ASSESSMENT OF THREAT FROM FIRE AND TORRENTIAL AVENUES. CASE STUDY EXPERIENCE.

ABSTRACT

Climate change and extreme phenomena in the world have been causing countless human and material losses, which has led different governments to take action measures to mitigate and prevent possible natural disasters, from the generation of infrastructure to the creation of laws or guidelines that help normalize processes and action schemes. Specifically in Colombia, and as a consequence of the girl phenomenon that occurred in 2010 and 2011, the risk management law was created by the Congress of the Republic in 2012. This law has obliged the different construction sectors to accommodate new demands and depending on the different types of risks, depending on the type of work to be executed or designed. In this book, a guide is presented to determine the threats from fires and torrential floods that may occur in a typical Colombian basin, taking as reference a specific case study.

Keywords : [fire threats, torrential threats , risk management].

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS

1. INTRODUCTION

The identification of possible risks due to natural disasters in a basin allows the generation of instruments that provide for the mitigation or prevention of these in advance, through coordination between government institutions. This is why, through this guide, we seek to have a basic tool for making decisions and actions that are effective in the face of this problem, for future designs and studies based on this case study (CUENCA-QUEBRADA LA GAITANA, CUBARÁ, BOYACÁ, COLOMBIA).

1.1 HISTORICAL BACKGROUND OF THREATS

1.1.2 Floods occurred in the Quebrada la Gaitana micro-basin

The FAO defines floods as a natural and recurring event for a water flow, as a result of large or recurring rainfall, which exceeds the absorption capacity of the soil and the load of rivers, streams and coastal areas. The micro-basin of the Quebrada la Gaitana river, according to the records of the National Planning Department – DPN and the statistics of the Municipality of Cubara, has recorded the following floods:

Tabla 1. Recorded Flood History in the Gaitana ravine micro-basin.

Date	Paths or rivers with a flood report	Source
1998-06-03	rivers Royota , Cobaria , Quebrada Blanquita and Gaitana. Vereda Blanquita, Cañaguata and Royota affected	SOURCE UNGRD
1999-10-11	Veredas Puerto Nuevo, Cañaguata , La Gaitana , El Guamo, Brisas Del Arauca	SOURCE UNGRD
2006-07-14	The villages of El Cubugan , Cedeño, Mundo Nuevo, La Pista, Puerto Nuevo Upper Part, La Cañaguata , La Gaitana , El Guamo, La Esperanza, La Blanquita, El Royota , Brisas Del Arauca, El Bojaba, Campo Alicia.	SOURCE UNGRD
04/25/2011	Guamo and La Gaitana ravine flood	OPAD
05/04/2012	Bojabá , Gaitana , Cedeño, Fatima , Puerto Nuevo	OPAD
06/01/2015	New PTO, El Guamo, Cañaguata , La Gaitana , La Esperanza, Brisas Del Arauc	OPAD
05/25/2015	Vdas Royota , Brisas Del Arauca, Guamo, Gaitana, Esperanza, La Pista, Bongote , Manzana 001, Br Pablo Vi	OPAD
2016-07-11	Floods generated by the water sources of the Bojaba, Arauca, Cobaria , Quebrada Gaitana and Quebrada Clarita rivers	Corporinoquia
2018-09-07	A downpour that lasted more than 5 hours caused the Róyota River and the La Gaitana stream to overflow.	Snail

1.2 Mass Movements presented in the Quebrada la Gaitana micro-basin

Mass movements are geomorphological processes, by which soil and rock move downhill due to the force of gravity. In the area of the Quebrada la Gaitana micro-basin, there are the following landslide reports:

Tabla 2. Recorded History of Mass Movements in the Gaitana ravine micro-basin.

Date	Description	Source
2016-07-11	Mass removal phenomenon in the villages of Guamo, Bojaba, Brisas del Arauca, Royata , Gaitana , Clarita, Cedeño and Cubugón	Corporinoquia

2 THREAT ZONING

2.1 Forest Fire Threat Zoning in the Quebrada la Gaitana micro-basin

Forest fires are defined as the spread of fire, without control, through vegetation and endangering people, property and the environment. Below, the fires that occurred in the La Gaitana micro-basin are presented, based on publications from various media and the UNGRD.

Tabla 3. Recorded Fire History in the Gaitana ravine micro-basin.

Date	Description	Source
2020-04-15	In the Municipality of Cubará – Boyacá, Vereda La Caña Guata, Plant Cover Fire Event.	UNGRD
2020-03-05	Forest fire Municipality of Cubara	UNGRD
2018-11-08	Ecopetrol, through a press release, indicated that the emergency was registered due to an attack against the Caño Limón-Coveñas oil pipeline on Thursday afternoon, near the main road that leads from Saravena to Cubará. This event caused the fire of a natural forest and the contamination of about a kilometer of a runoff channel in the Cañaguata village.	SEMANA Magazine, November 2018. https://www.semana.com/medio-ambiente/articulo/atentado-a-oleoducto-en-cubara-produce-derrame-de-petroleo/42046/
2015-05-26	In the municipality of Cubará, around 300 people are estimated to be affected. The most affected villages were La Pista, Cañaguata , El Guamo, La Gaitana, La Esperanza, Puerto Nuevo, El Róyota , Bojabá and Brisas del Arauca. In these areas there is a loss of forests and crops of cocoa, banana, cassava and animals.	Humanitarian response, June, 2015.
2001-03-16	The CRE reports that the fire is of considerable magnitude, but does not quantify the impact.	UNGRD

2.1.2 Methodology

For Forest Fire Threat Zoning, the methodology set out in "Protocol for creating fire risk zoning maps of vegetation cover" was adapted, generated by IDEAM. The susceptibility of the vegetation cover was analyzed by identifying and assessing the pyrogenic condition of the vegetation, using the fuel model. The fire threat will be determined through the equation:

$$Amenaza\ Incendio = susceptibilidad\ \ vegetación * (0.17) + \ precipitación * (0{,}25) + \ temperatura * \ (0{,}25) + pendientes * (0{,}03) + \ frecuencia * (0.05) + \ accesibilidad * (0{,}03) \quad \textit{Equation 1}$$

The methodology and variables that affect the determination of the zoning of forest fire threats in the Gaitana basin are generally appreciated. The initial IDEAM methodology was taken into account, respecting the condition clarified in the adjusted document, where it is specified that if all the variables mentioned were not available, it could be weighted according to the available parameters or variables, so it was decided to adopt the original 2011 methodology.

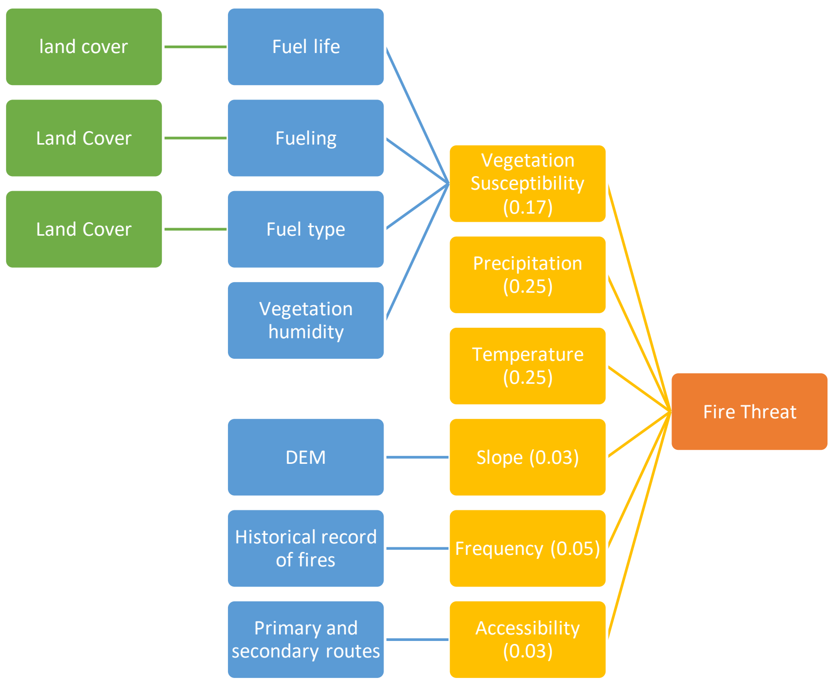


Figura 1. Procedure for determining susceptibility to Forest Fires

2.1.2.1 Vegetation susceptibility

The classification and subsequent qualification of the susceptibility of the vegetation (as a fundamental factor of the threat), to forest fires or of the vegetation cover; was carried out based on the information obtained from the analysis of the pyrogenic condition of the Colombian vegetation, based on the fuel model developed by Páramo 2007. For this, a qualification of the most relevant factors that characterize the pyrogenic condition and that have a high importance in establishing susceptibility.

a. Fuel type

From the vegetation cover map, a reclassification was generated by interpreting the types of cover, according to the dominant fuel types, generating a qualification value for each of them in accordance with what is established in Tabla 4. When analyzing the zoning obtained, a predominance of Threat is identified, according to type of Fuel, Low with 53% of the area and followed by Very High with 29% of the extension of the La Gaitana Microbasin , Mapa 1.

In the Northeast sector, corresponding to the lower area of the basin, there is a predominance of high susceptibility by type of Fuel, characteristic of the grass coverage. In the southwest zone, corresponding to the highest elevation zone of the microbasin, a predominance of low susceptibility is evident, distinctive of the shrub cover.

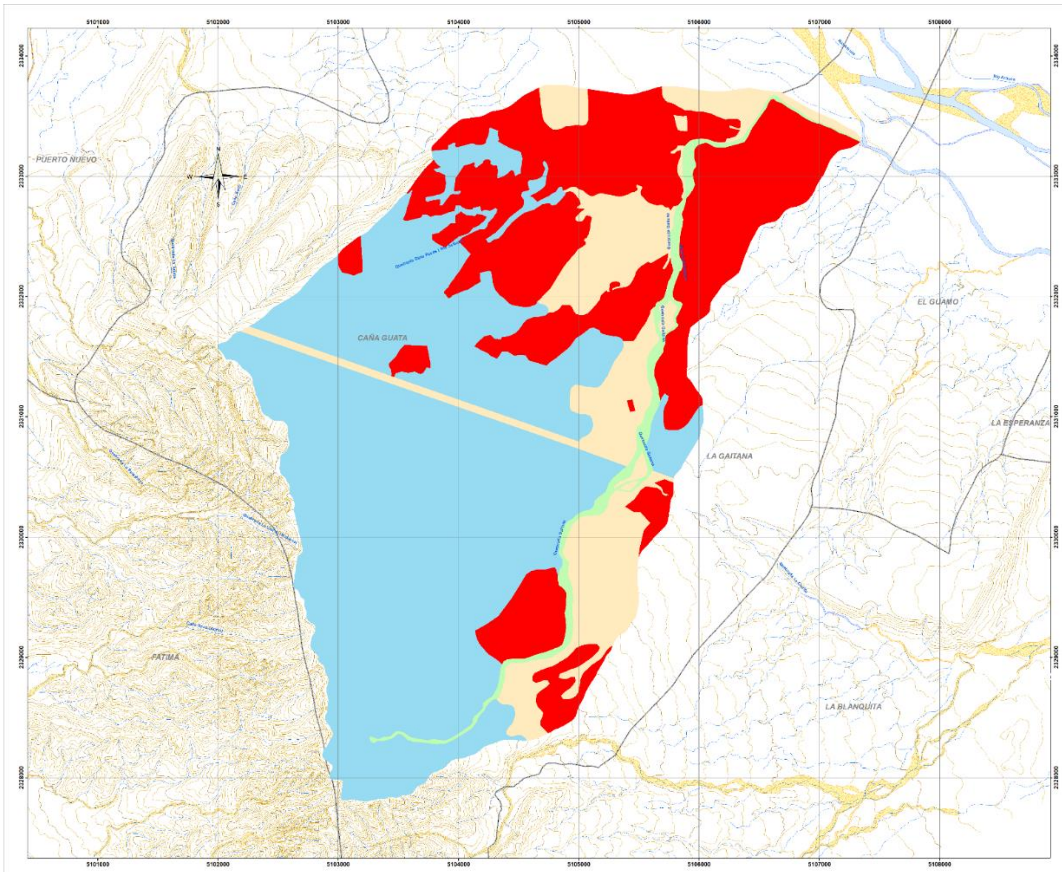
Tabla 4. Type of coverage and Type of fuel

Type of Coverage	**Fuel type Predominant**	**Type of coverage**	**Threat Category**	**Qualification Fuel type**
2.3.1.	Pastures	clean pastures	Very high	5
2.3.2	Pastures	clean pastures	Very high	5
2.3.3	Pastures	clean pastures	Very high	5
2.4.4	Grasses/Herbs	Pastures with natural spaces	Very high	5
3.1.1.	Shrubbery	Shrub	Low	2
3.2.3.	Trees/shrubs	dense forest	Moderate	3
5.1.1	Non-combustible	Water bodies	Very low	1

Source: Ideam , 2011

Tabla 5. Percentage of Threat area according to Fuel load, La Gaitana micro-basin

Fuel Type Threat	**Area_m2**	**%**
Low	9163742.15	53%
Moderate	2603691.97	fifteen%
Very high	4966722.8	29%
Very low	450839.19	3%



Mapa 1. Threat Map by Fuel Type

b. Fuel duration

From the vegetation cover map, a reclassification is generated by interpreting the types of cover, assigning a rating according to the predominant covers according to the duration of the fuels, as shown in Table Tabla 6. When analyzing the zoning obtained, a predominance of Threat is identified, by duration of the Fuel, Low with 53% of the area and followed by High with 29% of the extension of the La Gaitana Microbasin , see Tabla 7and Mapa 2.

In the Northeast sector, corresponding to the lower area of the basin, there is a predominance of high susceptibility due to the duration of the predominant Fuel, characteristic of the grass cover. In the southwest zone, corresponding to the highest elevation zone of the microbasin, a predominance of low susceptibility is evident in relation to the Duration of the Predominant Fuel, distinctive of the shrub cover.

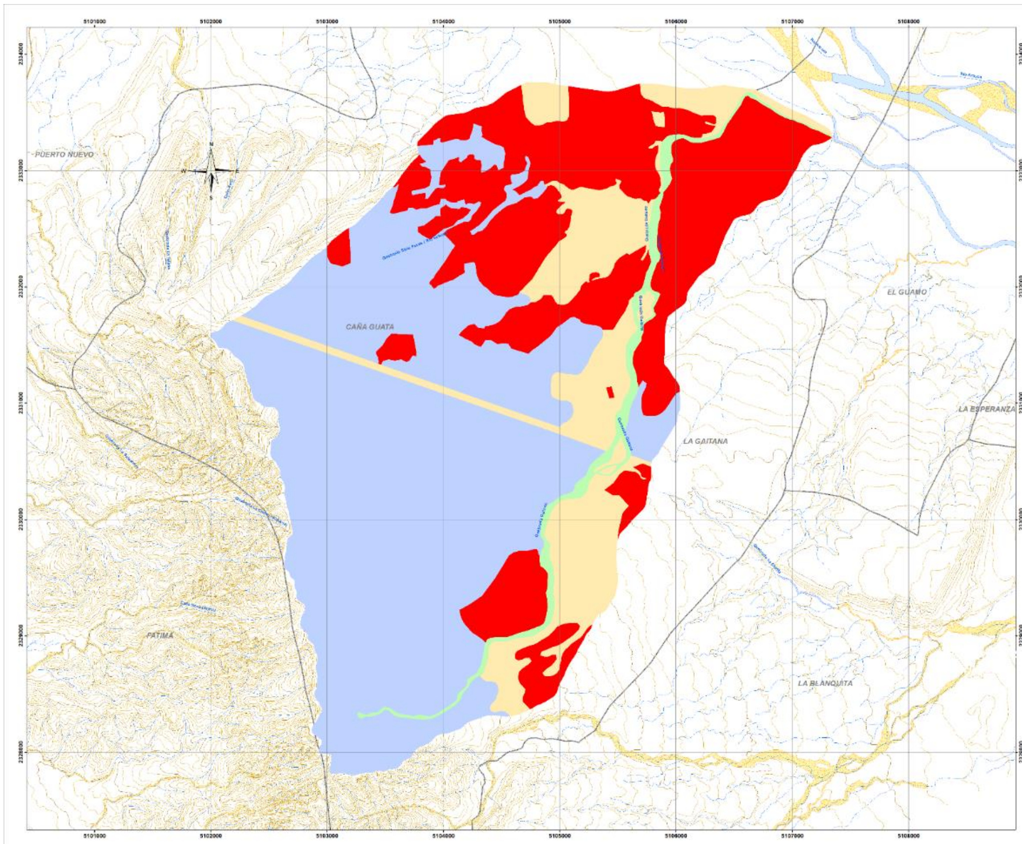
Tabla 6. Type of coverage and duration of the predominant fuel, IDEAM (2011)

Type of Coverage	Coverage	Fuel Life Predominant	Threat Category Fuel Duration	Qualification
2.3.1.	clean pastures	1 hour	high	4

2.3.2	Heterogeneous grasses	1 hour	high	4
2.3.3	Weeded Pastures	1 hour	high	4
2.4.4	Pastures with natural spaces	1 hour	high	4
3.1.1.	dense forest	100 hour	Low	2
3.2.3.	Shrub	10 hours	Moderate	3
5.1.1	Water bodies	Non-combustible	Very low	1

Tabla 7. Percentage of Threat area according to Fuel load, La Gaitana micro-basin

Threat Fuel Life	Area_m2	%
high	4966722.8	29%
Low	9163742.15	53%
Moderate	2603691.97	fifteen%
Very low	450839.19	3%



Mapa 2. Fuel Duration Threat

c. Fuel loading

Based on the vegetation cover map and specific information available on the biomass of the different types of cover (expressed in tons per hectare), a reclassification of the cover types is generated, assigning them according to the predominant covers and their content. of biomass (fuel load) a rating according to Tabla 8. When analyzing the zoning obtained, a predominance of Threat, due to Fuel load, is identified, Very High with 53% of the area and followed by Moderate with 25% of the extension of the La Gaitana Microbasin , see Tabla 9and Mapa 3. In the Northeast sector, corresponding to the lower zone of the basin, there is a predominance of moderate susceptibility due to Total Fuel Load, characteristic of the grass coverage. In the southwest area, corresponding to the highest elevation area of the microbasin, a predominance of very high susceptibility is evident, distinctive of the shrub cover.

Tabla 8. Type of coverage and total fuel load, IDEAM (2011)

Type of Coverage (Corine Land Cover Level 3)	**Total Load (Biomass) of Fuels**	**Threat Category**	**Qualification**
2.3.1.	Low (1-50 ton/ha)	MODERATE	3
2.3.2	Low (1-50 ton/ha)	MODERATE	3

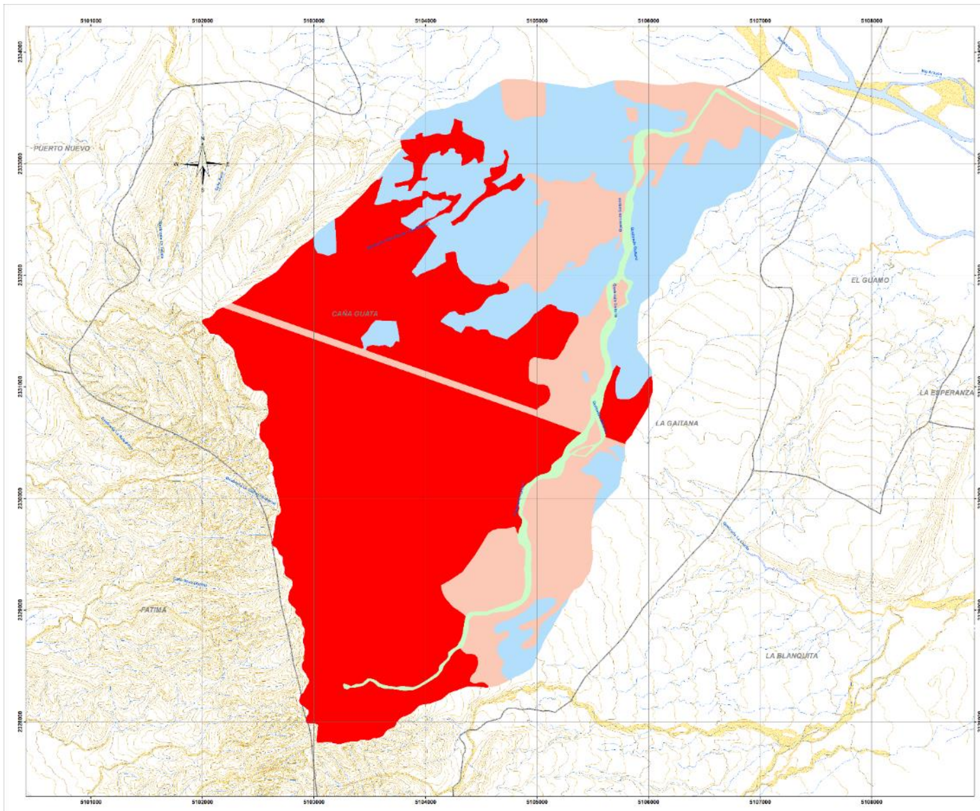
2.3.3	Low (1-50 ton/ha)	MODERATE	3
2.4.4	Moderate (50-100 tons/ha)	high	4
3.1.1.	Very high (more than 100 tons/ha)	Very high	5
3.2.3	Moderate (50-100 tons/ha)	high	4
5.1.1	Non-combustible	Very low	1

Source: IDEAM 2011

Tabla 9. Percentage of Threat area according to Fuel load, La Gaitana micro-basin

Fuel Load Threat	Area_m2	%
high	3328397.02	19%
Moderate	4242017.75	25%
Very high	9163742.15	53%
Very Low	450839.19	3%

Source: IDEAM 2011



Mapa 3. Total fuel load susceptibility

d. Generation of the vegetation susceptibility map to fires

Once the respective qualifications have been assigned and the type, duration and fuel load maps have been generated, the sum between each of them is carried out; The result obtained is normalized and subsequently grouped into 5 categories using a frequency distribution and each group is assigned a rating that varies between very low susceptibility (lower range) to very high susceptibility (higher range), using the following equation:

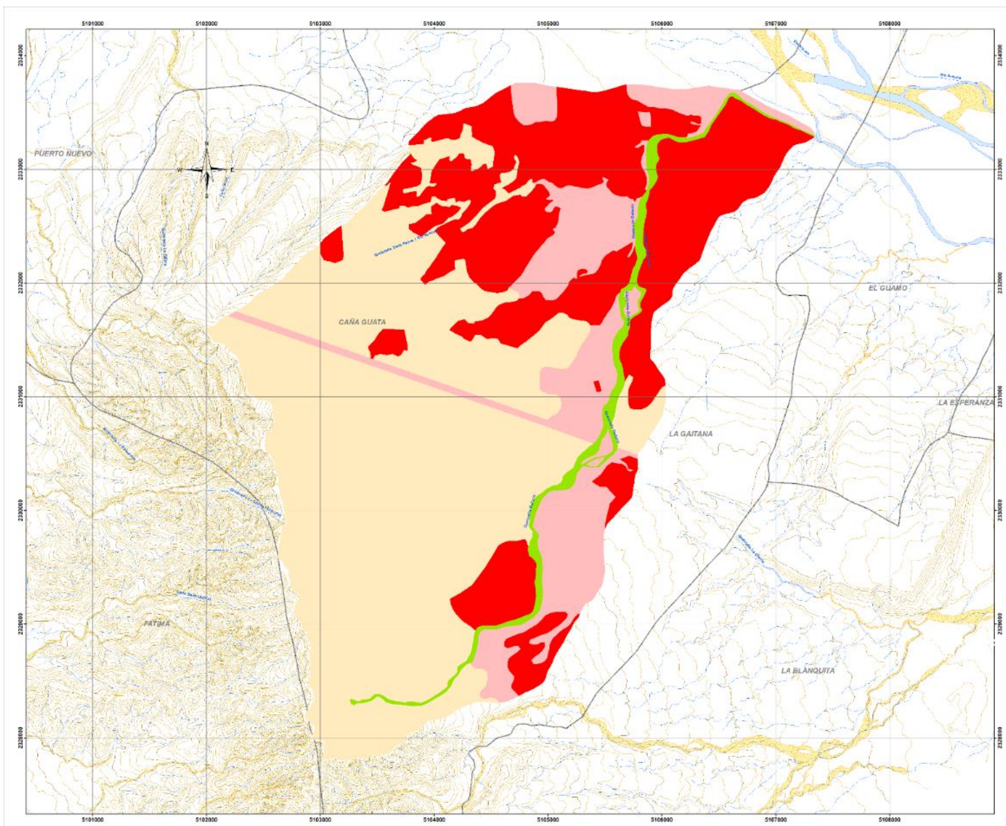
$$SUSC = CAL(tc) + CAL(dc) + CAL(ct)$$

Where:
SUSC: Vegetation susceptibility (gross susceptibility)
CAL (tc): Rating by fuel type
CAL (dc): Fuel life rating
CAL (ct): Total fuel load qualification

When analyzing the zoning obtained, a predominance of Vegetation Susceptibility to Fires is identified as Moderate with 53% of the area and followed by Very High with 29% of the extension of the La Gaitana Microbasin , see Tabla 10and Mapa 4.

Tabla 10. Percentage of vegetation susceptibility area, La Gaitana micro-basin

Fuel Load Threat	Area_m2	%
high	2603691.97	fifteen%
Moderate	9163742.15	53%
Very high	4966722.8	29%
Very Low	450839.19	3%



Mapa 4. Threat due to full fuel load

2.1.2.2 Climatic factors

Taking into account that the susceptibility of vegetation is affected by external factors, linked to intrinsic variations, mainly with regard to the humidity contained in plant tissues, it is considered necessary to generate a susceptibility rating under normal conditions. of precipitation and temperature prevailing in the country.

The susceptibility rating of the climatic variables, based on the precipitation and temperature information of the La Gaitana micro-basin, was Susceptibility Category due to Moderate precipitation and Susceptibility Category due to High Temperature, throughout the entire extension of the basin when presenting conditions with low climatic variability.

According to IDEAM methodology, a classification is based on the typical characterization of precipitation and temperatures of Colombian ecosystems (IDEAM, 2007):

Average Annual Precipitation (mm)	Threat Category	Qualification
Arid (0-500)	VERY LOW	1
Rainfall (>7000)	VERY LOW	1
Very humid (3000-7000)	MODERATE	2
Wet (2000-3000)	MODERATE	3
Dry (1000-2000)	HIGH	4
Very dry (500-1000)	VERY HIGH	5

Average Annual Temperature (°C)	Threat Category	Qualification
Nival (<1.5)	VERY LOW	1
Extremely cold (1.5-6)	VERY LOW	1
Very cold (6-12)	MODERATE	2
Cold (12-18)	MODERATE	3
Tempered (18-24)	HIGH	4
Warm (>24)	VERY HIGH	5

Source: IDEAM, 2007.

It was later contrasted with the information on precipitation and average temperatures from the La Gaitana basin. In the case of the average annual precipitation of the Gaitana basin, specifically related to the Tunebia station , which has the greatest contribution to the area of interest, there is a total of 4945 mm, which places it in a category medium threat according to IDEAM classification.

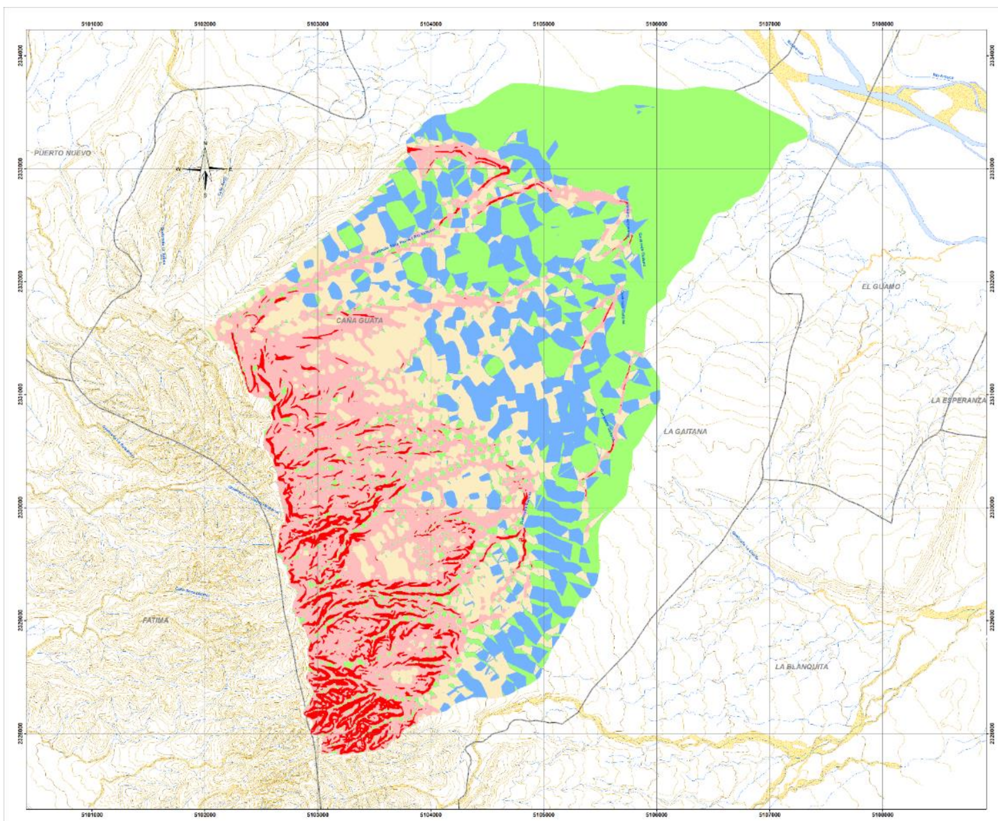
Tunebia climatological station , which has the greatest influence on the study area, shows an average temperature at a multiannual level of 22.5 degrees Celsius, which according to the IDEAM classification, places it in the category of High threat.

2.1.2.3 Highlight factor:

From the digital model of the terrain, the slope map was generated in percentage and the susceptibility by relief was determined, it was found that in the La Gaitana Microbasin, Very Low susceptibility prevails with 32%, followed by High susceptibility with 25%. as seen in Tabla 11and Mapa 5.

Tabla 11. Susceptibility to fires due to relief in the La Gaitana Microbasin.

Medium Slope	Threat Category	Qualification	Km2 Area	%
0 - 7%	VERY LOW	1	5.40	32%
7 - 12%	LOW	2	3.12	18%
12 - 25%	MODERATE	3	3.31	19%
25 - 75%	HIGH	4	4.29	25%
> 75%	VERY HIGH	5	1.01	6%



Mapa 5. Threat Map according to Slope

2.1.2.4 Historical factor

The historical factor refers to the frequency of fires that occurred in a defined area and during a determined period of time. For the analysis of this variable, statistics on the occurrence of forest fires in the municipality of Cubara were used, see Tabla 3. From the information of historical statistics on fires, the frequency index of this phenomenon was calculated, it is carried out by applying the equation presented below, obtaining that the fire frequency is 0.25.

$$Fi = \frac{1}{a}\sum ni$$

Where:
Fi: Fire frequency
a : Number of years
ni : Number of fires each year

2.1.2.5 Accessibility Factor

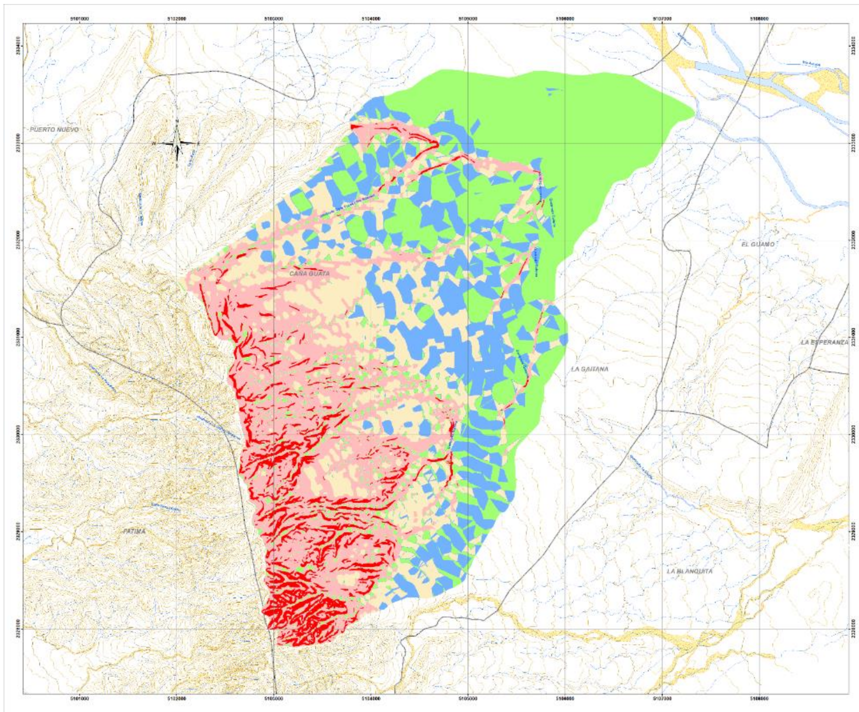
For this process, the generation of 4 buffer zones each 500 m thick must be carried out from the road map (main and secondary roads); Once the buffers are generated, they are classified to generate the threats that may arise on the coverage due to the greater or lesser possibility of access to them, according to the following criteria:

From the information on primary and secondary roads, the access susceptibility map was generated, finding that in the La Gaitana Microbasin a Very Low susceptibility prevails with 53%, followed by a Very High susceptibility with 15%, as shown. seen in Tabla 12and Mapa 6.

In the Northeast sector, corresponding to the lower area of the basin, there is a predominance of susceptibility due to very low and low accessibility. In the southwest area, corresponding to the highest elevation area of the microbasin, a predominance of high and very high susceptibility is evident.

Tabla 12. Susceptibility to fires due to Accessibility in the La Gaitana Microbasin.

Distance to track (m)	**Threat Category**	**Qualification**	**Area Km ^{2}**	**%**
More than 2000	VERY LOW	1	9.13	53%
1500 - 2000	LOW	2	1.72	10%
1000 - 1500	MODERATE	3	1.59	9%
500 - 1000	HIGH	4	2.18	13%
0 - 500	VERY HIGH	5	2.57	fifteen%



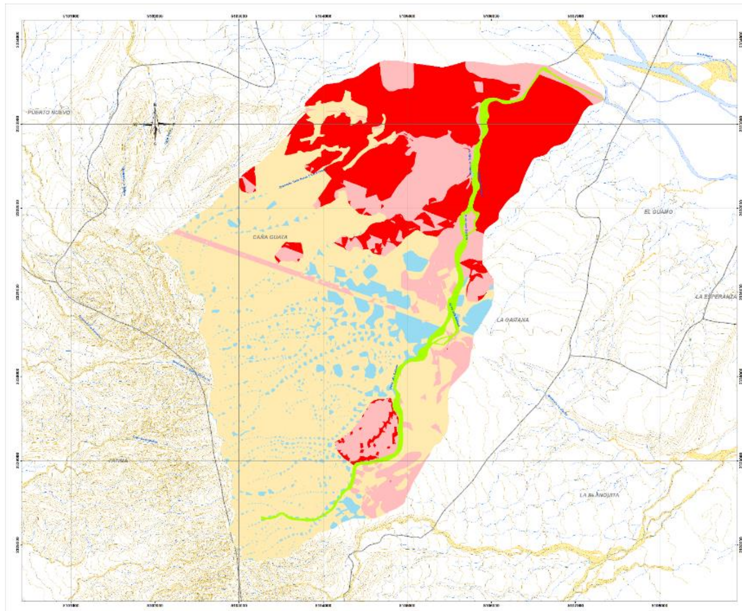
Mapa 6. Accessibility Threat Map

2.1.3 Threat due to fires in the Quebrada la Gaitana micro-basin

For Forest Fire Threat Zoning, the methodology set out in "Protocol for creating fire risk zoning maps of vegetation cover" was adapted, generated by IDEAM. Through the interception of the different susceptibilities that make up the fire threat, it was identified that the threat that prevails in the basin is Moderate, with 52% of the territory's extension, as seen in Table Tabla 13and Mapa 7.

Tabla 13. Threat due to fires in the La Gaitana Microbasin.

Threat Category	*Qualification*	*Km2 Area*	*%*
VERY LOW	1	0.45	3%
LOW	2	1.13	7%
MODERATE	3	8.94	52%
HIGH	4	2.78	16%
VERY HIGH	5	3.82	22%

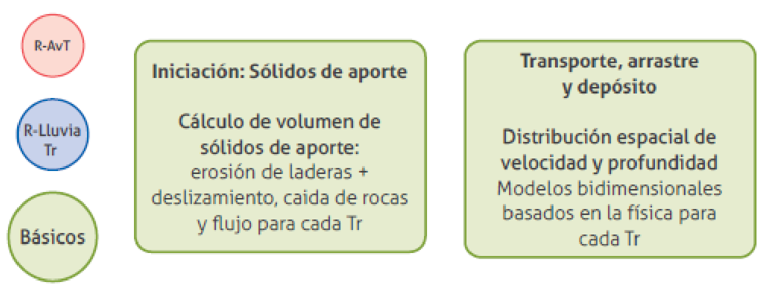


Mapa 7. Zoning of Fire Threats in the Quebrada la Gaitana micro-basin

In the Northeast sector, corresponding to the lower area of the basin, there is a predominance of high and very high susceptibility to Fire. In the southwest area, a predominance of moderate fire susceptibility is evident.

2.2 Threat Zoning for Torrencial Avenue

The Methodological Guide for Threat Zoning by Torrential Floods of the SGC, 2017. establishes the methodology for the zoning of torrential floods, for which the results of the Flood Threat and the geomorphological characteristics of the La Gaitana micro-basin are taken as a basis.



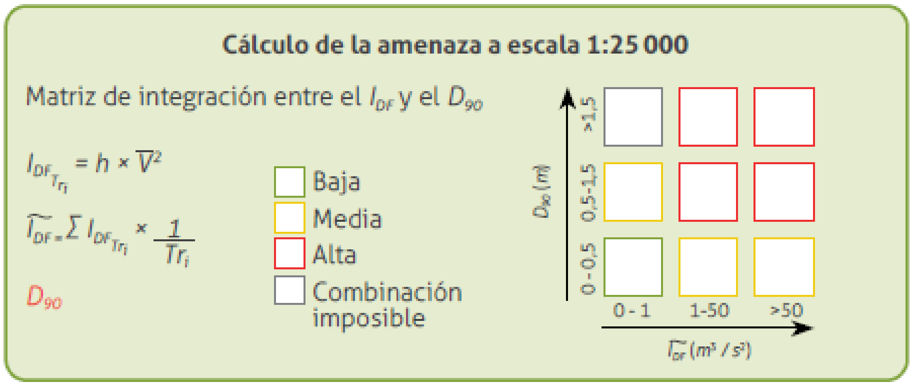


Figura 2. Components for Threat Characterization along Torrencial Avenue, scale 1:25000

Source: SCG, 2017.

Where:
h = height of water sheet in m
V= Speed in m/s
Tr = return periods
D90=m

Taking into account the methodology presented in Figura 2the was determined $\zeta_{DF}$from the sum of the quotient of $I_{DF_{Tri}}$with respect to Tr.

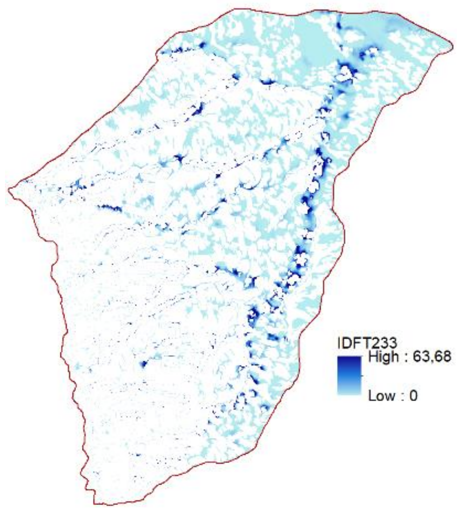


Figura 3. $I_{DF_{Tri}}$For example, according to the return period of the La Gaitana micro-basin

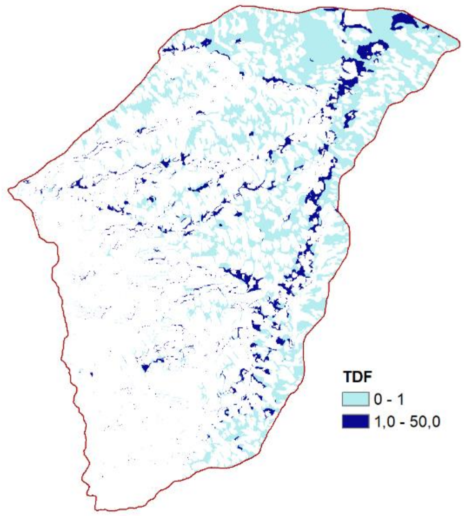


Figura 4. ζ_{DF} of the Gaitana micro-basin

To determine the D90, the Meyer-Peter- Muller equation (1948) was used, taking into account the Manning number assigned to each surface of the microbasin, the study of sediment discharge by bottom trawling was selected.

$$n = \frac{{D_{90}}^{1/6}}{26}$$

$$D_{90} = (26 * n)^6$$

Where:
D90= Diameter for which 90% of the particles pass, in meters (m).
n= Manning number

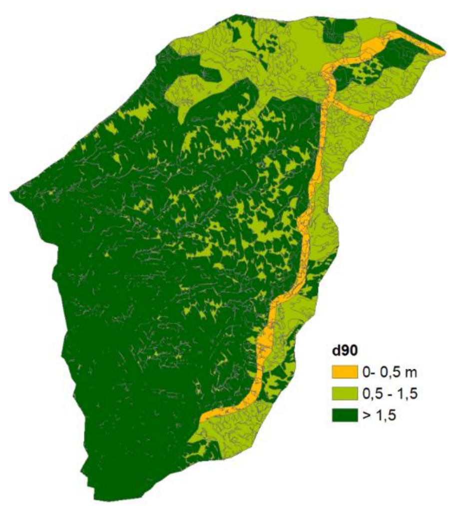
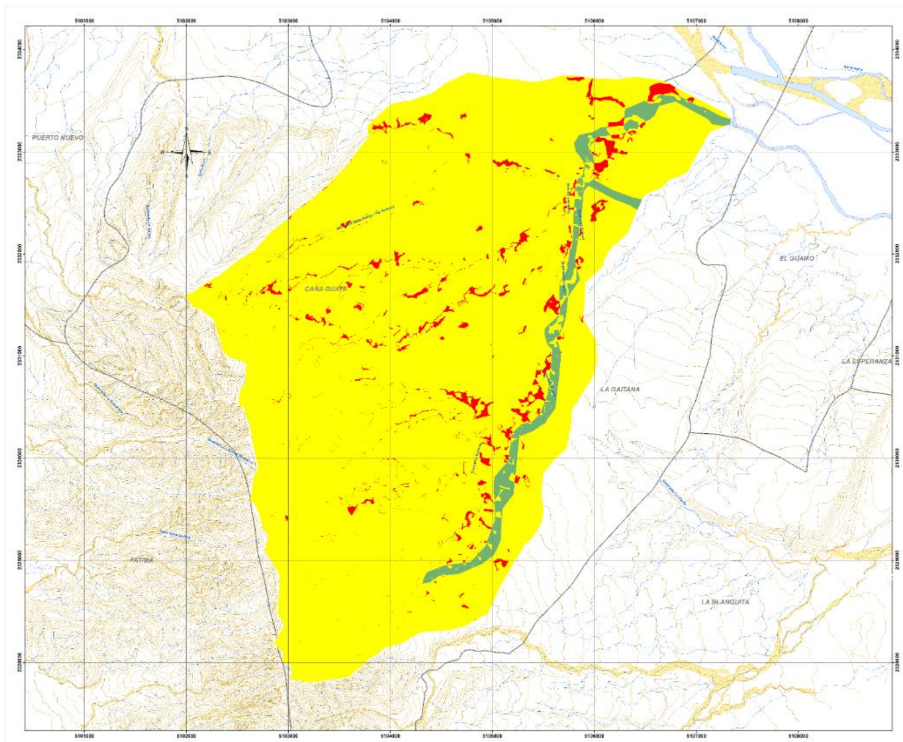


Figura 5. D90 classification in the Gaitana micro-basin

By overlaying the raster of D90 and ζ_{DF}, the threat was determined, finding that 93.5% of the basin's extension is exposed to a medium threat and 3.1% to a high threat, as shown in Tabla 14and Mapa 8.

Tabla 14. Threat due to Torrencial Avenues in the La Gaitana micro-basin

Threat Category	Threat	Area m2	%
1	Low	590424.14	3.4%
2	Half	16061261.95	93.5%
3	high	530891.64	3.1%



Mapa 8. Zoning of Threats along Torrencial Avenue in the Quebrada la Gaitana micro-basin

3 DEFINITION OF ACTIONS AND MEASURES, BOTH STRUCTURAL AND NON-STRUCTURAL, FOR THE REDUCTION OF THE ASSOCIATED RISK IN THE MICROBASIN.

The definition of structural and non-structural actions associated with the risk mentioned in the document is presented in light of the maximum possible events according to the threat. It is important to keep in mind that in many cases the measures associated with non-structural matters are based on sustainable actions, that is, they do not necessarily involve infrastructure designs and works. In this case, it is implied that these measures would be implemented for achievements and fulfillment of long-term objectives, where the idea is to prevent events associated with the current risk from seeing a low probability of occurrence in the future. These non- structural measures contemplate periods of effect that could vary between 10 and 20 years, according to the criteria of this consultant.

As structural measures, a general methodology is presented according to a state of the art of possible infrastructure works to be used in critical sites or points according to each of the threats detected. It is important to keep in mind that they are structural measures taken into account as a generality and are not part of a detailed design procedure or preliminary designs, according to the commitment made with the contractor and the scope of the study.

Regarding the necessary actions referring to non-structural measures associated with the flood risks referred to in this document, their own variety and the different scale of the problems make it advisable to organize a sectoral type, through horizontal programs that group measures of the same nature. nature. These programs could be structured as follows, taken from validated studies worldwide (García Peña, A, 2010):

• Reforestation, to reduce solid flows.

• Forecast and early warning systems, which are considered a key instrument for modern management of critical hydrological situations.

• Structural actions, which could encompass the channeling and river actions and security subprograms.

• Urban planning measures, which should include the adaptation of urban planning legislation to consider the risk of flooding (risk maps) in the urban planning process, the development of urban planning regulations for flood protection and the adaptation of urban planning plans to flood risk. already approved.

• Actions on the road network, with the double objective of saving human lives and reducing damage due to service interruption, including the removal of black spots and the signaling and marking of speed bumps and flood-prone sections.

• Insurance program, aimed at the protection of agricultural assets.

• Acquisition and renaturalization plan for riparian areas.

To guarantee the effectiveness of the actions in the most important flood zones, it is preferable to group them on each of the first order flood areas in an action plan coordinated between the different administrations involved. The action plan of this type is given thanks to the risk map associated with this report, existing territorial planning maps, hydrological study of flows, mathematical model of hydraulic behavior, impact study and program of environmental adaptation of the solutions, etc. …

In reference to structural measures, some considerations must be taken taking into account the present risk and threat report.

Determining the optimal level of protection is another issue on which various criteria can be adopted. On the one hand, adopting a very high level implies large investments and involves carrying out few interventions per year. On the other hand, the frequent occurrence of flood damage is unacceptable.

The desirable balance may consist of protecting the urban centers currently at risk, which in the case of this study refers to a few vulnerable homes near the area of the main bridge of the Gaitana national highway and that connects the municipality of Saravena with Cubará. , at the intersection with the Gaitana ravine, where there are problems with the homes around the ravine. There would be important structural defense measures against ordinary and moderately severe floods listed in the flood risk maps, so that no more than once in a generation the effects of material damage from the high return periods are suffered with respect to flood threats, and entrust non-structural measures with additional protection against extraordinary floods.

On the other hand, the same criteria used in the design of large dams should not be applied to channeling. Such high returns are adopted, and must be maintained, because the dam, if overwhelmed, can introduce serious additional risk. But in a channel the overflow does not aggravate the previous situation, except if the water line goes far above the ground, which is not at all recommended, although it inevitably happens on some occasions.

A reasonable return period for channel design may be 100 years, contemplated in this study, which may be reduced to 25 depending on the nature of the protected area and the territorial impact caused.

In the case of the agricultural areas present in the Gaitana basin, a high level of protection would only be justified in large flood-prone areas, specified in the flood threat maps and with high-value crops, so that the probable damage avoided were greater than the cost of the works plus the possible impact on the river ecosystem.

It does not seem logical to design protections for return periods greater than 50 years in these areas.

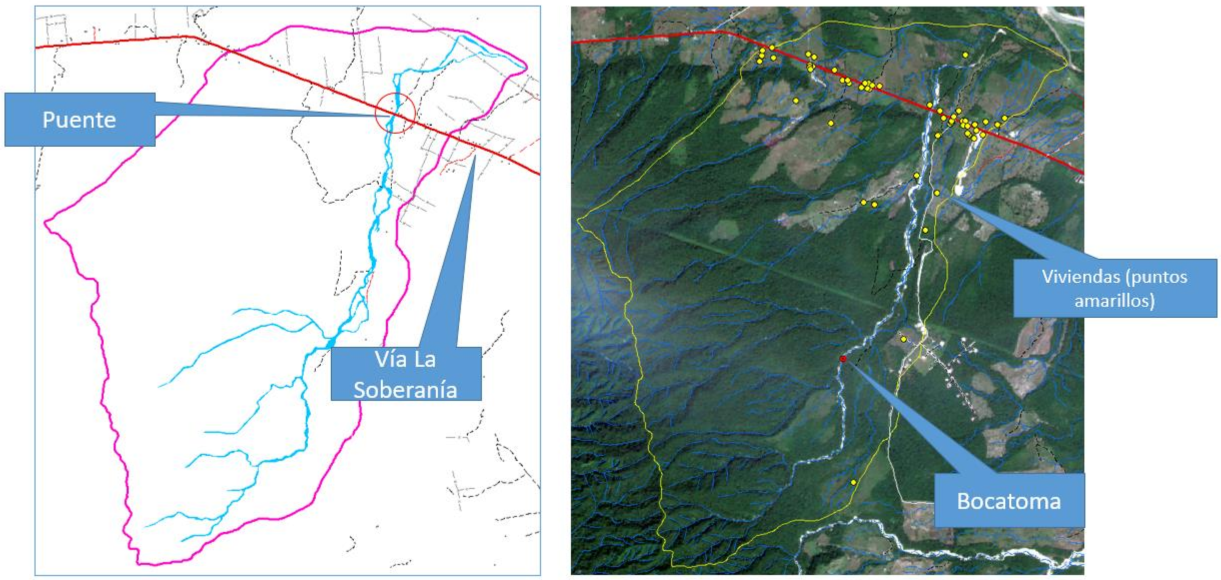


Figura 6. Location of Puente la Gaitana and its influence on the location of homes. Source: Contractor.

Likewise, in reference to structural measures, in the area of the bridge and according to secondary information sent by the contractor, there is a problem with its span, which can evidently be corroborated, where it can be seen that the main piers are located in such a way. so that the embankment is very deep in the average width of the channel, generating or facilitating flooding in the next round, when the flow exceeds the reference to the dominant flow of the river, that is, taking into account high return periods.

Figura 7. La Gaitana Bridge, river ring and location of residential properties.

This situation can directly affect the homes located within the La Gaitana ravine, for this reason it is recommended to intervene in the span of the bridge, that is, take structural measures on the bridge in such a way that it generates a much greater hydraulic capacity. greater and in accordance with the flood events for return periods of up to 100 years, shown in this report.

Likewise, it is recommended to take measures to stabilize the river bed, since the characterization based on secondary information, received from the contractor, shows a clear phenomenon of armoring and great movement of sediments from the upper to the lower part of the basin. , affecting critical points such as the passage through the bridge sector. Said stabilization should include a specific study taking into account the fluvial hydraulics of the Gaitana stream, in order to verify the appropriate sections of its channeling, avoiding sensitive points that could generate excessive erosion or increase in the bottom of the river bed in areas not suitable that could generate greater flooding in the respective plains.

Another of the recommended measures in reference to the hydraulic behavior of the Gaitana stream, which could directly affect anthropic processes in reference to settled populations, is what concerns the aqueduct intake present in the upper part of the basin.

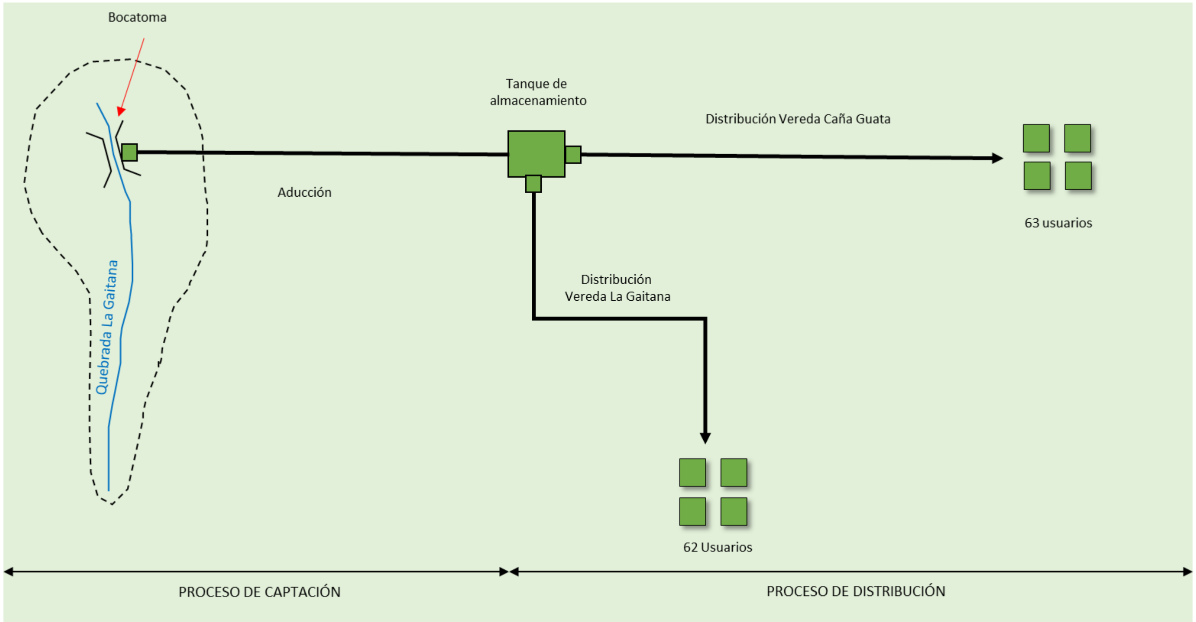


Figura 8. Location of the Aqueduct intake on the La Gaitana ravine.

This type of structure, which in this case would be considered a small catchment structure, and its dimensions presume vulnerability to flood events with high sediment transport, as is the case of the Quebrada La Gaitana. There are no retaining walls or a dam at the intake for high flood events, and this implies a passage and accumulation of sediments that over time can generate clogging problems in the different structures of the supply system, in this case main in the capture.

It is recommended to review and adjust complementary designs that represent an adaptation given the exposure of the type of flood threat exposed in this document, and due to the characteristics of the fluvial hydraulics of the stream, which, as mentioned above, includes solid flow transport. important. Additionally and Due to the high threat obtained by mass removal movements, despite the low erosive potential, it is recommended to implement protection measures for the adduction and conduction line in the supply system, since due to secondary information provided by the contracting party, It is seen with a low level of protection, in the face of possible removal phenomena in the face of macroclimatic phenomena with a high return period presented in this report within the description of threats due to mass removal and the records of maximum historical precipitation.

Figura 9. Aqueduct intake over the La Gaitana ravine.

In the same way, it is recommended to verify the heights of gabion walls located on the margin of specific points on the La Gaitana stream, verifying the maximum heights of the water table shown in the annexes to this report, as an extra input to it.

Figura 10. Sectoral protections in gabions over the La Gaitana ravine.

It is recommended to use the zoning of maximum water table heights and the material threat map that is supplied as an extra input, in addition to the flood threat map for each return period, in order to take into account the heights of maximum sectoral water level and the maximum dangers, in order to build gabion walls in said critical sectors to protect said slopes on the margins of the stream. It is recommended to take the material threat map as a guide (Extra Annex provided in this study), since the maximum heights contemplated there exceed those of the threat due to dangerous flooding.

It is recommended based on (García Peña, A, 2010), the use of protection measures against flood events according to the return periods set forth in this report:

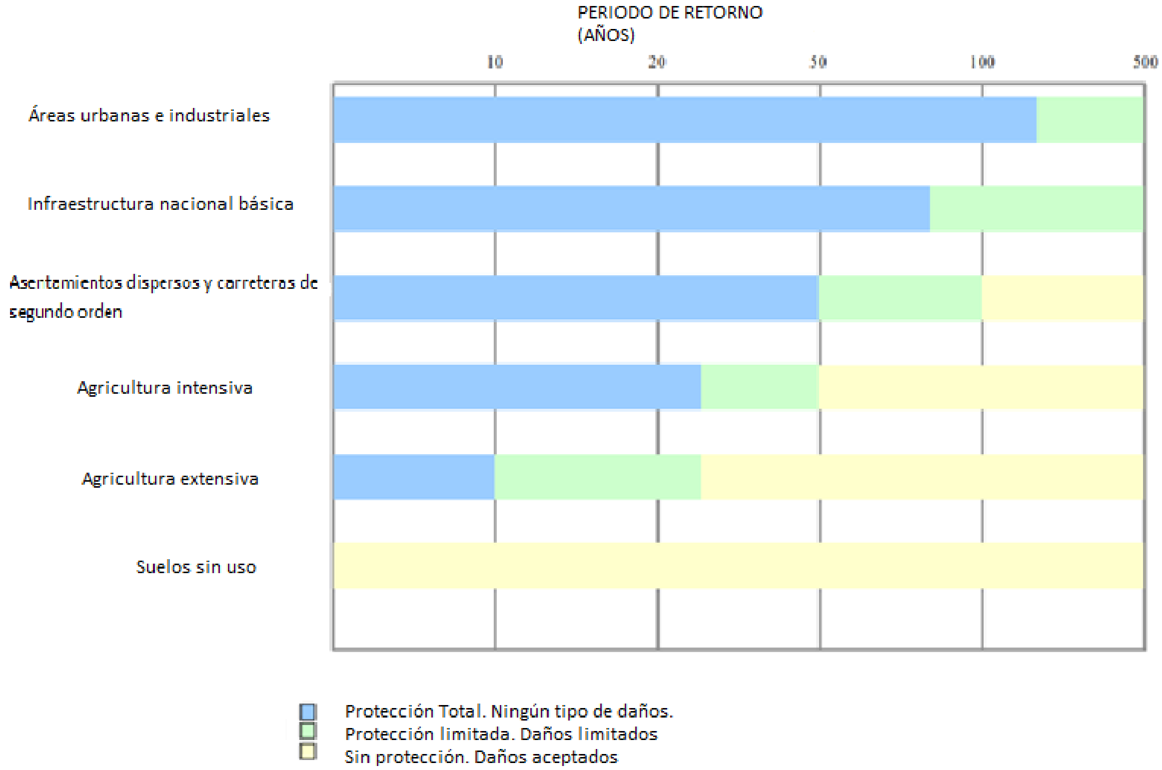


Figura 11. Example of flood protection levels depending on land use. Source: García A, et al, 2010.

The previous figure according to the recommendations of (García A, et al, 2010) shows a need for protection in accordance with what is stated in this chapter, according to the type of coverage and for each of the return periods in reference to flood levels.

Theoretically, recommendations are contemplated at a global level, which in this case the consultant also recommends, based on what is stated in the White Book on Water (MIMAM, 2000), in reference to zoning criteria with a theoretical scheme of the different uses of water. admissible soil for a subsequent new approach that should be developed in those flood-prone areas.

Tabla 15. General recommendations by type of MIMAM zone.

ZONE TYPE	Agricultural	Livestock	Residential land		Industrial land		modest industry	Equipment
			Low density	High density	Light-duty	Heavy	Unhealthy or dangerous	
FLOODABLE								

High risk	YES (1)	NO	NOT (3)	NO	NOT (3)	NO	NO	NO 6)
Medium risk	YEAH	YES 2)	YES (4)	YES (4) (6)	YES (4) (6)	NO	NO	NO 6)
Low risk	YEAH	YES 2)	YES (5)	YES (5)	YES (5)	YES (4) (6)	NO	YES (5)

(1) Restrictions on facilities permissible for farm use.

(2) Restriction on the number of livestock.

(3) It will only be admitted if the entire municipal area is high risk, the response time is greater than 3 hours and an early warning system is operational, conditional on the adoption of severe Urban Planning Ordinances regarding the requirement of safety measures. flood defense.

(4) Conditional on the adoption of the Planning Ordinances indicated in (3), and provided that the response time is greater than 3 hours and an early warning system is operational.

(5) Conditional on the adoption of Urban Planning Ordinances less demanding than those indicated in (3).

(6) It will only be admitted if there is no safer alternative land in the municipality.

(7) The facilities will only be for the exclusive use of the land being developed.

(8) The response time must be greater than 1 hour.

(9) Categories A, B and C correspond to a gradation of the importance of the facilities from vital (A) to parks, sports areas, etc. (C)

As can be seen, a gradation of greater severity in the use restrictions is proposed as the risk increases. The adopted criterion attempts to generate a smooth urban transition between safe areas and those that are not, avoiding sudden changes that generate legal conflicts and environmental degradation.

In reference to structural measures, we can also consider what is related to the optimization of road drainage since they reduce the duration of flooding events. Transverse drainage works are essential at the intersections of linear infrastructure works (roads and railways) with river and stream channels. Although the implementation of different regulations for the design and execution of these works has largely reduced the elevation of levels and flooding times, insufficiently sized or poorly maintained drains still persist.

In the design of the structural actions mentioned in this chapter, it must be assumed that they will never be able to completely eliminate the risk, so their operation with flow rates higher than the project must be carefully analyzed, a situation for which non-structural measures are contemplated (also mentioned in the chapter). Likewise, structural actions must consider, from the beginning of their design, both environmental restrictions and the possible modification of the current flow scheme, trying to avoid possible negative effects on other areas.

Hydrological-forest restoration, improvement of vegetation cover and soil conservation, have a favorable effect on the genesis of flood flows, but especially notable on the production of sediments and solid contributions.

The known effect of reducing runoff volume and increasing the response time of the catchment basins leads to a decrease in maximum flood flows.

These measures are more effective and necessary in terms of reducing the significant sediment load that the floods in the main river , as mentioned previously in this chapter for the La Gaitana stream, and its tributaries transport and deposit mostly in the alluvial plains.

Likewise, the reforestation plan in all the areas contributing to the Gaitana ravine reduces in the future the threats already calculated in this report due to mass removal phenomena, given current uses. The critical removal points must be identified (THREAT MAPS BY MASS REMOVAL), and the state of the ground conditions must be verified, to reinforce the reforestation plans.

In reference to the return period and its effects in terms of danger or threat, set forth in this document,

Within the limits of a road with intense drainage, understood as those dual-type drainage elements, such as roads or roads with ditches, it is recommended to limit the following uses:

• Agricultural use, such as arable land, horticulture pastures, viticulture, lawns, outdoor nurseries, etc.

• Industrial – commercial use, such as temporary storage areas, parking areas, etc.

• Residential uses, such as lawns, gardens, play areas, etc.

• Public and private recreational uses, such as golf courses, outdoor sports courts, rest areas, hiking or horse riding circuits, etc.

In any case, no use must unfavorably affect the drainage capacity of the intense drainage route or give rise to significant damage. The recommended land use limitations for flood-prone areas outside the VIDs are the following:

• Future residential buildings must have the ground floor, or the basement if any, at a level such that they are not affected by the 100-year flood, nor does the condition of dangerous flooding occur with that return period.

• Non-residential constructions (industrial, commercial, etc.) must be located at sufficient levels to prevent flooding heights above the ground greater than 0.50 m from occurring during the centenary avenue, unless measures have been adopted throughout the contour. waterproofing up to the level of said avenue (See map of material threat with heights of sectoral water sheet).

Another advisable measure is to place the benches of machinery sensitive to flooding above the level of the centenary avenue.

Neither vital facilities in the event of a disaster such as hospitals, fire stations, police stations, etc., nor other potentially polluting facilities such as some should be affected by the 100-year flood (see Tr 100-year material threat map) chemical industries, certain landfills, cemeteries, etc.

Some measures are also viable to reduce the susceptibility to damage to existing assets in the flood zone, providing incentives from the administration with financial aid:

• The installation of temporary or permanent closures in building openings, or the construction of small dams around them.

• The relocation of valuable properties within the same property.

• The relocation of certain homes and facilities to non-flood areas (See Tr 100 year material threat map)

Early warning systems :

They are considered another of the highly recommended non-structural measures. Real-time hydrological information systems can play an important role as elements of forecasting and hydrological information in flood emergency situations. In these cases, they must provide information on rainfall and levels recorded at selected control points. This information should make it possible to estimate the foreseeable evolution of levels and flows based on meteorological forecasts and determine, where appropriate, possible flooding areas. In this case, and given the return period of the rain received, thanks to the generation of threat maps of the present study, there may be an anticipation of action to be taken.

Insurance:

Another highly recommended non-structural measure. Insurance constitutes an ideal protection instrument when the cost of defense exceeds the value of the protected area, and should be the basis of protection in non-urban areas, particularly against damage to agriculture and livestock. Flood insurance could be included in agricultural insurance and should cover various types of damage: pending harvest, damage to trees, loss of crop land due to bank erosion, etc. Although the structural and structural works or measures proposed above for the La Gaitana basin are based on the characteristics referring to the different threats and risks characterized in this document, they also serve as a guide of action for any contribution basin, since they are based on globally accepted actions and procedures.

4 CONCLUSIONS AND GENERAL RECOMMENDATIONS DERIVED FROM STRUCTURAL AND NON-STRUCTURAL MEASURES

The basin presents diversified levels of flood threat, critical points in the lower area of the basin, but there is a high danger of flooding in the area or ring of the river at the height of the La Gaitana bridge, due to the presence of a light and span of the present bridge of dimensions to be reviewed by what is required by the dominant flow of the stream and by what was obtained in the maximum flood levels in the sector, in addition to the growing vulnerability due to the housing settlements present there. Although there are no wetlands or natural parks or moors in the area, there has been a strong degradation of what is a natural reserve.

A 13% overuse of land, 11% underuse, infers the need to require processes to reduce these conflicts for the benefit of the forest reserve.

The municipality's fiscal performance index is low (DPN) and generates high vulnerability to the respective threats due to resource management.

The homes do not have control systems by the municipality to comply with the earthquake-resistant construction regulations, which increases the levels of general vulnerability. It is also recommended that territorial organizations generate the evaluation of an updated POMCA for the region.

The basin has a medium susceptibility to mass removal, however, being in an area of high exposure to earthquakes and rain (triggers), it generates a high final threat.

In reference to deforestation and erosion, if it is not controlled, since an increase in the level or recent rates is evident, the character of a forest reserve is put at risk.

The area with the greatest threat of fires is the low area and is where the highest population census is present. The main cause of this threat is the degradation of soil cover throughout the sector. It is recommended to reforest at a high level, to reach 100% of the entire forest reserve.

The potential erosion of the Gaitana basin has a greater probability of occurrence due to water processes, the threat from wind erosion is very low due to the low wind speeds that occur in the area, it is recommended to take care of the use of the land in order to reduce the potential.

The threat from torrential floods to the basin is medium, which reinforces the recommendation regarding reforestation and recovery of forest cover in the basin.

5 REFERENCES

Barrios R., AG & Quiñonez, E. (2000). Erosion evaluation using the (r) USLE model, with GIS support. Application in a micro-basin of the Venezuelan Andes. Rev. Forest. 44 (1), pp 65-71.

Cascini , L., Bonnard, Ch., Corominas, J., Jibson R., and Monteroolarte , J., Landslide Hazard , (2005) and risk zoning for urban planning and development . In: O. Hungr , R. Fell , R. Couture and E. Eberthardt , Editors , Landslide Risk Management, Taylor and Francis, London, pp. 199–235.

Castro Mendoza, Itzel, López Báez, Walter, López Hernández, Marcos Antonio, & Guillén Villar, Luis Fernando. (2015). Conservation areas in sub-basins contributing to the Grijalva hydroelectric system, Mexico. Hydraulic and Environmental Engineering, 36(1), 73-87, from http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S1680-03382015000100006&lng=es&tlng=es .

Colombiano, SG (2017). Methodological guide for threat zoning due to mass movements scale 1: 25000. Bogotá: Imprenta Nacional de Colombia.

Cubara, (2015). Municipal Municipal File as an Evaluation Tool of the Basic Planning Plan of the Municipality of Cubará, Department of Boyacá. Municipality of Cubará.

Eltaif , N.I., & Gharaibeh , M.A. (2011). Application of a mathematical model to predict and reduce wind erosion in unprotected arid lands. Chapingo Magazine series forestry and environmental sciences, 17(spe), 195-206. https://doi.org/10.5154/r.rchscfa.2010.08.061

Eltaif , N.I., & Gharaibeh , M.A. (2011). Application of a mathematical model to predict and reduce wind erosion in unprotected arid lands. Chapingo Magazine series forestry and environmental sciences, 17(SPE), 195-206.

European Environment agency , (2021), Copernicus Land Monitoring Service , Corine Land Cover , Copernicus .

FAO, (1980). Provisional methodology for the evaluation of soil degradation. Rome. 44 pages

García Peña, Abraham, (2010). Structural measures and non-structural defense measures against floods. CEDEX.

Government of Boyacá, UPTC and CAR. (2020). Geomorphological Atlas of the Department of Boyacá. First edition. Technological and Pedagogical University of Colombia. Sogamoso Boyacá.

Hoek , E., & Brown, E. (1997). Estimation of the Strength of Rock Masses in Practice. First Interdivisional Geotechnical Workshop . Chuquicamata-Chile.

Hoek , E., & Brown, E. (1997). Estimation of the Strength of Rock Masses in Practice. First Interdivisional Geotechnical Workshop . Chuquicamata-Chile.

IDEAM, (2017). Methodological Guide for the preparation of Flood maps. Bogotá, DC, 110 pages.

IDEAM. (2016). Map of continental, coastal and marine ecosystems of Colombia, scale 1:100,000.

IDEAM-UDCA (2017). Soil degradation due to salinization.

IGAC (2005). General soil and land zoning department of Boyacá. Volume I. Bogotá.

IGAC, (2014), Caldas Lang Climatic Zoning Instructions.

IGAC, IDEAM, MAVDT (2010). Protocol for soil and land degradation due to desertification Ministry of Environment and Sustainable Development (2015). National Policy for Comprehensive Management Taken from: http://www.minambiente.gov.co/images/Atencion_y_particpacion_al_ciudadano/Consulta_Publica/Politica-degestion-integral-del-suelo.pd

IGAC. (2011). Guide for the Digital Update of Homogeneous Areas of Land for Cadastral Purposes.

INGEOMINAS, National University (2010). Update of the National Seismic Hazard Map.

INGEOMINAS. (2004). Methodological Development and Standards of Geomechanical Zoning taking into account the Edaphic Variable, Volume V. 24p

INGEOMINAS. (2009). Regional classification of relative threat due to mass movements in Colombia. Bogota

Kirkby , M., & Morgan, R. (1984). Soil erosion. Mexico: Limusa Editorial

Lianes E., Marchamalo M. and Roldán M. (2009). Evaluation of the Rusle C factor for the management of vegetation covers in the control of erosion in the Birrís River basin . Costa Rican Agronomy, vol. 33, no. 2, pp. 217-235, Costa Rica.

MAVDT-IDEAM, (2005). Interactive Atlas of Land Degradation due to Desertification in Colombia.

McLaughlin Engineers (1969) Distributed by urban Drainage & Flood Control District .

MESÉN, R., (2009). Considerations and conclusions when applying the RUSLE erosion model in some basins of the coastal row, Costa Rica. Research Program on Sustainable Urban Development (ProDUS -UCR). School of Civil Engineering, University of Costa Rica (UCR). Costa Rica, Central America.

MIMAM, (2000) White Paper on Water, State Secretariat for Waters and Coasts, General Directorate of Hydraulic Works and Water Quality.

Páramo, GE (2007). Analysis, diagnosis and preparation of the fire susceptibility map of the vegetation cover in Colombia. Consulting Contract No. 2062372 (MAVDT-FONADE). Final report.

Renard, KG, Foster, GR, Weesies , GA, McCool , DK, & Yoder , DC (1997). Predicting Soil Erosion by Water : A Guide to Conservation Planning With the Revised Universal Soil loss Equation (RUSLE). US Department of Agriculture , Agriculture Handbook No. 703

Rodríguez, LME (2005). Morphoedaphogenesis : a renewed concept in the study of landscape. SCIENCE ergo-sum, Multidisciplinary Scientific Journal of Prospective, 12(2), 162-166.

Salamanca Alejandro (2015). Identification of potential desertification in the hydrographic zone of Sogamoso Colombia. UNIGIS.

SCS (Soil Conservation Service). (1972). national engineering handbook . Section 4. Hydrology . US Department of Agriculture . Washington, DC, USA.

SGC. (2012). Methodological document for the zoning of susceptibility and relative threat due to mass movement, scale 1:100,000. Colombian Geological Service. Bogotá DC 135 page.

Suárez, J. (2001). Erosion control in tropical areas (Bucaramanga: Industrial University of Santander).

Témez , J. (1978). Hydrometeorological Calculation of Maximum Flows in Small Natural Basins. General Directorate of Highways. Madrid. Spain. 111p.

Vargas, G. (1999). Technical guide for zoning susceptibility and threat from mass movements. Special publication, German Society for Technical Cooperation (GTZ), Río Guatiquía Project (PRG), Villavicencio, 55-153

Vargas, MR and Díaz-Granados, DM (1998). Regionalized Synthetic Curves of IntensityDuration -Frequency for Colombia. University of the Andes, Santafé de Bogotá.

Velásquez, S. (2008). Soil erosion using EUPSR (RUSLE). Coronado, Costa Rica: Tropical agronomic research and teaching center

Ven Te Chow , Maidment , D.R., & Mays , L.W. (2003). Applied hydrology. McGraw-Hill.

Vera Rodríguez, JM, & Albarracín Calderón, AP (2017). Methodology for the analysis of vulnerability to threats of flooding, mass removal and torrential flows in hydrographic basins. New Granada Science and Engineering, 27(2), 109-136.

Woodruff , N. P., & Siddoway , F. H. (1965). A wind erosion equation . Soil Sci . Soc. Amer . Proc . 29: (S): 602-608

Wright -McLaughlin Engineers , (1969) . ; Denver City