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ADVANCES IN GEOTECHNICAL MONITORING OF GAS PIPELINES: APPLICATION OF UAV FOR EFFICIENT AND SAFE MANAGEMENT

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SUMMARY

In the field of pipeline geotechnics, the use of Unmanned Aerial Vehicles (UAV) has emerged as a relatively new alternative for geotechnical monitoring; their built-in sensors allow us to collect data along the route of gas pipelines. In this process, photogrammetric processes are used to create Digital Elevation Models (DEM), as well as geospatial data related to visual inspections, which are used in many aspects other than geotechnics.

The main advantage of using UAVs is that they can overcome the complexity of certain types of terrain, in areas with limitations such as topography, water, etc. This method is characterized by faster information processing compared to traditional topographic methods. In addition, UAV overflights can be programmed to reflect the timing of a specific geotechnical event, thus providing the image history to identify changes over time within the area of interest.

Based on the captured images in the form of orthophotos, panoramic photographs, oblique photographs, specific photographs and videos, different aspects of interest can be monitored: geotechnical events, damage to structures, invasions, existing infrastructure, buildings, changes in land use, interferences with intersections of water bodies, roads, among others, facilitating the analysis and monitoring of these sights.

The results obtained provide valuable information about possible threats to the stability of the ROW (Right of Way). The study area selected for this paper covers 4.7 km2, where 14 sites of interest were identified, located in a mountainous area with slopes of more than 35° and an average annual rainfall of more than 5500 mm, in the Apiay-Usme gas pipeline.

According to the information obtained, the methodology applied consisted of three stages (assessment of the problem context, recognition of UAV flights and assessment of the geotechnical risk through a matrix of the type "RAM: Risk Analysis Methodology"). Based on the matrix, an action plan was developed to protect the integrity of the pipeline and the stability of the ROW, demonstrating the effectiveness and efficiency of monitoring geotechnical events in pipelines using UAVs. This technique provides valuable information for geohazard management and supports timely decision making.

1. INTRODUCTION

Gas pipelines are essential infrastructure for the safe and efficient transportation of gas and play a critical role in supplying energy to various regions. However, ensuring the integrity and safety of these networks is a constant challenge due to the natural dynamics of the field that create geotechnical risks.

In recent years, technological advances have evolved the geotechnical monitoring of pipelines, allowing the use of UAV as an essential tool in the management and maintenance of these infrastructures. UAV equipped with image sensors, LiDAR (Light Detection and Ranging), thermography and gas detectors have proven to be an efficient and safe solution to monitor extensive gas pipeline networks more quickly, accurately and cost-effectively.

In this paper we will explore the advances in alternatives for pipeline monitoring using UAV. We will analyze the benefits of this technology, ranging from the early detection of potential instabilities to the assessment of the geotechnical conditions of the surrounding soil. We will also look at the practical applications of data collected by UAV for

maintenance decisions and efficient management of gas pipelines.
The study area was located in the Apiay - Usme Gas Pipeline, which is part of District 4 of the network operated by Transportadora de Gas Internacional (TGI), and also has six (6) 2" diameter branches, identified as Guayabetal, Chipaque, Cáqueza, Fosca, Quetame and Une, with lengths of 0.6 km, 3.1 km, 4.15 km, 3.1 km, 3.3 km and 0.1 km, respectively. The main line consists of a 6" diameter pipe that begins its journey at PK0+000, corresponding to the city gate located in Apiay, Villavicencio, department of Meta, and ends at the reception trap located in Usme, a town in Bogota DC (PK122+000).

The section crosses 89.6 km of the Eastern Cordillera of Colombia, in the department of Meta, over sections with elevations ranging from 447m to 3188m, as well as slopes from 5% to 51%, in addition, the most superficial strata are conformed by materials derived from the weathering of sedimentary rocks and transported soils such as colluvium and alluvial terraces.

2. UNMANNED AERIAL VEHICLES (UAV) - BASED INFORMATION CAPTURE TECHNIQUES

There are several techniques for capturing information with UAV. The choice of technique depends on the specific objectives of the project and the type of information desired.

Some of the most common techniques are:

- Aerial Photography: This technique is commonly used for capturing information using UAV. Unmanned Aerial Vehicles (UAV) can carry high-resolution cameras for visual inspections and large-scale mapping. An added value is the ability to identify and characterize soil flows or debris based on the loss of vegetation cover, in addition to tracking the flow's progression.
- Photogrammetry: Photogrammetry is an objective technique that involves using images captured from different vantage points for calculating the dimensions and shape of objects or terrain. These images can be processed to create accurate three-dimensional models. These models can be utilized as maps featuring contour lines, although their accuracy may vary based on the presence of den.
- Lidar (Light Detection and Ranging): This sensor employs laser light pulses to gauge the distance between the UAV and objects or terrain. This technique is highly advantageous in producing high-resolution digital elevation models (DEMs) and precise point clouds. DEMs obtained with Lidar technology are substantially more accurate than photogrammetric ones.
- Thermography: Unmanned aerial vehicles (UAV) can be outfitted with thermal cameras that detect infrared radiation emitted by objects. This technology is valuable for identifying temperature fluctuations in structures and terrain, which may indicate structural defects or leaks from pipes transporting materials.
- Multispectral: Unmanned Aerial Vehicles (UAV) have the capability to transport multispectral cameras that capture data in various wavelengths of the electromagnetic spectrum. This enables the collection of information on crop health, vegetation, and soil quality.
- Gas Detectors: Recently, good results have been achieved in measuring the presence of methane and ethane gases in the environment using detectors mounted on UAV. These detectors achieve optimal measurements at altitudes below 150m and are used in gas pipeline leak detection.

3. IMPLEMENTED TECHNIQUE

The photogrammetry technique was chosen for information capture due to significant advantages in terms of precision, efficiency, and versatility in carrying out the activities requested by the client.

Photogrammetry allowed for precise measurements of distances, heights, and dimensions of instabilities and structures within the area of interest.

Equipped with high-resolution cameras, UAV captured images over large areas rapidly and affordably, significantly reducing costs and field time compared to traditional surveying methods.

4. INFORMATION PROCESSING METHODOLOGY

The implemented methodology consists of three stages:

4.1 Stage 1: Problem Context Evaluation

Based on the information processed from the Geographic Database Development (GDB), 14 geotechnical events were identified. Support was provided by secondary information sources such as geology, regional geomorphology, and available digital terrain models (satellite images) to characterize the analysis area. A specific "RAM" matrix was developed for the site and type of instability (flows) in order to prioritize activities based on geotechnical risk.

4.2 Stage 2: Field Reconnaissance

An attempt was made to conduct on-site visits, which aimed to identify the specific characteristics of each location, as well as potential factors contributing to any failures. UAV flights were undertaken from adjacent areas to refine the ultimate flight blueprint. However, a major limitation of this stage was the dense vegetation cover present in the area, as well as the adverse topographic conditions.

Given the limitations previously mentioned, the decision was made to gather information through UAV flights. This choice was based on the UAV's ability to safely and efficiently fly over hard-to-reach areas, overcoming natural obstacles that prevented direct access to the site. UAV equipped with advanced sensors allowed for capturing images and data such as distance from the events to the pipeline and event area, providing a detailed view of the area in question without compromising personnel safety or causing environmental damage.

4.3 Stage 3: Geotechnical Risk Assessment

According to the concept of risk stated in the Law 1523 of 2012 of the Colombian Republic, "Disaster risk derives from the combination of threat and vulnerability." A 5x4 matrix called "RAM: Risk Analysis Methodology" was developed, defining risk as the product of threat and vulnerability. This matrix was specifically designed for conditions of soil and debris flows in steep and forest areas. Scores for geotechnical risk conditions were obtained from 1 to 5, with 1 representing the lowest risk category and 5 indicating the highest risk.

4.3.1 Threat Characterization:

The threat was considered through the area covered by the unstable process, in which sectors with larger areas were expected to continue increasing while initial smaller areas needed to be monitored through Unmanned Aerial Vehicle (UAV) images, or their area would not increase due to some structural limit condition. Table 4.1 presents the weight assigned for each range in which the unstable process area was divided is presented as follows:

Table 4.1 - Weights for Threat Characterization

FLOW AREA	WEIGHTING
$A <= 500m^2$	2
$500m^2 < A <= 1000m^2$	3
$1000m^2 < A <= 2500m^2$	4
$A > 2500m^2$	5

4.3.2 Vulnerability Characterization:

Vulnerability will be assessed through the closest distance from the flow's crest to the axis of the gas pipeline. Table 4.2 presents the assigned weighting based on the adopted distance range.

Table 4.2 Weightings for Vulnerability Characterization

DISTANCE BETWEEN THE CROWN AND THE DUCT (meter)	WEIGHTING
d <= 2 m	10
2 m< d<= 5 m	8
5 m < d <= 10 m	6
10 m < d <= 20 m	4
d > 20 m	3

Figure 4-1 illustrates the graphical representation of the parameters adopted to perform the geotechnical risk classification in steep and wooded areas.

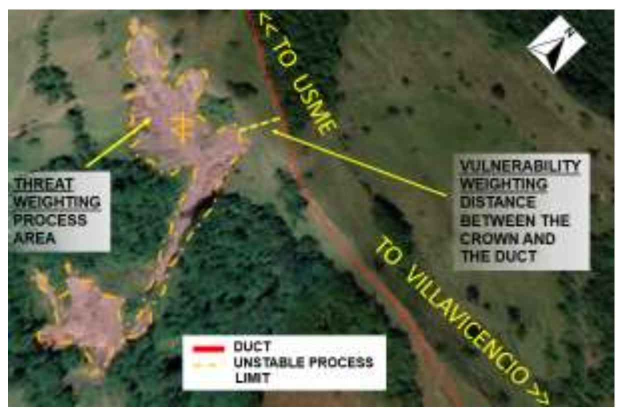


Figure 4.1 Graphic Explanation of Adopted Parameters for Risk Classification

4.3.3 Risk Value and Recommended Action Plan:

Table 4-3 outlines the structure of the proposed "RAM" matrix for assessing geotechnical risk (R) from flows in steep and wooded areas. **Table 4-4** displays the matrix of scores obtained by applying the defined weights for vulnerability and threat. To estimate risk, the threat value is multiplied by the vulnerability value, and this product defines the geotechnical risk condition as per **Table 4-5**. This table also includes the recommended action plan to mitigate or maintain the obtained risk level.

Table 4.3 Proposed RAM Matrix Structure for Risk (R) Assessment

Vulnerability \ Threat	$Af>2500m^2$ (5)	$2500m^2 \leq Af>1000m^2$ (4)	$1000m^2 \leq Af>500m^2$ (3)	$Af \leq 500m^2$ (2)
0m<d<=2m (10)	5	5	5	4
2m<d<=5m (8)	5	5	4	3
5m<d<=10m (6)	5	4	3	2
10m<d<=20m (4)	4	3	2	1
d>20m (3)	3	2	1	1

d = Closest distance between the crown of the flow and the duct, meters
Af= Flow area in square meters

Table 4.4 Matrix of Scores Obtained by Applying the T x V Product

Vulnerability \ Threat	Af>2500 (5)	2500 ≤Af>1000 (4)	1000 ≤Af>500 (3)	Af≤500 (2)
0<d<=2 (10)	50	40	30	20
2<d<=5 (8)	40	32	24	16
5<d<=10 (6)	30	24	13	12
10<d<=20 (4)	20	16	12	8
20<d (3)	15	12	9	6

d = Closest distance between the crown of the flow and the duct, meters
Af= Flow area in square meters
(#): Weighting Value

Table 4.5 Risk Classification and Recommended Action Plan

Classification	Level of risk	Color	Recommended action plan
VERY HIGH RISK 50 < R ≤ 30	5		**ACTION 5** - Immediate visit by the geotechnical specialist (ensuring prior access to the area). - Include the site in the project's geotechnical event baseline if not already included. - Weekly monitoring by the crew and/or specialist personnel between the months of June to August, and monthly monitoring for the rest of the year; subject to area access. - Monthly monitoring using Unmanned Aerial Vehicles (UAV). - Development of a corrective action plan for immediate execution. - Soil study or complementary assessment
HIGH RISK 30<R<=20	4		**ACTION 4** - Monthly monitoring by the crew and/or specialist personnel; subject to area access. - Bimonthly monitoring using Unmanned Aerial Vehicles (UAV). - Include the site in the project's geotechnical event baseline if not already included. - Development of a corrective action plan for short-term execution (less than three months). - New or complementary soil study
MEDIUM RISK 20<R<=15	3		**ACTION 3** - Monthly monitoring by the crew and/or specialist personnel; subject to area access. - Quarterly monitoring using Unmanned Aerial Vehicles (UAV), between the months of April to August (higher precipitation) and bimonthly for the rest of the year. - Include the site in the project's baseline if not already included. - Development of a corrective or preventive action plan, subject to client authorization, for execution in the medium term (3 to 6 months).
LOW RISK 15<R<=10	2		**ACTION 2** - Monitoring to be executed as per schedules for inspection through unmanned flights. - Include the site in the project's baseline if not already included and generate a preventive action plan for execution in the long term, subject to client authorization.
VERY LOW RISK R<10	1		**ACTION 1** - Monitoring to be executed as per schedules for inspection through unmanned flights. - Not included in the baseline or excluded, if already present

Weighting facilitates risk calculation; however, if the suggested weighting in sections 4.3.1 and 4.3.2 is not desired to be applied, it can be worked out with the implementation of **Table 4.3**. This table shows the input values for the flow area (threat) and the nearest distance between the flow and the pipeline (vulnerability). From the resulting risk level, it can then be decided the recommended action plan as outlined in **Table 4.5**.

5. CREATION OF GDB (GEODATABASE GENERATION)

To ensure the consistency, accuracy, and replicability of the processing of images from UAV flights, the implementation of a Geodatabase (GDB) is conducted. This is particularly useful in areas that require decision-making, from project management to data-driven decisions. The ability to capture, store, and access detailed information coherently over time not only enhances the efficiency and reliability of the product but also provides a solid foundation for analysis and planning.

Similarly, capturing images at regular intervals and storing them in a centralized GDB enables historical comparison and analysis. For example, this allows verification of the increase in distance between the flow´s crown and the axis of the buried pipeline. This function is valuable for monitoring length changes over time, as with geotechnical events in general, vegetation cover, water bodies, invasions, and pipeline infrastructure, among others. By repeating aerial inspections over time, trends can be more effectively detected, contributing to the early identification of potential issues and informed decision-making. Replicability ensures consistent and accurate assessment, essential for ensuring safety and long-term success as the condition advances.

One of the highlighted aspects is the ability to create a centralized repository of detailed and up-to-date information. This geodatabase not only stores essential data but also facilitates organization and quick access to information by involved teams. Furthermore, implementing a GDB promotes collaboration and communication across different departments and teams, aligning all stakeholders with the same source of verified and consistent information.

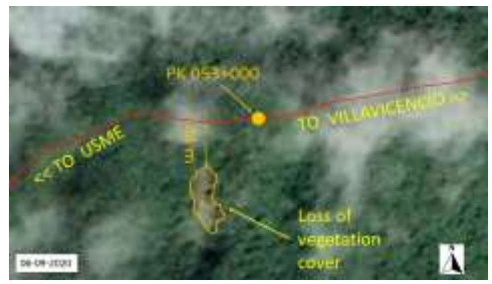
Tables 5.1 and **5.2** present two study sites (Site 4 and Site 9) where the advancement in flow area and distance to the pipeline, as well as the tracking conducted using the GDB, are observed.

5.1 SITE 4

Site 4 is located at station PK053+045 of the Apiay - Usme gas pipeline, which has a diameter of 6".

Based on the conducted tracking (see **Table 5.1**), vegetation loss is identified on the left side of the pipeline at a distance of 44 meters in September 2020. By January 2022, an advancement in the flow is observed, with the flow being 18 meters away from the pipeline and covering an area of 2400 m². Additionally, another area with vegetation loss on the right side is observed at a distance of 34 meters.

Table 5.1 Background of Site 4 - Apiay - Usme Mainline

<table>
<tr><th>Date</th><th>Image</th></tr>
<tr><td>20-08-2019</td><td>
</td></tr>
<tr><td>06-09-2020</td><td>
</td></tr>
<tr><td>16-01-2022</td><td>
</td></tr>
</table>

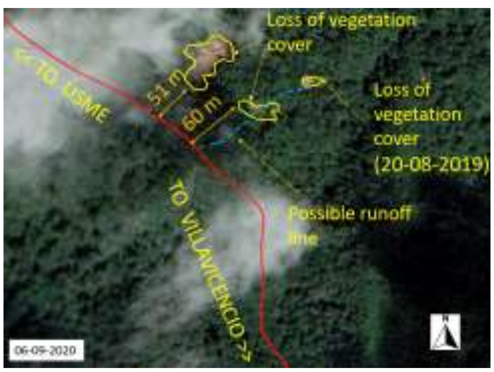
5.2 SITE 9

Site 9 is located on the Apiay - Usme mainline gas pipeline at station PK 55+703, with a pipe diameter of 6". According to the conducted tracking (see **Table 5.2**), vegetation loss on the right side of the pipeline is identified at a distance of 110 meters in August 2019.

By September 2020, two areas without vegetation cover are identified, suggesting the occurrence of unstable processes. The first area is located 60 meters from the pipeline and appears to correspond to a regression of the process identified in the image dated 20-08-2019. The second identified process is situated 51 meters from the pipeline on the right side.

Based on the January 2022 image, it can be observed that the said process is located 15 meters from the pipeline. Additionally, the process was classified as a retrogressive trend, active, and successive style landside flow, as it consists of two unstable processes. The first flow has a length of 80 meters and a width of 20 meters, while the second flow is 70 meters long and 35 meters wide, with an affected area of 2900 m².

Table 5.2 Background of Site 9 - Villavicencio - Usme Mainline

<table>
<tr><th>Date</th><th>Image</th></tr>
<tr><td>20-08-2019</td><td>
</td></tr>
<tr><td>06-09-2020</td><td>
</td></tr>
<tr><td>16-01-2022</td><td>
</td></tr>
</table>

6. ZONE ASSESSMENT

Due to constraints arising from the lack of access openings to the Valve Distribution Device (DDV) and dense tree cover, the mentioned methodology was implemented. Based on the information obtained from UAV flights, 14 sites of interest were identified and evaluated using the matrix (see Table 6.1).

Table 6.1 Geotechnical Findings to Evaluate

Sites	Description
Site 1	Erosion process with a total affected area of 0.012 hectares outside the Valve Distribution Device (DDV) at a distance of approximately 124 meters to the left side of the gas pipeline. No implementation of surface drainage control measures is identified in the area affected by the erosion process.
Site 2	Erosion process with a total affected area of 0.015 hectares outside the DDV at a distance of approximately 43 meters to the right side of the gas pipeline. No implementation of surface drainage control measures is identified in the area affected by the erosion process.
Site 3	Flows of sandy-silty material with some debris and fallen trees, covering a total affected area of 0.127 hectares outside the DDV at a distance of approximately 78 meters to the left side of the gas pipeline. No implementation of surface drainage control measures is identified in the area affected by the process.
Site 4	Flows of sandy-silty material with some debris and loss of vegetation cover, covering a total affected area of 0.24 hectares outside the DDV at a distance of approximately 18 meters to the left side of the gas pipeline. No implementation of surface drainage control measures is identified in the area affected by the process.
Site 5	Flows of earth and loss of vegetation cover, covering a total affected area of 0.17 hectares outside the DDV at a distance of approximately 62 meters to the right side of the gas pipeline. No implementation of surface drainage control measures is identified in the affected area.
Site 6	Flows of sandy-silty material and loss of vegetation cover, covering a total affected area of 0.072 hectares outside the DDV at a distance of approximately 173 meters to the left side of the gas pipeline. No implementation of surface drainage control measures is identified in the area affected by the process.
Site 7	Flows of sandy-silty material and fallen trees, covering a total affected area of 0.024 hectares outside the DDV at a distance of approximately 55 meters to the right side of the gas pipeline. No implementation of surface drainage control measures is identified in the area affected by the process.
Site 8	Flows of sandy-silty material and loss of vegetation cover, covering a total affected area of 0.39 hectares outside the DDV at a distance of approximately 57 meters to the left side of the gas pipeline. No implementation of surface drainage control measures is identified in the area affected by the process.
Site 9	Flow-type movement with erosion processes in rocky material and loss of vegetation cover, covering a total affected area of 0.29 hectares outside the DDV at a distance of approximately 15 meters to the right side of the gas pipeline. No implementation of surface drainage control measures is identified in the area affected by the process.
Site 10	Loss of vegetation cover, covering a total affected area of 0.051 hectares outside the DDV at a distance of approximately 57 meters to the left side of the gas pipeline. No implementation of surface drainage control measures is identified in the area affected by the erosion process.
Site 11	Debris flows and loss of vegetation cover, covering a total affected area of 0.064 hectares outside the DDV at a distance of approximately 159 meters to the right side of the gas pipeline. No implementation of surface drainage control measures is identified in the area affected by the process.
Site 12	Debris flows and loss of vegetation cover, covering a total affected area of 0.104 hectares outside the DDV at a distance of approximately 137 meters to the right side of the gas pipeline. No implementation of surface drainage control measures is identified in the area affected by the process.
Site 13	Debris flows and loss of vegetation cover, covering a total affected area of 0.25 hectares outside the DDV at a distance of approximately 93 meters to the left side of the

Sites	Description
	gas pipeline. No implementation of surface drainage control measures is identified in the area affected by the process.
Site 14	Earth and debris flow, with a total affected area of 1.18 hectares, located 26 meters to the left side of the pipeline. No implementation of surface drainage control measures is identified.

6.1 TERRAIN SLOPE

In order to determine the terrain slopes in the area, and due to the absence of Lidar lifting, conventional topography or similar data, supplementary information of the project was utilized.

Figure 6.1 depicts the longitudinal profile of the pipeline between station PK47+000 and PK60+000, with the locations of the sites of interest.

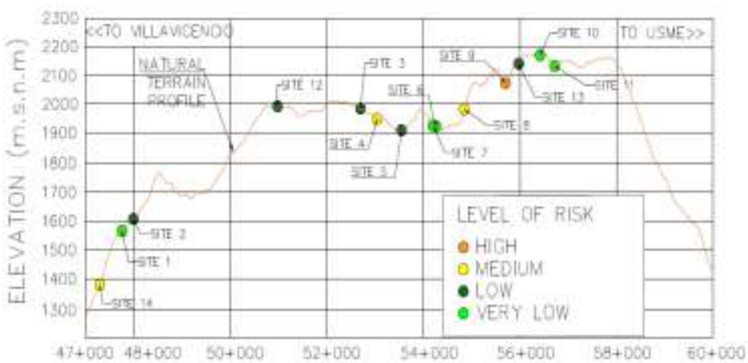


Figure 6.1 Longitudinal profile of the pipeline between station PK47+000 and PK60+000. (Scale 1V:5H)

7. GEOTECHNICAL RISK ASSESSMENT

7.1 Input Parameters

Table 7.1 presents the input parameters for each of the fourteen (14) sites on which the risk level evaluation was conducted, following the previously proposed matrix.

Table 7.1 Input Parameters for Threat Evaluation

Site	Side	Area (m^2)	Distance to pipeline (m)
Site 1	Left	120	124
Site 2	Right	150	43
Site 3	Left	1270	78
Site 4	Left	2400	18
Site 5	Right	1700	62
Site 6	Left	720	173
Site 7	Right	240	55
Site 8	Left	3900	57
Site 9	Right	2900	15
Site 10	Left	510	57
Site 11	Right	640	159
Site 12	Right	1050	137
Site 13	Left	2500	93
Site 14	Left	10182	26

7.2 Threat Characterization

Table 7.2 presents the results of threat characterization, based on the weighting presented in **Table 4.1**.

Table 7.2 Results of Threat Characterization

Site	Side	Area (m^2)	Threat weighting (T)
Site 1	Left	120	2
Site 2	Right	150	2
Site 3	Left	1270	4
Site 4	Left	2400	4
Site 5	Right	1700	4
Site 6	Left	720	3
Site 7	Right	240	2
Site 8	Left	3900	5
Site 9	Right	2900	5
Site 10	Left	510	3
Site 11	Right	640	3
Site 12	Right	1050	4
Site 13	Left	2500	4
Site 14	Left	10182	5

7.3 Vulnerability Characterization

Table 7.3 presents the results of vulnerability characterization, based on the weighting presented in **Table 4.2**.

Table 7.3 Results of Vulnerability Characterization

Site	Side	Distance to pipeline (m)	Vulnerability weighting (V)
Site 1	Left	124	3
Site 2	Right	43	3
Site 3	Left	78	3
Site 4	Left	18	4
Site 5	Right	62	3
Site 6	Left	173	3
Site 7	Right	55	3
Site 8	Left	57	3
Site 9	Right	15	4
Site 10	Left	57	3
Site 11	Right	159	3
Site 12	Right	137	3
Site 13	Left	93	3
Site 14	Left	26	3

7.4 Risk Value

Table 7.4 presents the resulting weights from applying the parameters outlined in the matrix for the geotechnical risk assessment due to flows in areas with high slopes and dense vegetation. Additionally, in **Table 7.5**, the filled out "RAM" matrix is presented, taking into account the results obtained for each evaluated point. In **Figure 7.1**, a graphical representation of the number of findings by obtained risk level is shown.

Table 7.4 Results of Geotechnical Risk Assessment

Site	T	V	R	RL	RC
Site 1	2	3	6	1	VERY LOW
Site 2	2	3	6	1	VERY LOW
Site 3	4	3	12	2	LOW
Site 4	4	4	16	3	MEDIUM
Site 5	4	3	12	2	LOW
Site 6	3	3	9	1	VERY LOW
Site 7	2	3	6	1	VERY LOW
Site 8	5	3	15	3	MEDIUM
Site 9	5	4	20	4	HIGH
Site 10	3	3	9	1	VERY LOW
Site 11	3	3	9	1	VERY LOW
Site 12	4	3	12	2	LOW
Site 13	4	3	12	2	LOW
Site 14	5	3	15	3	MEDIUM

T: Threat weighting
V: Vulnerability weighting
R: Risk weighting
RL: Risk level
RC: Risk Category

Table 4-1 Results Matrix

Threat / Vulnerability	Af>2500m² (5)	2500m² ≤Af>1000 m² (4)	1000m² ≤Af>500 m² (3)	Af≤500 m² (2)
0m<d<=2m (10)				
2m<d<=5m (8)				
5m<d<=10m (6)				
10m<d<=20m (4)	9	4		
d>20m (3)	8,14	3,5,12,13	6,10,11	1,2,7

d = Closest distance between the crown of the flow and the duct, meters
Af= Flow area in square meters

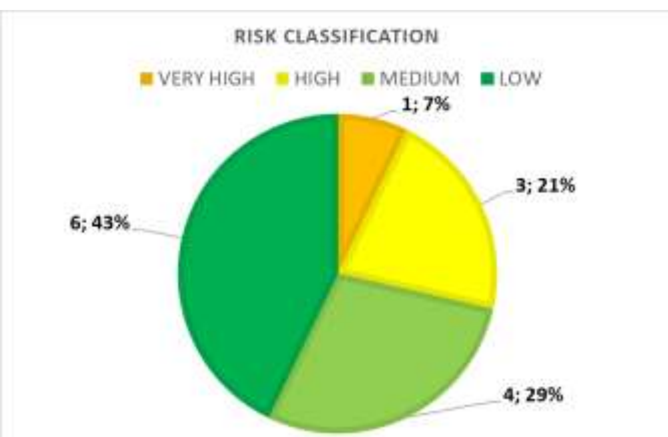


Figure 7.1 Results of Risk Classification

7.5 Action Plan

Based on the information provided in **Table 4.5** of this report, the recommended actions for each of the findings are presented in Table 7.6, taking into consideration their risk classification.

Table 7.6 Recommended Action Plan for Each Classified Finding

Site	Side	Category	Type of action
Site 1	Left	VERY LOW	1
Site 2	Right	VERY LOW	1
Site 3	Left	LOW	2
Site 4	Left	MEDIUM	3
Site 5	Right	LOW	2
Site 6	Left	VERY LOW	1
Site 7	Right	VERY LOW	1
Site 8	Left	MEDIUM	3
Site 9	Right	HIGH	4
Site 10	Left	VERY LOW	1
Site 11	Right	VERY LOW	1
Site 12	Right	LOW	2
Site 13	Left	LOW	2
Site 14	Left	MEDIUM	3

8. CONCLUSIONS

- Unmanned Aerial Vehicles (UAV) flights emerge as the favorable option for monitoring pipelines with limited access due to their efficiency, precision, and capability to access hard-to-reach areas. By combining their technological advantages with a safe and responsible operational approach, UAV flights become an essential tool for effective infrastructure management and maintenance in pipeline geotechnics.
- The photogrammetry technique was chosen due to its ability to provide detailed and accurate information, efficiency in data capture, and versatility in applications. This choice allowed for high-quality results and informed decision-making based on the collected information.
- This document presents a proposed methodology for geotechnical risk assessment due to flows in forested and high-slope areas, using a "RAM" matrix approach. Threat characterization was considered based on the area covered by the unstable process. Vulnerability was estimated based on the shortest distance between the process crown and the pipeline. Risk classification was derived from the product of the established weights for threat and vulnerability, resulting in five (5) risk levels, with 1 being the lowest and 5 being the highest.
- The implementation of a GDB in pipeline monitoring allows for precision and replicability in the processing of obtained images, detecting changes in the area of geotechnical events and vegetation coverage, which aids in early decision-making.
- The matrix was applied to fourteen (14) identified sites through unmanned aerial inspections, resulting in six (6) sites

classified as very low risk, four (4) sites as low risk, three (3) sites as medium risk, and one (1) site as high risk; no site was classified as very high risk among those evaluated.

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