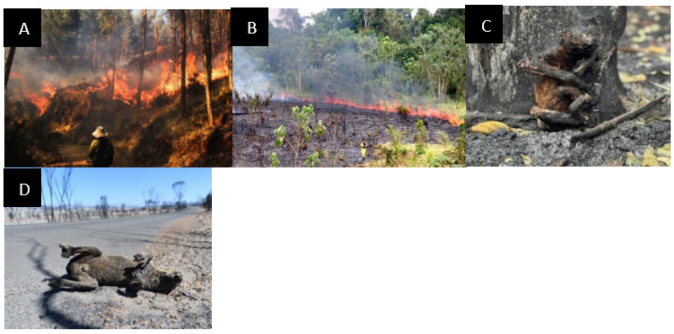

Figures 9A-9D Fires destroy habitats and kill wildlife.

Article 24 of Law No. 29763[27] states that the National Forest and Wildlife Plan includes aspects of forest fire prevention and control, and Article 73 promotes the reduction of the vulnerability of Andean forests to climate change. The aforementioned Plan for the Prevention and Reduction of Forest Fire Risks grants significant authority to SERFOR as the governing body for forest and wildlife management.

Supreme Decree No. 018-2015-MINAGRI approves the Regulations for Forest Management and, in Article 20, states that the Forest and Wildlife Management Committees (CGFFS) carry out various actions, such as promoting and implementing activities aimed at preventing forest fires; Decree-Law No. 1237-2015, in Article 310, states that it constitutes an environmental crime, among other offenses, to burn all or part of forests or other wooded areas, whether natural or planted. This regulation amends several articles of the Penal Code (approved by Legislative Decree No. 635 of 1991).

There is a sufficient legal framework, as well as competent authorities such as SERFOR—the governing body of the forestry sector with specific responsibilities—MINAM, and the PCM, which is in charge of disaster management; other sectors such as the Interior and Education ministries; and regional governments and municipalities, which must work in close coordination to implement the mandates related to the prevention and control of forest fires.

SERFOR, in its capacity as the National Forestry and Wildlife Authority—responsible for promoting the sustainable management of forest and wildlife resources—presents the Plan for the Prevention and Risk Reduction of Forest Fires; consequently, this agency is responsible for promoting the plan, forming surveillance committees, and training other sectors in the prevention and control of forest fires throughout the country.

b. Responsibility of local government.

The Organic Law on Municipalities (Law 27972) mandates in Article 09. Powers of the Municipal Council, paragraph 7: *"to approve the SLGA and its* instruments….”; the local environmental management system, which constitutes an institutional management tool, must include the prevention and control of forest fires within the municipal jurisdiction; furthermore, Article 73: Competence of Municipalities, paragraph 3. Protection and Conservation of the Environment. 3.3 states: *"Promote* environmental education….”; that is, the municipality must actively and dynamically promote environmental education that leads to the protection of its ecosystems; similarly, Article 79, 1.4.7, relates to environmental impact assessments (EIA), and Article 80. 1.2 mandates: *"to regulate and control the emission of smoke,* gases…”; consequently, provincial or district municipalities have powers and responsibilities regarding fire incidents; unfortunately, these responsibilities are not being fulfilled, nor are preventive measures being promoted.

c. **Regional governments**. Investment projects in afforestation, reforestation, and ecological restoration in the Cusco Regional Government have been carried out with adequate human, logistical, and financial resources; however, preventive measures are still lacking (Figures 10A–10C).

The information generated by SERFOR and SENAMHI must be disseminated and utilized for prevention and planning across all sectors, especially at the local government level; it is important to note that mayors chair the Civil Defense Committee and are responsible for developing and coordinating all measures aimed at predicting and preventing disasters of any origin—including, without a doubt, wildfires.[28]

d. Universities should promote research on fire-vulnerable ecosystems within the region; restoration processes; fire ecology; the biology of forest species; soil erosion; revegetation; and other aspects related to fire prevention.

Forest fires contribute to climate change primarily due to the emission of greenhouse gases (GHGs) from the combustion of biomass and the loss of carbon sequestration associated with the destruction of carbon sinks.

Figures 10A-10C Reforestation and afforestation efforts must prioritize native species.

As outlined, the prevention strategy includes various factors: analysis of hotspots, meteorological conditions, fire occurrence statistics (recurrence, impact, affected area, etc.), topography, identification of vulnerable areas, identification and assessment of fire-prone ecosystems, and institutional strengthening to develop capabilities in forest fire prevention and risk reduction.

With the appropriate information obtained from primary or secondary sources, forest fires can be predicted, which would allow for the design and implementation of effective prevention strategies and measures.

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Conflicts of interest

The authors declare no conflict of interest.

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