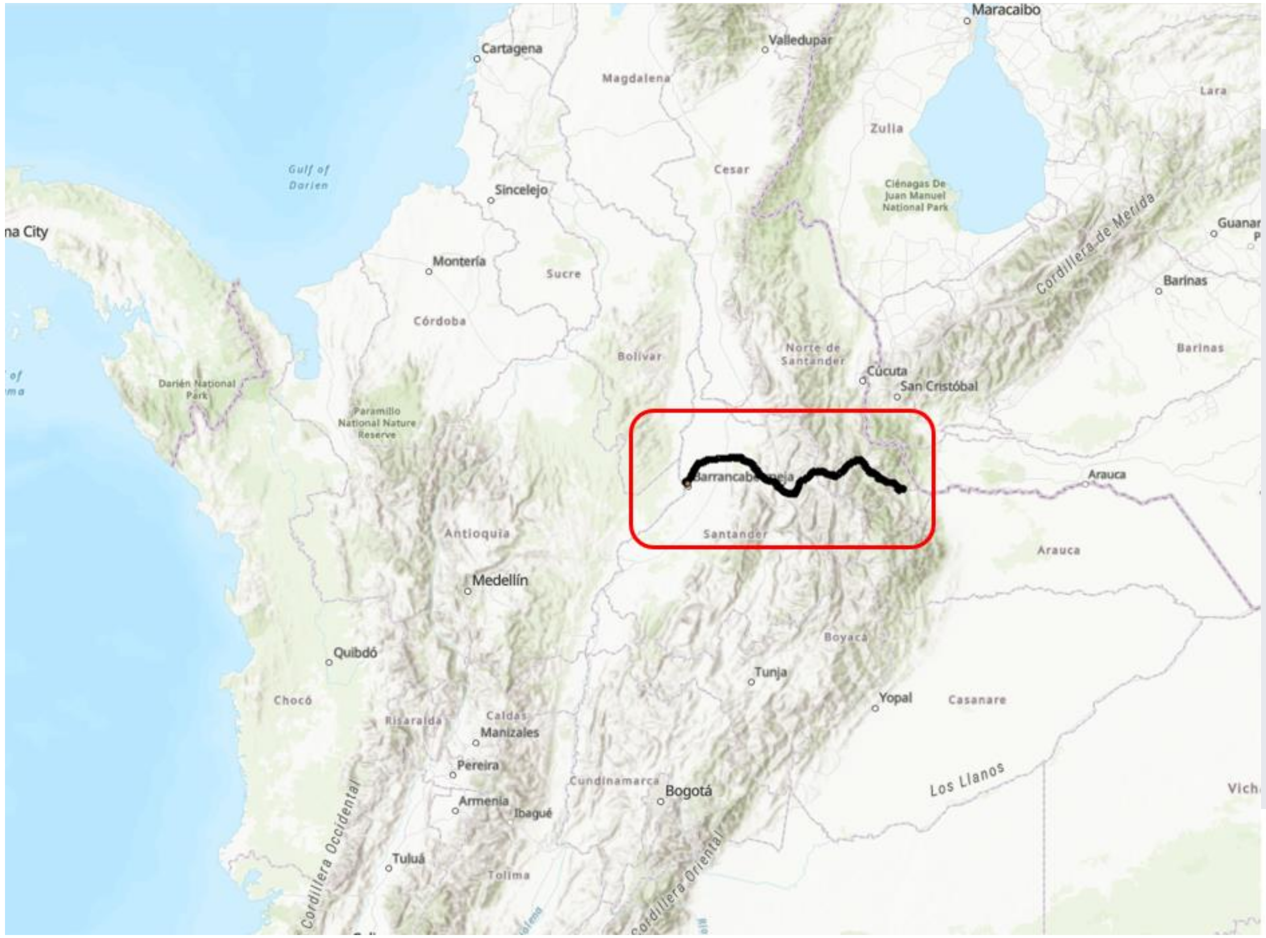
INNOVATION IN GEOTECHNICAL RISK MANAGEMENT THAT INTEGRATES DIFFERENT COMPONENTS FOR MANAGEMENT OF GEO-HAZARDS IN NATURAL GAS TRANSPORT INFRASTRUCTURE.

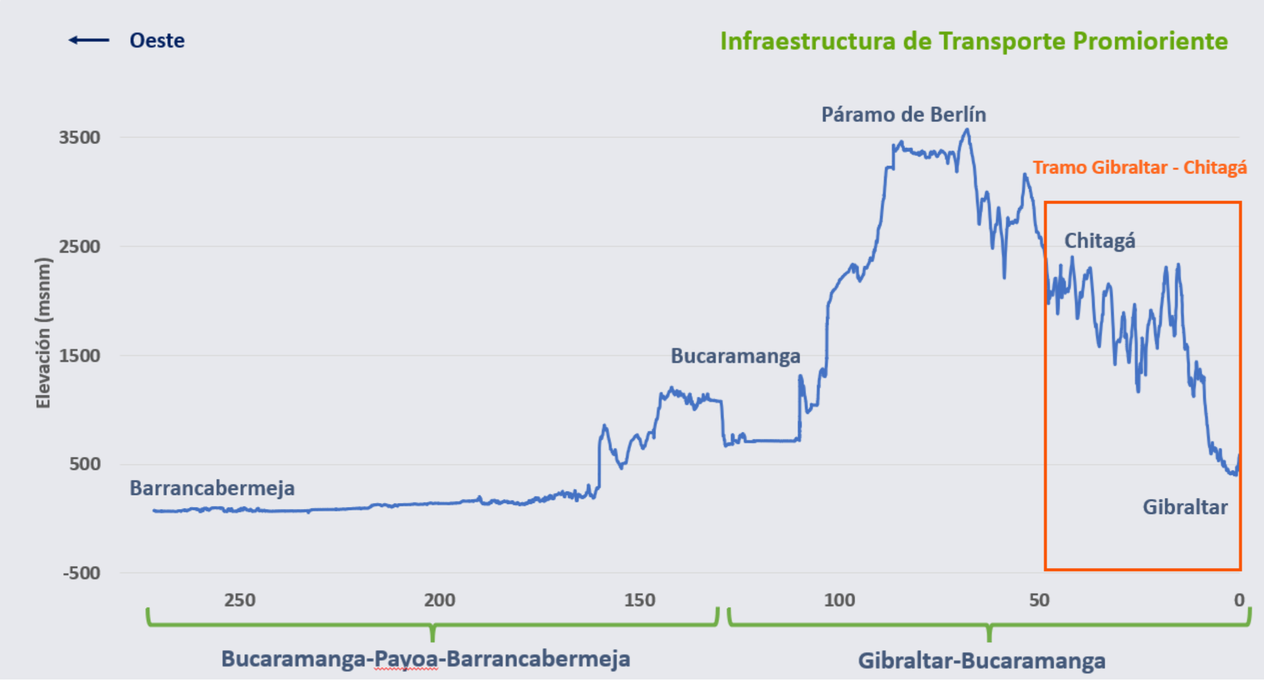
SALUS BENITEZ

06 07 de Noviembre de 2025

UBICATION

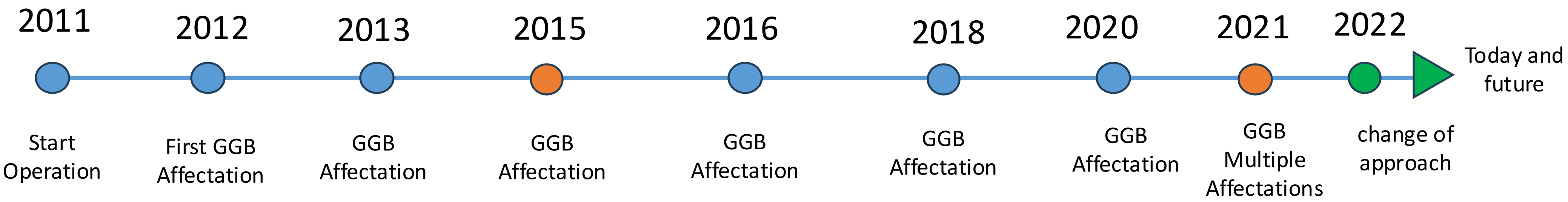
Location and elevation profile of the first 87.7 kilometers of the route





BACKGROUND

Timeline



2011
Start Operation
2012
First GGB Affectation
2013
GGB Affectation
2015
GGB Affectation
2016
GGB Affectation
2018
GGB Affectation
2020
GGB Affectation
2021
GGB Multiple Affectations
2022
change of approach
Today and future

2015

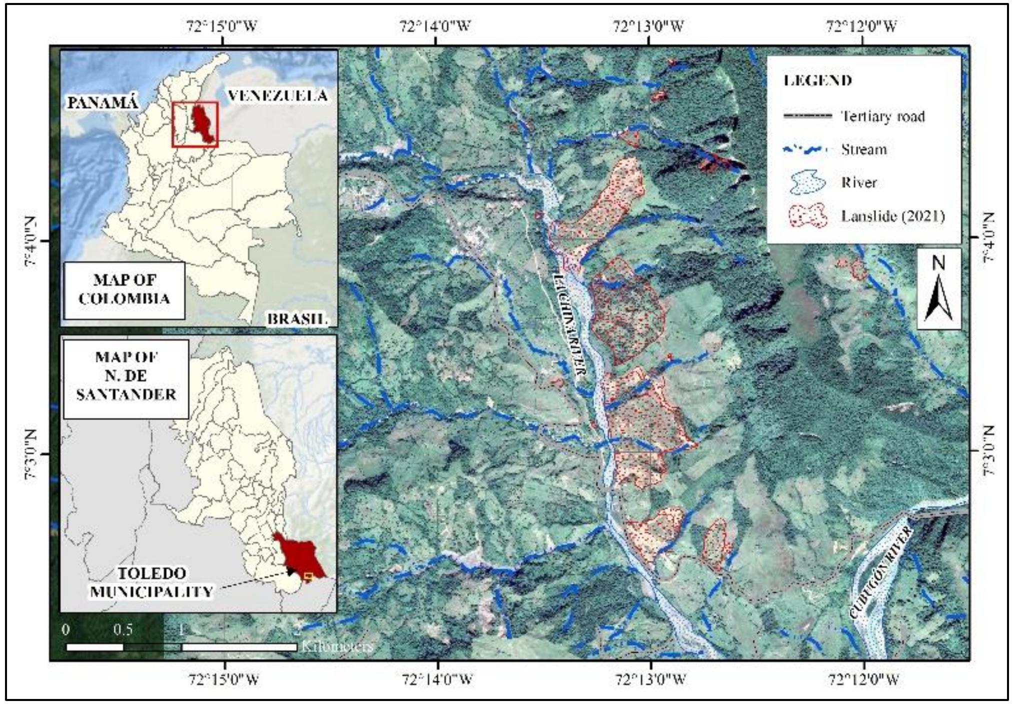
36 anomalies on the right of way, 3 of which involved breakage, resulting in infrastructure unavailability for 57 days

2015-2017

A plan was developed to identify the threat posed by mass movement phenomena to which the infrastructure was exposed, in order to subsequently implement an action plan and mitigate this threat.

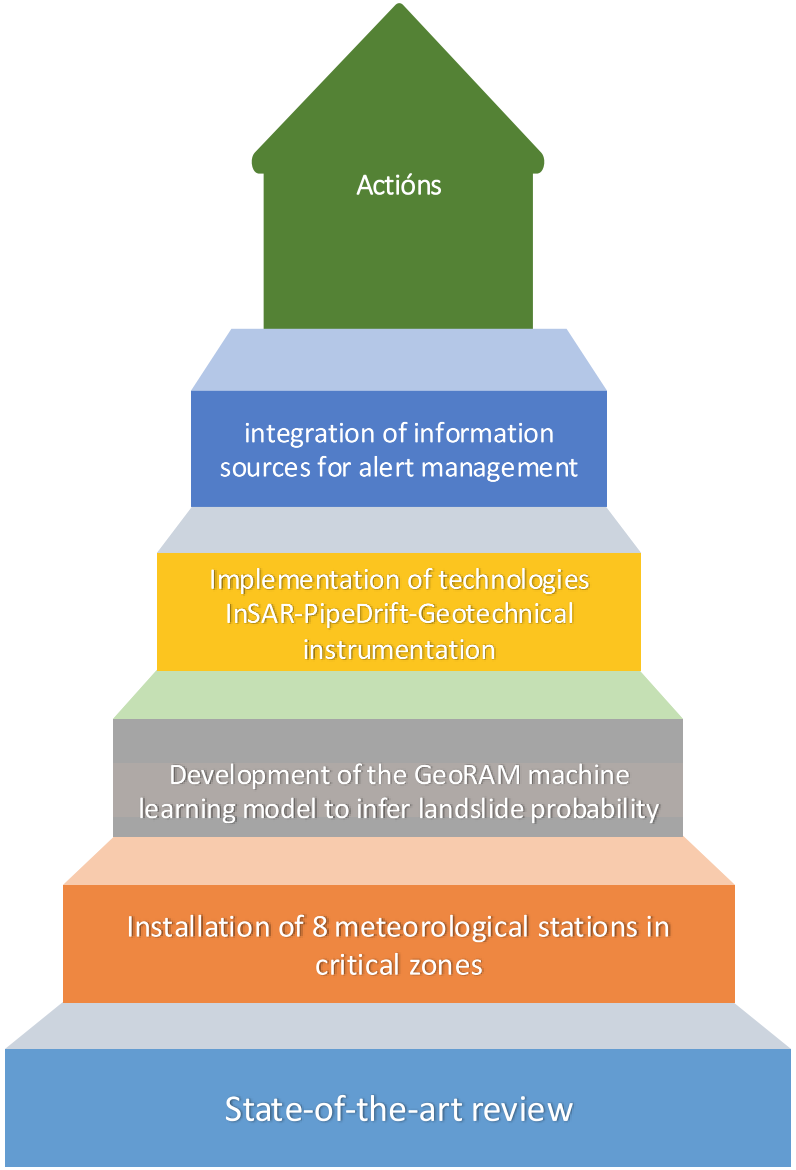
2021

Aerial view of the landslide in 2021.



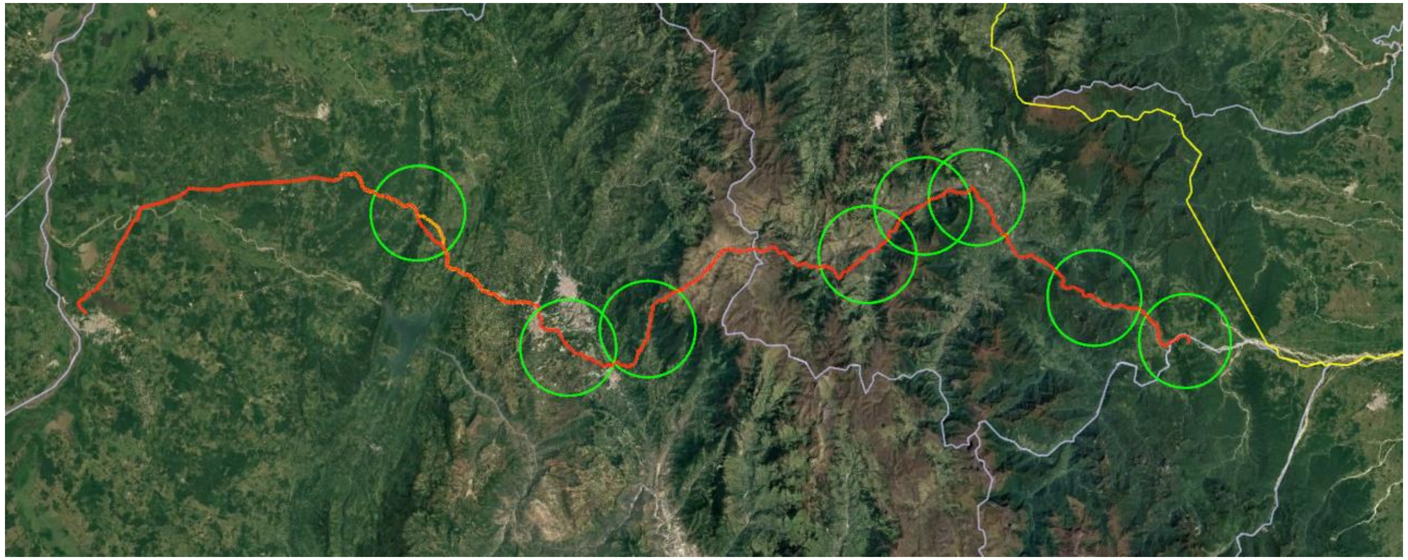
Main impacts of landslides on the right of way in 2021

METHODOLOGY

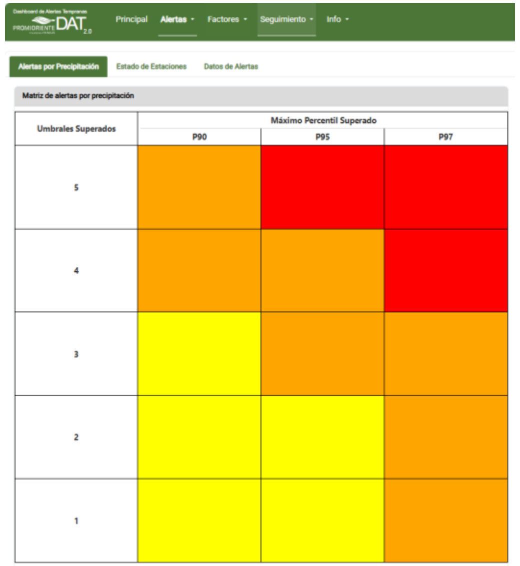

Actións
integration of information sources for alert management
Implementation of technologies InSAR-PipeDrift-Geotechnical instrumentation
Development of the GeoRAM machine learning model to infer landslide probability
Installation of 8 meteorological stations in critical zones
State-of-the-art review


Recorridos metro a metro para identificar anomalías
Rutinas de monitoreo topográfico
Seguimiento de sitios a través de imágenes SAR
Acciones Operativas / Estudios de suelo / construcción de obras de control geotécnico
01
02
03
04
Gestión de Alertas Identificadas

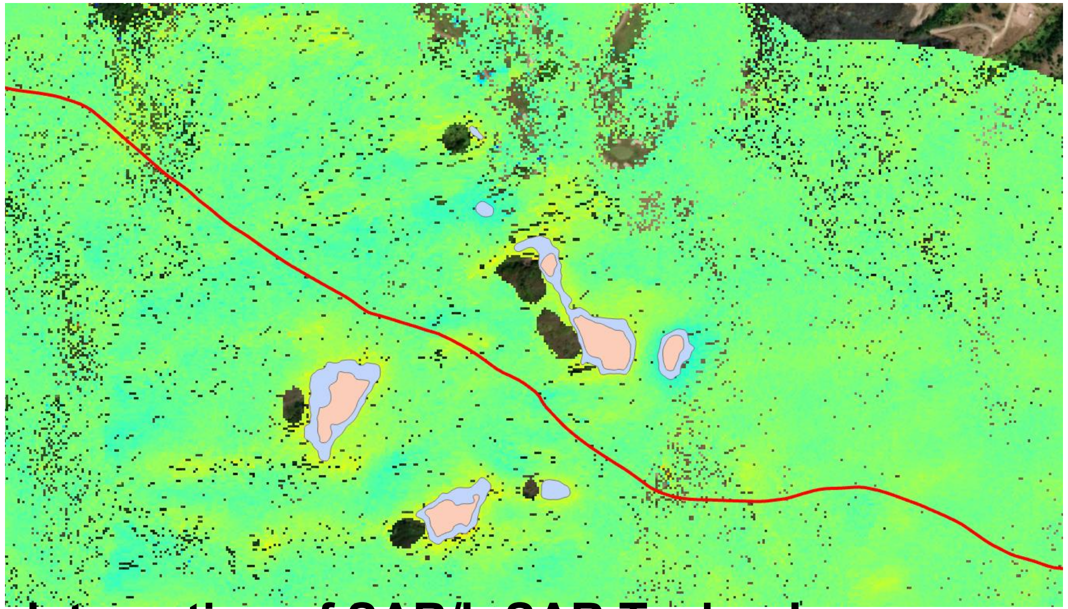
RESULTS



Impact of Weather Stations



Results of the predictive model



Integration of SAR/InSAR Technology

CONCLUSIONS

- Transformation of the Risk Management Approach
- Effective Technological Integration
- Strengthening Predictive Capability
- Strategic Value of Technology Surveillance
- System Scalability and Sustainability

¡Gracias!

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INNOVATION IN GEOTECHNICAL RISK MANAGEMENT THAT INTEGRATES DIFFERENT COMPONENTS FOR MANAGEMENT OF GEO-HAZARDS IN NATURAL GAS TRANSPORT INFRASTRUCTURE.

Salus Benítez
Promigas
Bucaramanga-Colombia

ABSTRACT

The Gibraltar-Bucaramanga gas pipeline constitutes a segment of Promioriente's transportation network, traversing the eastern Colombian mountain range from the from the foothills of the eastern plains to the capital of the department of Santander and subsequently extending to Barrancabermeja, recognized as Colombia's oil capital. Of its 335 km trajectory, 144 km of the pipeline traverses high and mid-mountain regions, where colluvial deposits and the prevailing climatic conditions present a significant risk of landslides.

This situation has necessitated the continuous development of strategies and techniques Promioriente to monitor geotechnical risk and ensure operational continuity. These techniques encompass a range of methods, including:

- *topographic monitoring,*
- *photogrammetry,*
- *Optical satellite imagery*
- *Synthetic Aperture Radar.*
- *Interferometric of Synthetic Aperture Radar*
- *Implementation of meteorological stations, and.*
- *machine learning model to infer the probability of landslides.*

As well as the updating of the status of the conditioning factors. All of this has become an early warning system to mitigate the impacts derived from geotechnical risk, moving from a reactive to a preventive approach.

Keywords: *Natural gas transportation, mass movement, risk mitigation, monitoring*

1. INTRODUCTION

The route of the Gibraltar–Bucaramanga Gas Pipeline faces significant geotechnical challenges due to the topographic, climatic, and geological conditions of the regions it crosses. The Gibraltar–Bucaramanga section passes through areas highly susceptible to mass movement phenomena, which poses a constant risk to the integrity of the pipeline and the continuity of the service.

Figure 1.Ubication for Promioriente Pipeline.

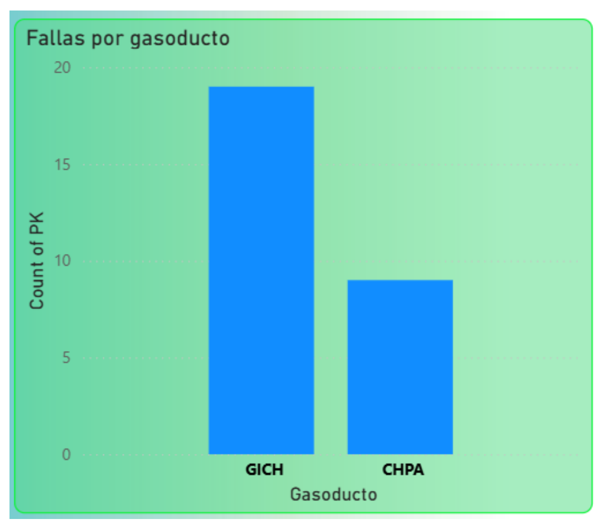

Figure 2. Number of fails for Landslides in Gibraltar Bucaramanga Pipeline.

Normally, sites with a high susceptibility to landslides were included in a monitoring plan with a special frequency, and if an anomaly was found, civil works for geotechnical protection were designed. However, during the winter season of 2021, there were incidents affecting the gas pipeline's right of way, which disrupted service for 120 days

A high percentage of gas pipeline failure events have occurred in the first 87 km of the pipeline.
In this section of the route, abrupt slope changes, combined with climatic and geomorphological characteristics, give the layout unique features.

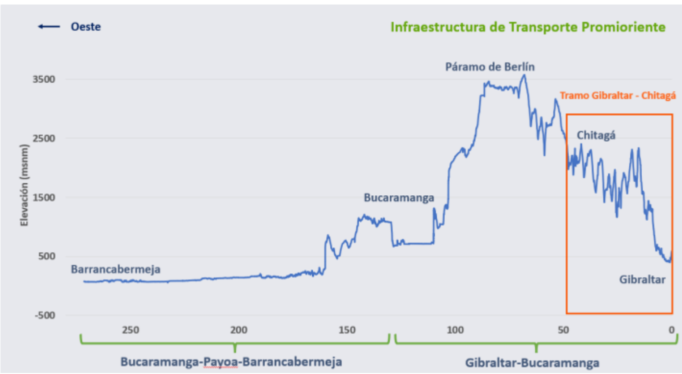

Figure 3. elevation profile and location of the first 87.7 kilometers of the route.

As a precedent, there were events in 2015, where there were 36 incidents affecting the right of way of the gas pipeline, which led to a service interruption lasting 57 days.
This led the organization to assess its susceptibility to geotechnical risk, and between 2015 and 2017, it conducted a study to determine the threat, vulnerability, and risk to the transport infrastructure.

***Figure 4**. Threat rating in the transportation infrastructure*

After identifying the susceptibility to geotechnical risk, a civil works construction plan was implemented to mitigate the threat. However, despite efforts to mitigate the threat, in 2021, there were impacts on the right of way, which affected service for more than four months.

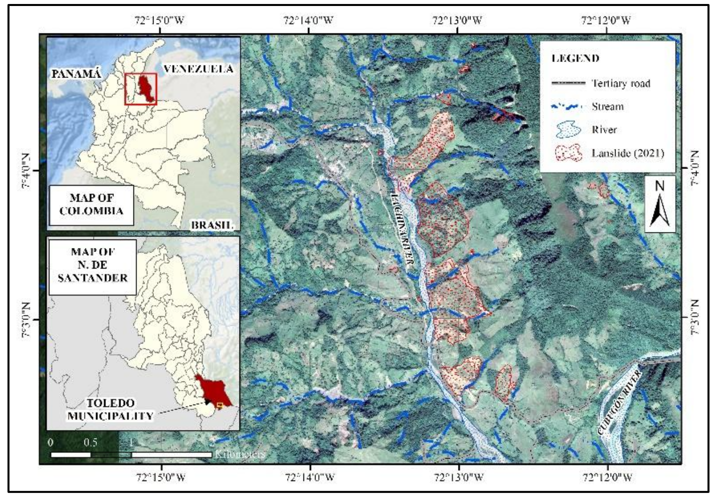

Figure 5. Main impacts of landslides on the right of way in 2021


Figure 6. Aerial view of the landslide in 2021.

2. Methodology

To monitor right-of-way behavior, it is necessary to apply the principle of redundancy and the intersection of different methods to reduce uncertainty. Each of the monitoring methods included in this case is described below.

2.1 Review of the state of the art to identify available technologies that would enable geotechnical risk monitoring.

With the support of the National University, technologies that are available and suitable for the conditions of the gas pipeline were identified.

Technologies such as:
- Synthetic Aperture Radar Images.
- Geotechnical Instrumentation

Considering that rainfall was identified as the main trigger for landslides in this case, eight weather stations were installed to monitor this trigger in real time.

2.2 Creation of a dataset and machine learning model.

Construction of a dataset with the main variables of the gas pipeline environment, such as slope, geological engineering units, land cover, event history, among others, to later form part of the variables of our machine learning model (GeoRAM), which infers the probability of landslides occurring.

At this point, geospatial data began to gain relevance, along with all the information on variables such as:

- Geology
- Slope
- Land cover
- Distance to geological faults
- Precipitation
- Seismicity
- Geological units
- Variation in soil moisture
- Changes in resistance parameters over time due to deterioration and recovery.

At this point, with the construction of eight weather stations in the most susceptible areas of the gas pipeline, together with the machine learning model (GeoRAM)

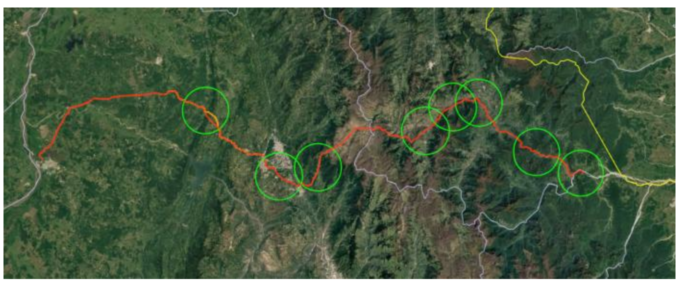

Figure 7. weather stations in the most susceptible areas of the gas pipeline

The analysis and statistics of historical data began to shape the Early Warning project for the prevention and mitigation of geotechnical risk in transport infrastructure.

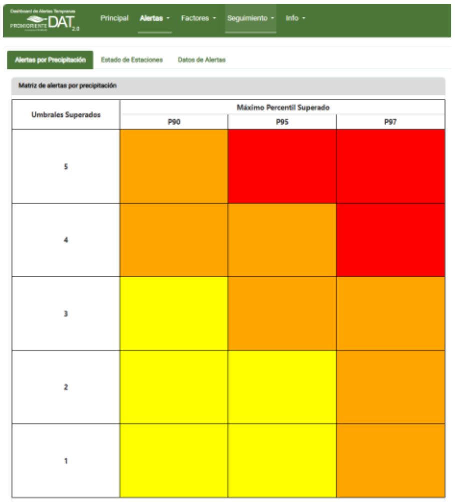

Figure 8. Precipitation thresholds defined for alerts in the Early Warning program

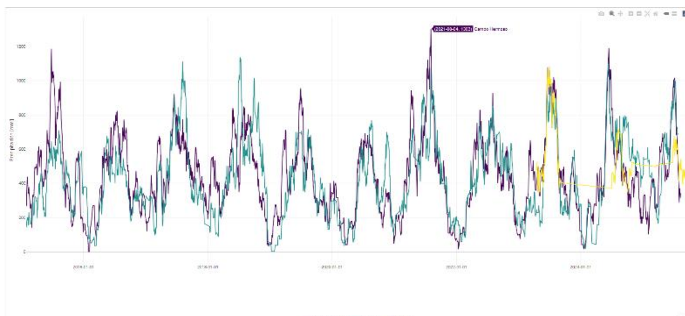

Figure 9. Precipitation in the Gibraltar Bucaramanga sector between 2015 and 2021

Data from proprietary meteorological stations, along with historical data from public sources dating back to the 1970s, were subjected to descriptive statistical analysis. This led to the establishment of sectorized precipitation threshold limits to guide action plans.

These actions range from increasing the frequency of monitoring routines at identified critical sites to site visits by geotechnical specialists for specific studies that enable the design of appropriate protection or geotechnical control works.

3. RESULTS AND DISCUSSION

I. Consolidation of a multicomponent monitoring system

A five-component early warning system was successfully implemented:

- Technological surveillance.
- Meteorological Stations
- Machine learning model
  - Geotechnical sensors
  - Real-time monitoring platform

This approach enabled a shift from reactive to preventive geotechnical risk management, improving the ability to anticipate mass movement events.

II. Results of the predictive model

The machine learning model, fed with meteorological, topographic, and geological data, has generated alerts with a high correlation to actual events. For example, rainfall increases exceeding 200 mm were identified in critical areas such as Gibraltar–La Virgen, which triggered preventive action plans.

Figure 10. Landslide probability prediction result with GeoRAM

III. Impact of Weather Stations

The installed weather stations (Gibraltar, La Virgen, Chitagá, Labateca, Cristales, Tane, La Hormiga and vega Duque) have enabled effective monitoring coverage along the gas pipeline corridor, providing real-time data on precipitation, humidity, and temperature. Data from weather stations is transmitted via GPRS to a workflow in AZURE, which feeds geoRAM predictions and allows actions to be established based on its behavior.

Figure 11. structure of a weather station installed

IV. Integration of SAR/InSAR Technology

The integration of radar satellite imagery (SAR) and his interferometric (InSAR) will enable the detection of sub-metric deformations, even under cloudy or low-visibility conditions. This technology has strengthened monitoring capabilities in areas that are difficult to access due to topographic constraints as well as physical security concerns.

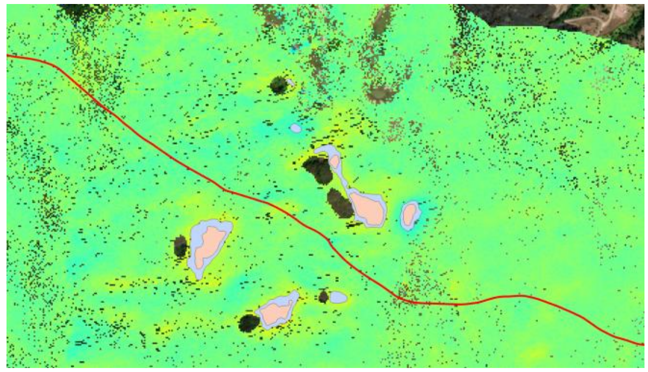

Figure 12. InSAR results.

The results demonstrate that the integration of advanced technologies and data analytics significantly enhances geotechnical risk management in linear infrastructure. However, several challenges have been identified, including:

- The need to keep models updated with recent data.
- Dependence on connectivity for real-time data transmission.
- Long-term operational sustainability of the system.
- The importance of continuous improvement in machine learning models, including testing alternative algorithms, developing zone-specific models based on varying susceptibility levels, and exploring the use of neural networks.

4. CONCLUSION

I. Transformation of the Risk Management Approach

The early warning project has enabled Promioriente to evolve from a reactive to a preventive approach in geotechnical risk management, through the integration of advanced technologies, continuous monitoring, and data analytics.

II. Effective Technological Integration

The implementation of weather stations, geotechnical sensors, satellite imagery (SAR/InSAR), and machine learning models has proven to be an effective strategy for anticipating mass movement events and triggering timely action plans.

III. Strengthening Predictive Capability

The developed machine learning model has successfully inferred high-susceptibility zones, powered by meteorological, geospatial, and topographic data. This has enabled the generation of alerts with sufficient lead time to mitigate impacts on infrastructure.

IV. Strategic Value of Technology Surveillance

Understanding available technologies and reviewing the state of the art have been essential for selecting appropriate technologies for each segment of the gas pipeline, optimizing resources and improving monitoring system coverage.

V. **System Scalability and Sustainability**

The early warning system is designed to be scalable and adaptable to other segments of the organization's transport infrastructure, and even to other types of linear infrastructure. Its sustainability will depend on continuous data updates, sensor maintenance, and effective knowledge management.

ACKNOWLEDGEMENTS

To the managerial and operational personnel who have actively participated in the development and implementation of the various technologies for geotechnical risk management. Their commitment, expertise, and willingness to adopt new technologies have been fundamental in consolidating a preventive and resilient approach to the protection of natural gas transportation infrastructure. The joint effort between operational execution and strategic planning in the implementation process has been key to transforming geotechnical risk management into a proactive, data-driven tool that strengthens safety, service continuity, and operational sustainability.

REFERENCES

[1] Ballesteros Parra, J. R., Muñoz García, A. M., & Flórez Celis, H. (2022). *Tecnologías de monitoreo de infraestructura lineal con énfasis en riesgo geotécnico* (Versión 4.0). Universidad Nacional de Colombia – Sede Medellín, Departamento de Ciencias de la Computación y de la Decisión. Informe técnico para PROMIORIENTE S.A. E.S.P., 2022.

[2] León, A., Buitrago, C., Benítez, S., Bohorquez, J. D., Ramírez, M., Guillín, W., Llerena, L., Landázury, F., & Sanjuan, M. (2025). *Machine learning for early detection of landslides in gas transportation pipelines*. Paper presented at the World Gas Conference 2025.

	Accumulated Precipitation (mm)			
Days	**26 August 2015**	**3 August 2021**	**30 May 2024**	**15 June 2024**
0–2	74.0	304.2	292.1	221.0
2–4	168.0	480.2	437.1	339.1
4–8	300.8	660.6	690.6	456.7
8–16	643.7	1152.8	1151.3	958.2
16–35	1154.5	2087.8	2113.5	1702.2
35–55	1744.7	2790.5	2803.9	2080.1