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Methodological instruments for the analysis of the severity of fire in vegetation and its perception in the communities

Instrumentos metodológicos para el análisis de la severidad del fuego en la vegetación y su percepción en las comunidades

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Abstract

Forest fires in Colombia have an ecological, economic, cultural and political connotation, in which studies tend to envision their effects on these different areas with a disciplinary approach. However, this article aims to present an analysis of the different methodological instruments, which allow determining the severity of fire in vegetation and its perception in communities, selecting which are the most appropriate from a multidisciplinary approach to Environmental Sciences. Obtaining as a result a mixed methodology, based on a quantitative method in which from the Difference Normalized Burn Ratio the reflected energy of a forest area is analyzed in order to expose the change in the study area before and after the passage of fire, obtaining severity in technical or scientific terms. And a qualitative method where, based on the dialogue of knowledge, the tool entitled "Guidebook" was created so that both parties (researcher and selected actors) can exchange knowledge on how the effects of fire on ecosystems are addressed. This in order to achieve the integration of the scientific and social factor, where each one is complemented and in its execution it is exposed what are the differences or similarities between the interpretation of the severity of the fire on the vegetation by the communities involved and what happens technically in the vegetation.

Keywords: Communities, fire, forest, fires, methodology, severity, vegetation.

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Resumen

Los incendios forestales en Colombia tienen una connotación ecológica, económica, cultural y política, en la que los estudios suelen vislumbrar sus efectos sobre estas diferentes áreas con un enfoque disciplinar. Sin embargo, el presente artículo pretende dar a conocer un análisis de los diferentes instrumentos metodológicos, que permiten determinar la severidad del fuego en la vegetación y su percepción en las comunidades, seleccionando cuales son los más adecuados desde un abordaje multidisciplinar de las Ciencias Ambientales. Obteniendo como resultado una metodología mixta, basada en un método cuantitativo en el que a partir del *Difference Normalized Burn Ratio* se analiza la energía reflejada de un área forestal con el fin de exponer el cambio en la zona de estudio antes y después del paso del fuego, obteniendo la severidad en términos técnicos o científicos. Y un método cualitativo donde a partir del diálogo de saberes se creó la herramienta titulada "Cartilla Orientadora" para que ambas partes (investigador y actores seleccionados) puedan intercambiar conocimiento sobre cómo son abordados los efectos del fuego en los ecosistemas. Esto con el fin de lograr la integración del factor científico y social, donde cada uno se complementa y en su ejecución se expone cuáles son las diferencias o semejanzas entre la interpretación de la severidad del fuego sobre la vegetación por comunidades involucradas y lo que sucede técnicamente en la vegetación.

Palabras Clave: comunidades, fuego, Incendios forestales, métodos, severidad, vegetación.

Introduction

Fire is a natural or induced phenomenon, which originates when a combustible body (living or dead vegetation) receives heat in the presence of air. If it spreads without control or pre-established limits, consuming vegetal material of forestry aptitude or, in those that, without being so, fulfill an environmental function and whose size exceeds 0.5 hectares, it is considered as a forest fire. [1], [2].

For forest fires to be generated, three elements must converge at the same time and place: heat, oxygen and fuel in conditions in which the weather, topography and fuel have a considerable influence on the potential type of fire: surface, subway, and aerial. [3].

In Colombia, it is estimated that the majority (95%) of forest fires are generated anthropically, that is, due to human activity, considered as a type of disturbance that generates large modifications in the vegetation layer, ostensibly modifying the natural state of the ecosystem [4], [5].

The Colombian Ministry of Environment and Sustainable Development (MinAmbiente, as it is commonly called in Colombia) is responsible for "defining the National Environmental Policy and promoting the recovery, conservation, protection, planning, management, use and exploitation of renewable natural resources, in order to ensure sustainable development and guarantee the right of all citizens to enjoy and inherit a healthy environment" [7]; it considers forest fires as an increasingly recurrent phenomenon that must be managed as a risk both for the community and for the vegetation that, as they occur, consume more and more hectares. [8].

In Colombia, due to effects associated with "El Niño" between 2015 and 2016 (which intensified the dry season), a greater amount of area affected by forest fires was reflected with 99,084 hectares (ha), (of which 89% of the area was affected in 2016 with 72,416 hectares (ha) of forest associated with deforestation). These occur especially in the Andean, Caribbean and Orinoquia regions, disturbing Andean rainforests, moorlands, and forest plantation areas, generated by the needs of agricultural and livestock expansion, absence of environmental education and knowledge of risk among the population, according to the National Unit for Risk and Disaster Management (UNGD according to its initials in spanish). [5]

Forest fires have implications or impacts in different areas such as economics, where costs associated with prevention, control, elimination, restoration of affected areas and investment in maintenance of restored areas are generated; these costs can be easily calculated, as they are financial assets.

However, there are also costs that are difficult to compute, such as those associated with the impact that these fires have on nature (such as the loss of ecosystem services) and the implications on public health, whose consequences weigh directly on the welfare of society [9]. In the case of Colombia, considered costs are related to:

Extinction:

- The work of different entities such as the Fire Department (UAECOB), IDIGER, Red Cross and Civil Defense.
- Tools, equipment, protection elements, vehicles, tanker trucks, ambulances, fuel, refreshments, among others.

Economic valuation:

- Hedonic prices
- Loss of land and timber.
- Erosion prevention and diversity.
- CO2 capture
- Aesthetic beauty. [10]

However, the costs associated with the effects of the lack of normal tourist and recreational activities are difficult to quantify in economic and environmental terms, directly affecting the welfare of the social groups that interact. [5].

In the ecological one, due to the diversity of landscape conditions and the diversity of flora, the impacts are variable, this depends on the recurrence, intensity, and duration of the deflagration. The direct effects can be loss of fauna, vegetation, and soil degradation. Indirect effects, on the other hand, can range from soil erosion, water pollution, to landslides. [11].

The vegetation present in a landscape unit at a given time is the product of the influence of multiple factors such as: the climate that determines the potential vegetation of the different bioclimatic zones, the intrazonal variation of vegetation due to the geomorphology and the different The degree of impact or effect depends on the type of fire, its intensity, the type of ecosystem and the severity that is not only related to the frequency (due to fuel accumulation during the interval between fires) and intensity of the fires, but also to the response of the vegetation to the effects of fire; the vegetation that establishes after a fire directly influences future fires and alternative states may occur under presence of species succession. [14], [15].

Among other effects that influence the construction of policies such as the National Code of Police and Coexistence, in Article 30, paragraph 5, which states that burning and fires are prohibited activities, to ensure the safety and integrity of people [16]. Or documents focused on management and prevention such as the national plan for forest fire prevention and control and restoration of affected areas, the guidance booklet for forest fire risk management in the framework of Law 1523 of 2012 and the strategy for social co-responsibility in the fight against forest fires. [17],[18], [19].

However, there is a clearly different vision that arises from Fire Ecology, in which forest fires are phenomena that constitute an environmental factor of low frequency, but of considerable effect, as important as temperature, wind, soil or precipitation, since it determines the structure and functionality of many of the world's ecosystems, contributing significantly to the temporal and spatial heterogeneity of ecosystems. [20].

Understanding what role fire plays in Colombia and how it can be approached from different areas, this article is intended to expose and select the different methods to evaluate the severity of forest fires on vegetation to technically dimension how fires behave beyond the extension consumed by the fires, together with the perception of the community, which is really important since knowing how communities perceive natural phenomena, it is possible to understand the complexity of the phenomenon and why it is an issue associated with loss and damage.

Methodology

This article used the collection of documentary sources such as Scopus, Research Gate, FAO AGRIS and Sciencedirect, which are among the largest databases with access to scientific articles. In addition to the use of academic search engines such as Google Scholar.

The methodological route that was selected basically comprised three stages:

1. Exploration: where the specific topic (such as severity assessment in forest fires) or key words (such as forest fires, fire severity, etc.) are searched in the different search engines, selecting those that have ample information on the subject.

2. Focusing of the information: where the documents from reliable sources are selected. Those can come from institutional sources regardless of the country or from indexed journals.

3. Deepening: where the information is extracted, contrasted with different authors and verified that it is the original author of the exposed information.

Results

After the deflagration, there was no information on the intensity of the fire, causing a lack of operatively useful metrics, for this reason it is necessary to establish its intensity, which is related to the impact on the ecosystems and whose effects can be variable within and between the types of ecosystems. [21].

Fire severity is defined as the "degree to which a site has been freely altered or interrupted by fire, product of fire intensity and residence time" [22], adding to the severity of the severity "Burn Severity " as a qualitative assessment of the pulse of heat that is transmitted to the ground in the presence of a fire, in addition to being related to the heating of the ground, the great consumption of fuel and plant material, the consumption of garbage and the organic layer of the trees and isolated shrubs, and mortality of subterranean plant parts [22]. But it is usually summarized in the resulting conditions of the fire (physical, chemical, and biological effects), which can be described by the degree of mortality in the vegetation above ground. [23], [24].

Technical analysis of forest fire severity assessment methods

There are different methods for severity assessment, but they can be summarized in field methods and remote sensing. The information about field methods is related to data collection through observation, for example the method used by Ryan and Nosle uses the observation of flame height in the area where the fire occurred or in areas of prescribed burns, in combination with the observation of soil characteristics after the burn, to create a matrix that provides the fire severity and the possible response of vegetation according to the classification [24]. Other authors who also use field observation focus on the measurement of factors such as plant death [25], also used by federal (and some state) government agencies in the USA, who conducted a Burned Area Emergency Response or BAER assessment, which focuses primarily on fire-induced soil changes and has often been referred to as the assessment of soil burn severity. Soil testing metric is based on soil organic matter loss [26]. However, this agency currently uses the remote sensing method, seeking to create a severity map (very low/unburned, low, moderate, and high categories) within 7 days of fire containment. [27], [28].

The remote sensing method is a technique that aims to capture satellite images, to later process and analyze them [29]. This is based on the analysis of the energy reflected by the earth's surface, represented in images that denote the reflectivity of the burned areas in the case of the presence of fire [30]. Thus, when a forest fire occurs, the vegetation cover is altered, decreasing the amount of chlorophyll, humidity, and in turn increasing the area of bare soil, altering its color and humidity, producing alter-

ations in the reflectivity patterns, which can be studied by analyzing satellite images. [31].

The use of the remote sensing method has been increasingly employed for the study of fires and not only for their evaluation but also for post-fire recovery processes [32]. The evaluation of fire severity, which is part of fire studies, is based on the collection of satellite images from various remote sensors (e.g. MODIS, AVIRIS) [21], [30] or satellites such as Landsat, which is currently managed by the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA) and the United States Geological Survey (USGS) and is one of the programs with the most missions launched and is very successful due to the combination of spectral band sensors, high spatial resolution and wide coverage in near-polar orbits synchronized with the sun [33]. Another well-known one is the Sentinel satellite, a project of the European Space Agency (ESA) in the framework of the Global Monitoring for Environment and Security (GMES) program, which has 6 missions [34], [35], designed with a multispectral scanner that allows obtaining information depending on the analyzed mission. For example, Sentinel-2 is a multispectral optical satellite of intermediate resolution for the observation of land areas, vegetation, and water, with 13 spectral bands with resolutions of 10, 20 and 60 m, allowing the monitoring of changes in land and vegetation, as well as global monitoring of climate change. [36], [37].

After the selection of images, different indices can be applied to find the severity of forest fires, one of the most used is the Normalized Difference Vegetation Index (NDVI), which allows knowing the presence or absence of vegetation from the measurement of the spectral response of two bands of the electromagnetic spectrum, red (Landsat 8 Band 4, Sentinel Band 4) and near infrared (Landsat 8 Band 5, Sentinel Band 8) [38], [39]. See equation (1) and Table I.

Where:

NIR: It is the reflectance of wavelengths from 0.76 to 0.9 µm.

RED: It is the reflectance from 0.63 to 0.69 µm. [40]

Table I. NDVI Classification

Values	Classification
<0-0,2	Land without vegetation
0, 3-1	Land with vegetation

The next index is the Differenced Normalized Burn Ratio (dNBR). It contrasts the pre-fire normalized burn ratio (NBR) and the post-fire NBR, obtained from the use of the near-infrared and short-wave near-infrared bands. [40].

Where:

NIR: Near infrared

SWIR: Infrarrojo de onda corta [40]

The results of the NBR reflect values between -1 and 1 (where negative values correspond to burned areas) [41]; it is also related to the NDVI, since both measure how much energy is reflected by the vegetation with respect to the incident solar energy. [38].

After the individual NBR is obtained, it is compared and the dNBR index is obtained, which is used to highlight the burned areas and estimate the severity of the fire. [42].

dNBR=NBRpre-NBRpost [41] [43].

Table II.Severity Level and After Burn Regeneration

ΔNBR OR DNBR	SEVERITY LEVEL
<-0.25	High post-fire regeneration
-0.25 A -0.1	Low regeneration after fire
-0.1 A +0.1	No burned
0.1 A 0.27	Low Severity
0.27 A 0.44	Moderate Low
0.44 A 0.66	Moderate High
> 0.66	High

Fuente: Adaptación propia en base de [42].

The last index evaluated for severity is the BAI, the Burned Area Index proposed by [44], which specifically discriminates the area affected by fire on NOAA satellite images - AVHRR (Advanced very high resolution radiometer) [45]. However, it has also been used with Landsat [46] and MODIS [47] images. Based on the spectral behavior between the image values in the near infrared and red with the convergence point defined as the typical spectral response of recently burned areas, for those bands. [48].

Where:

$_{\rho IRC}$ and $_{\rho R}$ are the near-infrared and red reflectivity values, respectively;

pc_{IRC}: 0,06 and pc_R: 0,l, are the convergence values for the near-infrared and red, respectively [44],[49].

Each of these methodologies have been evaluated by different authors such as [44],[47], [50] and different studies that combine the indices, such as the case study entitled "Detection of burned areas in southeastern Mexico, using pre- and post-fire indices NBR and BAI, derived from MODIS composites" that agreed on their similarity by using the same bands to create an algorithm (AQM2008) to detect the areas affected by forest fires in Mexico; However, they emphasize that the NBR achieves a better discrimination of burned areas since the information from the NIR and SWIR bands presents a greater contrast compared to the NDVI index [51]. The latter, agrees with the study entitled "Landscape Assessment (LA) Sampling and Analysis Methods" stating that thanks to its wide range of severity within the burn (depending on the characteristics of the fire), it better portrays the effects of the fire, revealing the complexity and spatial heterogeneity of the burn.

The NBR and BAI indices rather than compared are used together since they are quite similar [48], [51], however, authors such as [45] emphasize that the BAI index should be additionally normalized so that these two indices can be compared or used together.

Since the study area is in private areas and it was not possible to obtain access to them, the remote sensing methodology was selected. The index selected to obtain the severity of the forest fire on vegetation was the dNBR, since the method is constantly used [38], [45], [52], [53], [54], [55]. In addition to being a simple tool, which provides a large spatial coverage and becomes an instrument for the management of management plans, reforestation, and monitoring of burned areas [56]. For the same, Sentinel-2 satellite images were selected since it offers a resolution of 10 m., and the bands conform to what is proposed by the index [41]. A selection of images was made according to their resolution in the study area (images with the least cloud cover and the greatest coverage of the area), and then processed in the ArcGIS software.

Analysis of methodologies for the assessment of the severity of forest fires from the communities.

Forest fires are not an isolated phenomenon in the environment; the environmental problems they generate are closely related to the territory where they occur, both with the ecosystemic, climatic and edaphic characteristics, as well as with the land ownership models, private land (smallholdings or large estates) and human settlements present in these territories where a forest fire may occur. The perception and knowledge of the environmental dynamics, the development perspective, the economic relationship with them and the commitment they have with forest resources, both on the part of the community and the institutions related to forest fires, should be known. To understand the behavior of a forest fire beyond the analysis of physical parameters (climate, vegetation, slopes, etc.) it is relevant to analyze issues that refer "both to the individual level (risk perception, economic characteristics of the population, level of knowledge of the problem, etc.), and to the institutional-administrative level (legislation, land use policy and urban expansion), or the economic level (land value, local development initiatives, risk mitigation initiatives)". [57].

Understanding the perception of forest fires and how their effects are interpreted makes it possible to illustrate the degree of closeness or remoteness with the subject, the disposition and subjective significance with respect to it, contemplating that the origin of these conceptions is multiple and can come from conversations, news, formal education, preconceived ideas, etc. This, however, implies that each perception can be based on a moderately documented knowledge. [58].

To find the perception of stakeholders it is necessary to consider what will be data collection techniques, sampling techniques, the entry scenario, and the qualitative data analysis [59]. The main techniques are:

- Participant observation: This is where the observer participates constantly within the group being studied. The selected actors know their identification in such a way that the group considers them one more of its members. That is, the observer externalizes his participation in the activities and internalizes regarding feelings and concerns. Participant observation can start with a general problem, so that specific analysis scenarios can be defined based on the information collected [60]. Or it can also begin with the observation of a cultural scenario or a human situation, to identify problems that become the object of research. [61].

- Non-participant observation: this occurs when the participants do not see or notice the observer; the tool most used in this type of observation is video and photographs. [62].

- Ethnographic survey: This technique is based on the analysis of the cultural dimensions of the human reality under investigation. The mission is to have an inventory of cultural topics that allows, based on the survey, an exhaustive analysis of these dimensions in the study group. [61].

- The focus group interview: A technique for collecting information in which the researcher promotes and is attentive to the interactions of the participants in the group [63]. It is one of the most used in "applied" research in the fields of marketing, or to discuss important issues affecting specific human conglomerates. [61].

- The structured interview: This technique is characterized as a communicative process in which there is a meeting between researchers and selected actors, in which the interview is previously negotiated and planned [60]. Attitude or opinion surveys and questionnaires are used. It seeks to protect the structure and objectives of the interview. [61].

- Unstructured interview: It is characterized by not having a preset

structure or questions or scripts, but rather the topics of interest are addressed with the interviewee in a spontaneous and open way, so that he/she can express him/herself freely and maintain the conversation based on his/her own interests. [60].

- Participatory action: In this technique, the researcher not only wants to learn about a specific reality or problem, but also aims to solve it or contribute to its solution [64]. This is part of the dialogue of knowledge approach, methodological reference and as a type of action characterized by the recognition of the subjects that participate in the processes and their constant interaction, which allows negotiating to build common elements and differentiation that allow them to initiate joint tasks. [65].

For the use of these instruments, a type of sampling must be selected in a systemic structure that contributes to the research objective [64]. Three types of sampling stand out [60, 66]: purposive sampling, in which the sample is selected deliberately, based on the information needs detected in the initial results. Statistical sampling, in which a subgroup is drawn from a population under the condition that every member of the subgroup has the same chance of being chosen [66]. And finally, chain or snowball sampling, a non-probabilistic tool in which it is established that the members of an initial population have a social network, which can be contacted or referred to access new sources that occupy a relevant position in the research, or scenarios (organization, factory, civil association, etc.) [60], [67].

In an applied case of study, the fundamentals of participatory action were selected with the structured interview, where the starting point was the importance of knowing how the severity of forest fires on vegetation was perceived by the institutions in charge of prevention, response, restoration and monitoring of this type of forest events. But it was not only the intention of the research to extract the information, but it was also relevant to interact with the participants in a continuous way, where the objectives, conceptualization and preliminary findings of the research were presented to reach a dialogue of knowledge and understand from what position they were generating the perception about forest fires. For this purpose, an interactive booklet was created which contains information about the research focused on how the severity of forest fires is perceived on vegetation before, during and after they occur, since when talking about the severity of vegetation resulting from a forest fire, the ecosystemic characteristics prior to the forest fire must be taken into account, as well as the impact generated when the fire occurs, which in this case would be a visual change if perceived, and finally the changes in the vegetation cover.

At the time of selecting the sample, we had the support of the official Bogotá fire department, specifically with the Chapinero B-1 station, which oversees responding to forest fires, so it was taken as an initial sample. Taking the snowball sampling as a reference, the participants of the fire station suggested contacting other institutions of the district commission for forest fire prevention and mitigation (CDPMIF), the main advisory body on forest fires, responsible for dictating the functions of the different institutions and their dependencies, in addition to generating programs directed towards the different stages of forest fire management: before (risk analysis, prevention, mitigation, preparations and alert); during (response) and after (restoration and monitoring) [68]. Thanks to this recommendation, contact was made with actors of the Botanical Garden of Bogotá José Celestino Mutis and the District Institute of Risk Management and Climate Change (IDIGER). Results were obtained from IDIGER, the institution in charge of risk management and prevention, as well as from the Bogotá Fire Department, which oversees the first response to forest fires, and finally the Botanical Garden, which oversees the restoration and investigation of areas affected by forest fires. [68].

Conclusions

As mentioned before, this documentary research is multidisciplinary, in which through the analysis of the different methodological instruments to determine the severity in the two thematic axes exposed, it is intended to answer how is the technical severity of forest fires on vegetation and how forest fires are perceived in the institutions in charge of the control, management and prevention of forest fires; since these were the objectives of the Thesis for which this research was born.

Therefore, the methods associated with the technical detection of fire severity were exposed, finding methodological variations between field research and the remote sensing method. It was found that field investigations were used in the past due to the practicality they provided, however, as technology advanced and the availability of tools such as remote sensing, which is currently free of charge, increased, it moved towards an analysis focused on spatial information, which is currently the most widely used (information based on data collection from 2005-2020).

On the other hand, when analyzing the methodologies associated with the valuation by the communities of the severity of forest fires, it is concluded that the selection of the methodology varies according to the population to be approached and the different variables to be considered, since, although each methodology provides relevant information, the focus of the research and the selected actors are fundamental to respond to the objective.

It should be noted that, although the dNBR index and the combination of structured interview and participatory action methodologies were selected, there are many methods that are applicable and have demonstrated reliability, but for the interest of the final research these were the most appropriate methods for the study and can be easily replicated or deepened in other research. This is why the use of mixed methods for the analysis of complex problems in which it is intended to understand what the technical reality is and how it is approached by the actors related to it, generating a precedent in this type of studies, since being a topic that arises from the technical study that is usually approached disciplinarily, the holistic reality of the problem is not contemplated.

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