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PREDICTIVE SCHEMES IN GEOHAZARDS MANAGEMENT OF HYDROCLIMATOLOGICAL ORIGIN

Jaime Aristizabal[1], Carlos Motta[1], Carlos Capachero[2], Nelson Obregon[2], Leonardo Real[2]

[1]CENIT Transporte y Logística de Hidrocarburos
Bogotá D.C., Colombia
[2]CANAL CLIMA S.A.S
Bogotá D.C., Colombia.

ABSTRACT

CENIT, in association with the private sector, has recently developed and presented new approaches to susceptibility zoning for geohazards of hydroclimatic origin, through unsupervised learning algorithms (IPG2019-5343) and through the application of clustering techniques and algorithms. of supervised learning (IPG2021-65003), with which an adaptive zoning has been generated guided by model data and based on expert knowledge on the interaction of the pipeline, soils, and climatic conditions.

These approximations, in addition to considering the hydroclimatology of Colombia due to various phenomena of Climate Variability that accelerate the atmospheric condition at different scales, have been made the basis for the design, development and implementation of increasingly robust hybrids facing the requirements in the management of pipeline transportation systems with respect to Geohazards of this origin, and in their current state they facilitate decision-making in CENIT's integrity management and maintenance activities, with benefits in planning the maintenance and operational continuity of pipeline transportation systems.

On this occasion, a methodology is presented that allows implementation of predictive schemes in the process of identifying the occurrence of events of hydroclimatological origin with a high threat to the integrity of the pipeline transportation systems. For this, it is based on the implementation of zoning combined with expert knowledge, remote sensing, analysis of extreme precipitation events and modern visualization technologies that allow increasing the degree of assertiveness in the diagnosis of the condition. Finally, the results of the benefits identified in the application of the methodology are shown and a future work program is drawn up that seeks to contribute to risk management due to climatic events.

Keywords: Geohazards, hydroclimatology, Predictive, supervised learning algorithms, ITZC, ENSO, Susceptibility.

1. INTRODUCTION

The approach addressed for the optimization of the predictive scheme of hydroclimatological events from the zoning exercises that have been developed previously [1] [6] [9], consists of incorporation of different areas or basins to pipeline and analysis of events that occurred in the upper basin that had not previously been considered for zoning, but that constitute trigger events that could threaten the integrity of the pipeline at the crossing point.

This complement in the approach makes it possible to consider environment of transport infrastructure in greater detail, by involving morphometric characteristics of territory, changes in vegetation cover, historical events on right of way and the events located in the upper part of basins that escape to inventory of operators during the inspections to the DDV.

Figure 1 shows how delimitation of the hydrographic basins complements zoning approach at influence zone level, incorporating new areas (upper basin) in which processes eventually occur that could affect stability of rights of way and integrity of pipelines.

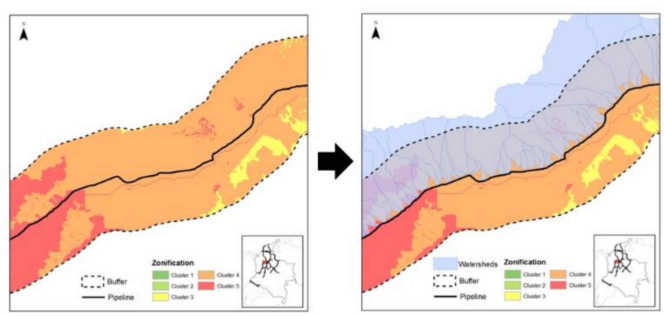

Figure 1. Incorporation of basins in zoning

Knowledge of the morphometric characteristics of the afferent areas, such as concentration times of basins and their torrential characteristics, contribute to the process of issuing alerts from different risk management instances for effects of sector.

In Colombia a progress has been made recently in the incorporation of Risk Management concepts and their application in territorial planning instruments. Although there are many challenges that must be faced to zone entire territory, there are currently the Plans for the Ordering and Management of Hydrographic Basins - POMCAS, prepared at a scale of 1:25,000 and derived from the National Policy for Comprehensive Care. Water Resources Management. (MADS, 2010). Although the POMCAS zoning is oriented to environmental planning of territory and is not per se an instrument to structure Geohazard Management systems, the elements provided by risk maps of torrential floods, floods and mass movements provide information that an operator can incorporate their analyses, generally at finer scales, when establishing predictive approaches to geographic risk management.

Thus, articulation of above with zoning, historical record of events (heterogeneous in structure), rainfall analysis, remote sensing techniques, base maps, geographic information systems, expert knowledge and techniques of visualization, allow to increase the degree of assertiveness of threat conditions on transport infrastructure, which could draw a methodological path as a contribution to Risk Management due to hydroclimatic events. This document presents a methodological process applied in Colombia that combines different sources of information, with different scales, and analysis techniques aimed at identifying potential threats to CENIT's transport infrastructure from adaptive zoning to an operational approach.

2. METHODOLOGY

The methodological process is grouped into three phases:

2.1 Consolidation and analysis of the data

Consolidation of the consists of structuring of spatial data in a geographic database that allows management of layers and spatial visualization of data. The main inputs used correspond to:

a) Zoning 2021 (CENIT/Climate Channel)

Zoning consists of a raster categorized with a cluster from 1 to 5 and has a spatial resolution of 30 m. The categories are described in Table 1, and further details can be found in [9]

Table 1. Zoning description

CLUSTER	DESCRIPTION
1	Lamellar erosive processes
2	Severe erosive processes, gullies, furrows
3	High geotechnical susceptibility. some landslides, falls and overturns occur.
4	Erosion in areas with high and very high geotechnical susceptibility, with landslides and falls.
5	Severe processes, occurs in these areas more than 40% of the landslides and flows of the entire ROW.

b) POMCAS risk zoning

Based on environmental zoning of POMCAS, risk areas due to floods, torrential floods and mass movements were consolidated, this with the purpose of complementing part of pipelines with lack of information or historical events. This analysis sought to incorporate elements that would indirectly consider aspects of territorial planning in the management of operational risk in oil and gas transportation industry. Figure 2 shows the zoning by type of phenomenon for various hydrographic subzones of Colombia.

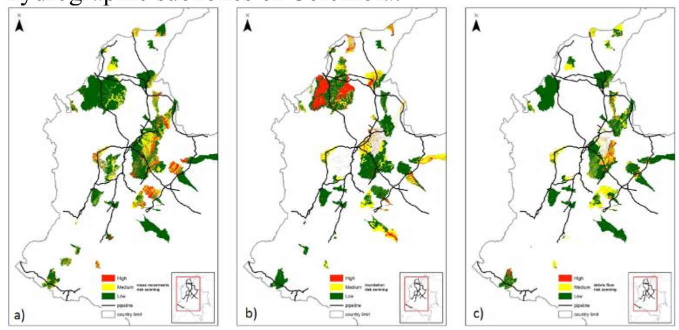

Figure 2. Hydrographic sub-zones with a) mass movement risk zoning b) inundation risk zoning c) debris flow risk zoning

c) Historical events

The historical events were consolidated in different layers of a geographic database, this due to heterogeneity in attributes. The most important aspect considered corresponds to spatial location of the point, additionally topological tests were carried out to avoid duplication of points. Table 2 shows records list used.

Table 2. Record of historical events

Source	Records	Dates
ECOPETROL	2375	NA
SIMMA SGC	3164	1916 - 2022
Baseline findings CENIT (dec 2020)	2741	2020 - 2021
Baseline findings CENIT (jul 2022)	2362	2021 - 2022
Baseline findings CENIT (may 2023)	2616	2022 - 2023

d) Association rules

In the analysis, association rules in which an event occurs for monitoring and follow-up purposes are considered. Although this input has not been considered in this analysis, it is considered that relating dates of occurrence of events could provide information for planning of operational or inspection activities.

e) Morphometries and concentration times

In POMCAS that are available for different hydrographic subzones of the country, it is possible to obtain information on concentration times of the main subbasins. With these parameters it is possible to estimate approximate transit times presented in upper basin that could generate a rise in level of the current with potential to affect the pipeline.

For example, Figure 3 shows times of concentration for a basin and estimated times of rising or sudden event that could occur in any of sub-basins. Figure 4 shows a 3D representation of this basin.

f) Analysis of rain and river levels

With concentration times data and monitoring of levels in hydrological stations available, progress is being made in design of individualized monitoring mechanisms since same instrumentation characteristics are not available in all basins.

However, knowing procedure for each case allows strengthening not only monitoring strategies, but also operational actions on transport infrastructure.

In this way, for the example of Figures 3 and 4, monitoring strategies make it possible to define time limit to response associated with activation of operational activities, which for this example were estimated to be less than 6 hours.

Subcuenca	Hmáx	Hmin	Longitud (m)	TC (h)
Q. Cimarrona	2744	2072	23	2.9
Q. La Mosca	2688	2071	27.3	3.6
Q. Marinilla	2409	2069	25.1	4.2
Río Pereira	2750	2085	28.6	3.7
Q. El Molino	2332	2080	12.7	2.3
Q La Paja	2882	1898	18	2.7
Q. El Bejuco - Barbacoas	2246	2061	18.1	3.6
Q. El Chocó	2425	1900	12.5	1.6
Río Negro afluentes directos 1	2135	2070	2.7	0.6
Río Negro afluentes directos 2	2117	2072	0	0.4
Q. La Tupia	2575	2088	15.1	2

Subcuenca	Hmáx	Hmin	Longitud (m)	TC (h)
Represa La Fé	2865	2150	22.3	2.7
Q. La Chuscala	2502	2113	10.9	1.5
Q. Agudelo	3106	2141	19.7	2.1
Río Pantanillo	2637	2150	23.1	3.3
Q. San Antonio - Emb. Abreo Mal Paso	2744	2072	23	2.9
Q. Arriba	2145	2071	6.2	1.5
Q. Yarumal	2683	2086	13.8	1.7

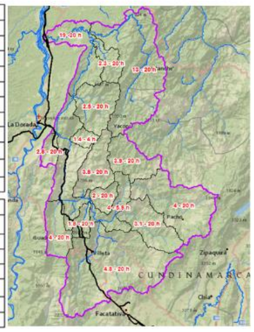

Figure 3. Concentration times for Negro River basin, Source: Own elaboration based on data from CONSORCIO POMCAS Oriente Antioqueño, 2016.

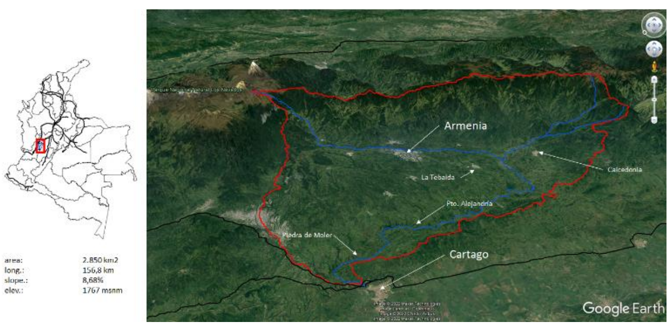

Figure 4. 3D representation of "La Vieja" river basin

2.2 Definition of grouping categories

To anticipate events that could affect stability of transport infrastructure and with the purpose of approaching a homogenization of criteria, a grouping into four classes was proposed, criteria of which are described in Table 3. This categorization considers that there is a high number of reports generated under different methodologies and conceptual criteria of survey and analysis.

2.3 Categories Assignment to pipeline segments

The purpose of this stage is to segment the pipeline into each category described in Table 3. As previously mentioned, this approach is used with the purpose of involving possible processes not considered for the area of influence of the previous zoning. Figure 5 shows a scheme for a basin, where a concentration of recurring historical events has been identified in the lower part of the basin, however, in upper part of basin it is possible to identify changes in vegetation cover or crowns of landslides that could constitute events with the potential to affect the pipeline.

Table 3. Criteria for categorizing pipeline segments

Category	Pipeline code category[1]	Criterion
No evidence	0	There are no historical reports in any source consulted. Stabilization works had been carried out. There is an isolated report, but of low reliability that could not be confirmed with images or base maps.
Erosion, scour, creep	3	Low risk of torrential avenues or floods. Evidence of erosion from the base map.
Flood, flows, torrential floods	2	Medium or high risk due to flooding. Medium or high risk due to flash floods. Evidence of deposits. Evidence of flows.
Mass removal (Landslide)	1	High or medium risk due to mass movements. Evidence of landslide crowns or scarps Coverage changes in the basin.

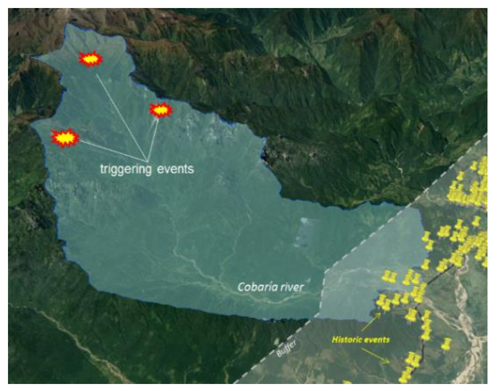

Figure 5. River basin with recurrence of events in its lower part

Based on this approach, a detailed review of pipelines ROW was carried out using base maps and different sources of remote sensing information to demonstrate changes in vegetation cover in areas of afferent basins not covered by zoning; likewise, events that occurred in these areas were identified from SIMMA (SGC) and concentration times of POMCAS were included.

The next step consists of editing pipeline under categories defined by expert judge in Table 3. This process also implies a process of analysis of geomorphology, including for example, tree lines, evidence of alluvial deposits or areas with traces of erosion and morphodynamic features.

The application of this set of criteria allowed assigning a category to pipeline segment, resulting in a detailed map for

[1] The category codes do not constitute an ordinal variable, the value is assigned to facilitate manipulation in the analyzes.

entire transportation infrastructure. For areas in which there are no historical records, or they are not easily evidenced from interpretation, we proceeded to assign categories to pipelines through a semi-automated process that consists of intersecting the risk categories of POMCAS with pipelines, according to criteria defined in Table 3. The result is a categorized map of transportation infrastructure (Figure 6).

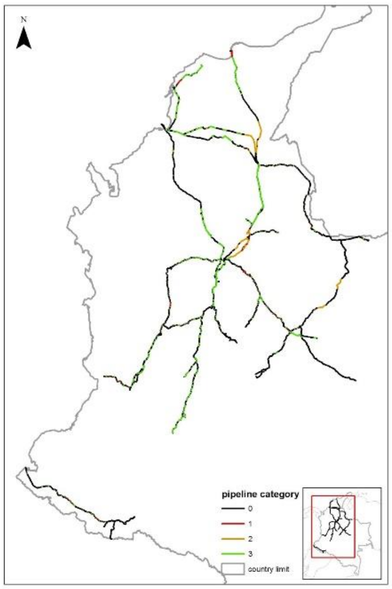

Figure 6. Pipeline Category

3. RESULTS AND DISCUSSION

Once all country's systems were analyzed applying criteria and procedures described in methodology, it was possible to show that there is a correspondence between latest reported events and pipeline categories in which a degree of threat had been assigned.

Considering that assignment of threat was not exclusively due to existence of historical reports, but rather considered identification of changes in cover or morphodynamic features, these aspects are considered as a success in application of methodology.

These elements not associated with historical reports, to which results obtained in previous zoning can be added, can be understood as tools to identify precursors of instability processes with potential to affect the transportation infrastructure. Some examples are shown below.

a) Case 1

Event occurred in the section of interest on May 4, 2023, in a segment of pipeline categorized as a threat due to mass movements (Category 1). Pipeline segments under this category could be affected by a sudden mass removal phenomenon, whether it be a landslide, a fall or detachment of material.

b) Case 2

Although the event presented did not directly affect transportation infrastructure, it was identified that this area belongs to a basin with high susceptibility to mass movements according to SGC threat map.

In this case, it was possible to establish that in landslide zone there was an important advance in revegetation processes in the past; however, a timeline allowed us to identify that in 2001 the land had a poor vegetation cover, predominantly shrubs and isolated trees; in 2012 the crown of a landslide appeared, which was revegetated, but intervention process in this area continued until 2021. Finally, in nearby areas on 02/04/2003 a landslide was reported upstream of the event site, and on 04/01/2017 a flow was reported. This timeline could be analyzed using inputs described in methodological process.

Figure 7. Location of landslide in Case 1

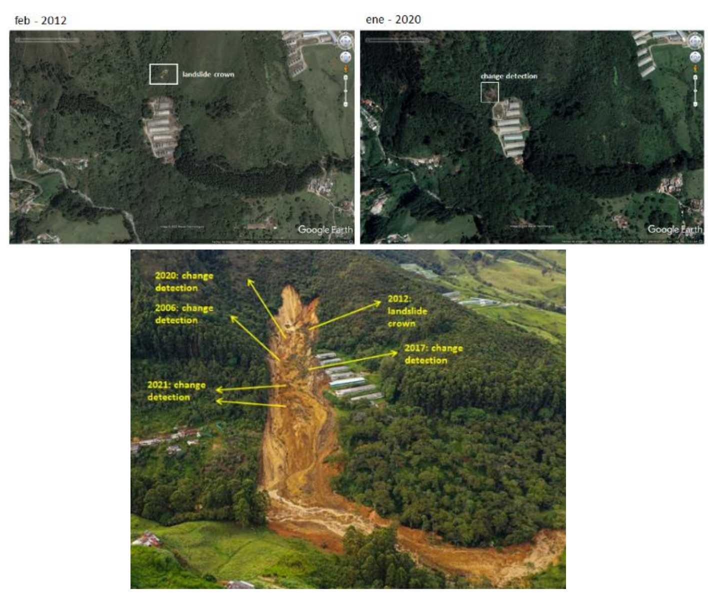

Figure 8. Timeline in Case 2

c) Case 3

This event occurred on June 24, 2022, and although an abundant vegetation cover is evident in the right-of-way, in watershed delimitation process, gully-type erosive processes, poorly consolidated soils and slopes with high slopes were evidenced. This is a specific case with very short concentration times; however, this case represents an opportunity to identify possible threats outside the inspection area.

Figure 9. Event 24/06/2022

4. CONCLUSION

Pipeline monitoring process is carried out on two fronts that could be summarized as information gathering through inspections and data analysis. Row patrol involves categorization of possible events on pipeline that are called findings, with defined criteria that allow its categorization.

When contrasting categorization by inspection and categorization resulting from the grouping of the data under expert criteria, interesting and non-exclusive elements are evident that trace a route towards a meeting point between operational perspective and that of climate risk management, which, additionally, can consider the geographical dispersion of infrastructure and identification of elements of interest in surrounding areas.

For example, a relevant aspect is that 95% of the findings in most recent and refined CENIT database have been categorized in inspection as findings with classifications I and II, generally without evidence of threat; however, based on proposed methodology and based on global and historical analysis, there is a coincidence in absence of evidence of threat for about 35% of cases, which could suggest an underestimation of phenomena observed in categorization by analysis methodology or it could be an indicator of changes that are occurring in the basin that are beginning to alter preconditions.

Faced with this panorama and considering that there is indeed a difference in criteria due to scale effects, it is essential to identify those areas of pipeline that could present differences between the categorization methodologies and that appear to be underestimated from inspection, but that at a methodological level are found to be categorized as category 1 (Threat by mass movements) or category 2 (Threat by flood, flow or torrential flood), would allow structuring complementary work plans in order to establish monitoring strategies in afferent basins.

Regarding future work perspectives, the first thing that is interesting is the development of dynamic analysis of findings. A first analysis of the dynamic behavior of the sites where events have occurred (Table 5), which reports the absolute frequency of occurrence according to the simultaneous occurrence of three variables (histograms in three dimensions). Such variables correspond to moments in time in which events classification or categorization exercises have been carried out (I, II, III, IV). Thus, for example, row for which frequency of 54 events is reported corresponds to categories I, II and II. In other words, in the exercise of December 2020, 54 events were categorized as type I (first column), which later in February 2022 evolve to type II (second column), prevailing in this same category for the exercise of May 2023 (third column). This, which in principle constitutes a monitoring exercise of findings evolution, can also establish the bases of a methodological process focused on data analytics that allows cross-validation between categorization methodologies. This process that begins to be explored from this new grouping approach will continue in analyzes that will be reported later.

Table 4. Cross categorization by ROW Patrol and categorization by analysis methodology

Findings category	Pipeline category				Total
	0	1	2	3	
Empty	1.5%	0.2%	0.3%	1.4%	3.4%
I	22.2%	7.8%	7.0%	29.6%	66.6%
II	13.2%	3.1%	3.2%	8.7%	28.2%
III	0.9%	0.2%	0.2%	0.4%	1.7%
IV	0.0%	0.0%	0.0%	0.0%	0.1%
Total	**37.9%**	**11.3%**	**10.6%**	**40.2%**	**100.0%**

Table 4. Findings evolution in time

Classif_Dec_2020	Classif_Feb_2022	Classif_May_2023	Frequency
0	0	0	82
0	0	I	278
0	0	II	149
0	0	III	10
0	0	IV	1
0	I	0	5
0	I	I	810
0	I	II	18
0	I	III	1
0	II	0	1
0	II	I	67
0	II	II	329
0	II	III	6
0	III	I	9
0	III	II	7
0	III	III	18
0	IV	III	1
0	IV	IV	1
I	0	0	2
I	0	I	20

Classif_Dec_2020	Classif_Feb_2022	Classif_May_2023	Frequency
I	0	II	4
I	I	I	269
I	I	II	5
I	II	I	7
I	II	II	54
I	III	III	1
II	0	I	7
II	0	II	9
II	0	III	1
II	I	I	223
II	I	II	3
II	II	I	33
II	II	II	150
II	II	III	2
II	III	III	1
III	0	I	1
III	0	II	1
III	0	III	1
III	I	I	13
III	II	I	1
III	II	II	7
III	III	I	4
III	III	II	2
III	III	III	2

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