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Landslide and Environmental Risk from Oil Spill due to the Rupture of SOTE and OCP Pipelines, San Rafael Falls, Amazon Basin, Ecuador

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***Abstract*— A landslide generated an environmental risk due to a provoked oil spill on April 7, 2020, with the SOTE and OCP pipelines rupture. This research aims to determine the areas susceptible to landslides in the river basin Quijos of the Coca River and estimate the environmental risk from exposure to the oil spill. A water analysis of the Coca River was performed by using the Mora-Vahrson method and GIS tools. The subsequent water sampling was probabilistic in a simple random way, and the analyzed parameters were oils and grease, Ba, Cd, Cr, BOD, COD, TPH, OD, Pb, and SST. The results show that 61.17% (572.68 km2) of the total studied area (936.19 km2) is susceptible to landslide hazards. In detail, 0.25% (2.34 km2) of the area is considered to be of very high susceptibility, 26.72% (250.12 km2) of high susceptibility, 11.82% (110.66 km2) of moderate susceptibility, and 0.04 (0.37 km2) of low susceptibility. Four of them were within the permissible limits from the ten analyzed parameters, which correspond to Ba with 0.70 mg/L, OD with 7.4% of saturation, BOD5 with 2 mg/L, and COD with 25 mg/L. The other six parameters, including oils and fats, exhibited a significant increase in concentrations after the oil spill, yielding Cd 0.05 mg/L, total Cr 0.45 mg/L, TPH 0.20 mg/L, Pb 0.20 mg/L, and SST 20%. These results are outside the permissible limits, meaning that the river waters are contaminated.**

***Keywords*— Oil spill; environmental hazard; GIS; landslide; heavy metals.**

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I. INTRODUCTION

Globally, it is estimated that there are some 70,000 oil fields with more than 1.6 billion barrels of crude oil [1]–[3], where crude oil exploration, exploitation, and transport activities are carried out. In the Ecuadorian Amazon, the exploitation of oil begins in 1967, with the drilling of the Lago Agrio1 well [1], [4], [5]. Since then, oil is one of the main sources of income for the country's economy. In 2019, the oil production was 539,000 barrels per day, considering it the world's largest exporter [8.9]. It is also well-known for being the country that hosts the densest biodiversity on the planet about the surface area [10]. Despite the positive impact on the country's economy, oil exploitation has caused significant damage to the environment, especially in the Amazon region, due to the non-compliance with environmental regulations, the law, and agreements where the state reserves the right to administer, regulate, and control the strategic sectors based on the principle of environmental sustainability, precaution, prevention, and efficiency, while also natural hazards like earthquakes and landslides have also led in the past to a variety of strong issues of oil spills [6]–[9].

Indeed, Ecuador is one of the countries in the world with the highest exposure to natural risks [10]–[13], particularly in protected areas that represent immense economic value to the world [6], [14], [15]. For instance, the factors that have caused damage to the abiotic, biotic and social components in the Ecuadorian Amazon are the contamination of rivers and estuaries (94.91% to the soil, 80.46% to the soil and animals and 95.71% to animals, soil and properties), pipeline spills (81.95% to soil, 70.18% to soil and animals, 87.14% to soil, animals and property), pool breakdown (65.05% to the ground, 55.57% to the ground and animals, 72.14% to the ground, animals and properties), seismic activity (46.25% to the soil, 37.77% to soil and animals, 65% to soil, animals and properties), oil facilities (51.46% soil, 43.27% soil and animals, 62.85% soil, animals and property), and road construction (30.24% to the ground, 25.18% to the ground and animals 30% to the ground, animals and properties) [16]–[19].

For example, the Province of Orellana registered a total of 151 spills until 2011, from which 50.10% have occurred in the Francisco de Orellana Canton (El Coca), 49.79% in the Joya de Los Sacha canton, and 0.21% in the Aguarico canton. These events are from natural or social origin have caused an imbalance in the environment and the waters of the Coca River and its effluents, putting the population, assets and resources at risk [12], [13], [20]. In this context, it is important to understand the capacities and vulnerabilities of the abiotic, biotic and social components to reduce the environmental risks of oil activities[16].

In this regard, the crude oil produced in the Amazon region, more specifically, from the Palo Azul-B018, Punino-B048, Pucuna-B044, PBHI-B047, Sacha-B060, MDC-B046, Indillana-B015, Auca-B061, Palanda Yuca Sur blocks, -B064, and Coca Payamino-B007 wells is transported to the Esmeralda's maritime terminal through flow lines that correspond to the Trans-Ecuadorian Pipeline System (SOTE) and the Heavy Oil Pipeline Company (OCP) Ecuador SA [17], [18]. These transfer lines or pipelines cross through high geological risk areas where the Ecuadorian state has not prioritize conducting geological studies to predict natural events such as landslides and prevent environmental hazards and risks that could affect nearby populations [12], [19]–[21].

Therefore, the lack of geological studies in a region threatened with undermining, high volcanic activity, and landslides posed an imminent risk to the people in the Francisco de Orellana (El Coca) canton, where a possible failure of the transfer lines along the San Rafael Waterfall may cause contamination at the point of water collection.

Consequently, on April 7, 2020, the general manager of Petroecuador EP, communicated to the general manager of Petroamazonas EP of the rupture of the SOTE due to a landslide in the San Rafael sector on the border between the Napo and Sucumbíos provinces. Through press releases on April 8, 2020, OCP reports that erosion was detected in the Coca River channel that triggered the pipeline's rupture. This event was described by the deputy minister in charge of hydrocarbons as irresistible and unpredictable of natural origin, being part of many previously occurred natural disasters in Ecuador [8], [22], [23]. On April 8, 2020, the first alerts for oil contamination in the Coca and Napo Rivers were presented, where the municipalities of the Francisco de Orellana and Aguarico cantons reported that the collection point had been suspended from the Coca and Napo Rivers.

Therefore, this research aims to determine the areas susceptible to landslide in the Quijos - Río Coca basin, through the Mora Vahrson method and the use of GIS tools, and to estimate the environmental risk from exposure of the recent oil spill along the adjacent area of the SOTE and OCP pipelines through the analysis of the water of the Coca river [16]. This information will allow zoning the environmental vulnerability and generate cartography where the areas of environmental risk and the exposure of the abiotic component of the Coca River after water quality alteration due to the contribution of sediment and the presence of oil are visualized.

II. Materials and Method

A. Study Area

In order to analyze the environmental risk by studying the threat of landslide, a study section of 15 km was delimited that comprised between the coordinates WGS 1984 UTM Zone 18S x; 213781; and: 9989615, based on historical data such as the oil spill that occurred on April 7, 2020, rupture of the SOTE and OCP, reports of the undermining situation Napo, Chaco, San Rafael reported by the National Service for Risk and Disaster Management from June 05, 2020, to July 22, 2020, and hydrological limitation criteria of the incidence area of the Quijos river basin, located in the province of Napo and Sucumbíos, canton El Chaco and Gonzalo Pizarro (Fig. 1). The study area contains the Cayambe Coca protected area.

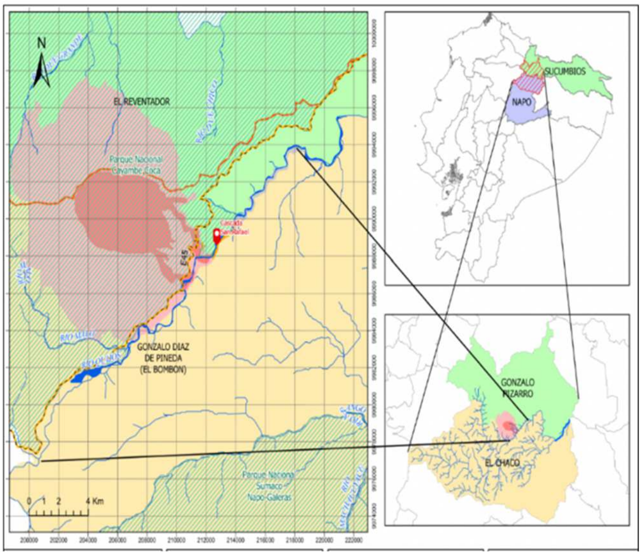

Fig. 1 Study area with location of the oil spill

The land use in the Gonzalo Pizarro canton is for agricultural land 9.95% and Forest 82.04%, conservation areas socio collective forest 0.07%, individual forest partner 0.25%, protective forest 4.04%, and protected areas 71.17% and ecosystems for environmental services such as restoration areas 7.69%, critical areas, while 85.98% and lands suitable for the forest that the protector of wildlife 37.65% [18], in the El Chaco canton the land use is forest 80.51%, agricultural land 5.50%, shrub vegetation 12.75%. According to the last census conducted in 2010 by the INEC in the Gonzalo Pizarro canton, there are 8599 inhabitants, where 4076 are women and 4523 are men. In the Chaco canton, there is a total of 7960 inhabitants distributed in 3832 women and 4128 men [24], [25]

B. Methodology

The methodology used to determine landslide susceptible areas in the Río Quijos - Río Coca basin will allow estimating the environmental risk from exposure of the oil spill (heavy metals and polycyclic aromatic hydrocarbons (HAPs) and Total Hydrocarbons (TPH)). This was carried out through two processes: one analysis of the threat, vulnerability, and risk of mass movement using the Mora Vahrson method [23]–[26], to determine areas susceptible to landslide in the Quijos-Río Coca basin [13], [16], [27], [28], and two comprehensive samplings and analysis of the water from five points of the

Coca River. The parameters analyzed were oils and fats, Ba, Cd, Cr, BOD, COD, TPH, OD, Pb, and SST. The information collected for finding out the exposition of the abiotic component along the Coca River after altering the water quality by the contribution of sediment and oil. The following is a detailed methodology (Fig. 2) which has been used to determine the areas susceptible to landslides in the Quijos - Coca River basin and the environmental risk due to the oil spill caused by the SOTE and OCP rupture.

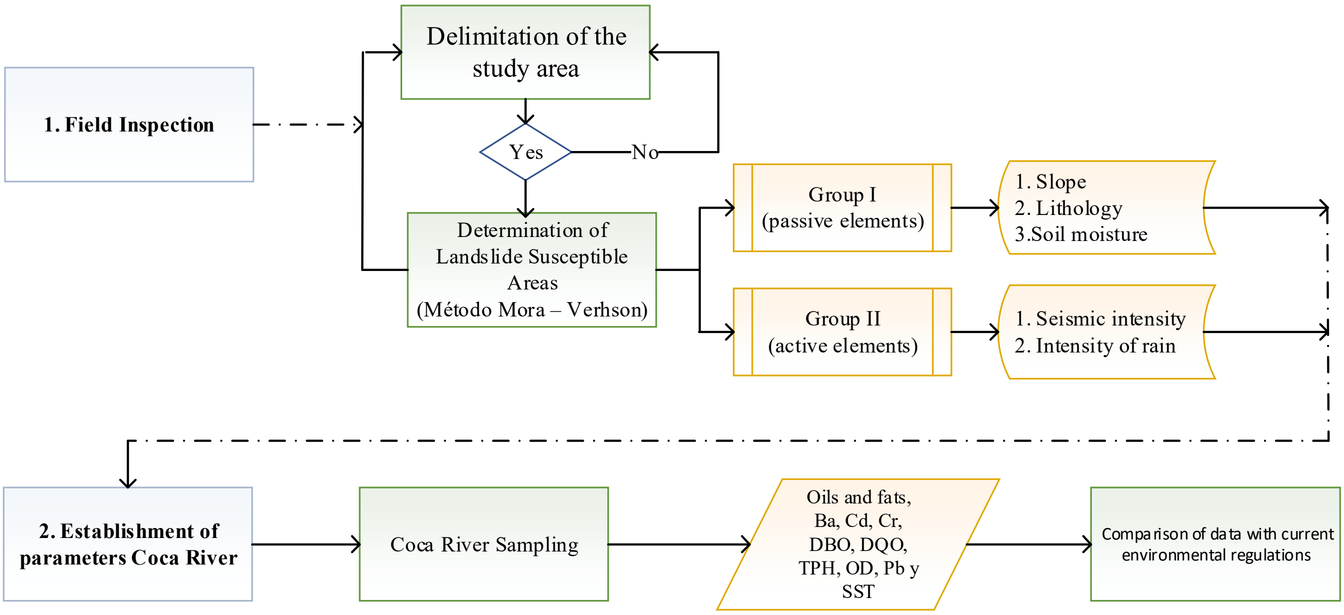

Fig. 2 Flow diagram which determines the areas susceptible to landslides in the Quijos - Coca River basin and environmental risk from the oil spill due to the SOTE and OCP rupture

1) Determination of Landslide Susceptible Areas: To determine landslide susceptible areas, it was used the Mora-Vahrson method [1], [19], [26], [29], that allows the classification of landslide risks in seismically active tropical zones [19]–[21], [30], considering five factors. These factors are divided into two groups detailed below:

- Group I. Susceptibility to passive elements: slope, lithology, soil moisture.
- Group II. Susceptibility to active elements: seismic intensity and intensity of rain.

For each factor, an influence index is defined for a certain site, and it is combined according to a specific weight. As a result of calculating the indexes, a relative level of threat (H) is obtained through the following equations [16], [31], [32].

$$H = (Sr\ x\ SI\ x\ Sh)\ x\ (Ts + Tp) \quad (1)$$

Where:
Sr = Slope (represents the study area)
SI = Lithology (influence of the types of materials, sediments and rocks).
Sh = Soil moisture (humidity accumulated throughout the year).
Ts = Seismic intensity (landslide caused by earthquake).
Tp = Rain intensity (influence of rain over time).

For the generation of the susceptibility maps associated with the seismic detonating factor (Ts) and the other maximum precipitation detonating factor (Tp), the following equation is calculated.

$$H = (S_r\ x\ S_l\ x\ S_h\ x\ T_s) + (S_r\ x\ S_l\ x\ S_h\ x\ T_p) \quad (2)$$

H = Degree of landslide susceptibility
Sr = Slope factor or relative relief
Sl = lithological factor
Sh = Soil moisture factor
Ts = Seismicity
Tp = Precipitation intensity

Therefore, to calculate the factors of slope, lithology, resulting humidity, seismic intensity, the influence of rain over time, and the monthly mean values of precipitation, the following ranges were used, which are assigned colors that allow differentiating the characteristics on the map detailed below in the following Table 1 and 2 [19], [23].

TABLE I
CLASSIFICATION OF THE SLOPE FACTOR

Terrain characteristics	Slope ranges (degrees)	Assigned weight (Sr)	Suggested colors
Flat or almost completely	0-2	1	Medium dark green
gentle slope	2-4	2	Light green
Steep slopes	4-8	3	Light yellow
Sheer model	8-16	4	Yellow orange
Steep	16-35	5	Light red
Very steep	35-55	6	Dark to medium red
Extremely steep	>55	7	Dark purple

The lithological factor represents the influence of the types of materials, sediments and rocks on the landslide activities as shown in Table 2. The further factors such as the monthly average values of rainfall, the average monthly precipitation index, the rain intensity factor of the influence of rain as well as the seismic intensity factor, have been based on the parameters presented in [25], [33].Hereby, the soil humidity quantifies the influence of accumulated humidity throughout the year. Therefore, calculating the humidity factor resulting from the classification of the accumulated values of the average monthly precipitation indices. The intensity of the rain is the factor calculating the influence of the rain over time that influences the landslide based on the maximum daily rainfall for a return period of 100 years. Likewise, the seismic intensity is determined by analyzing the landslides caused by earthquakes to calculate the seismic intensity [34], using the values of 100-year return periods, based on historical data [35].

TABLE II
EVALUATED LITHOLOGICAL FACTOR

Lithology	Classification	Factor (SI)
Sumaco Volcanoes	Very low	1
Pan de Azúcar-Sumaco Volcanoes	Very low	1
Mesa Formation	Low	2
Tena Formation	Low	2
Others	Low	2
Misahuallí unit	Low	2
Volcanic Reventador	Low	2
Chapiza Formation	Moderate	3
Cuyuja-Grupo Llanganates Formation	Moderate	3
Soot Formation	Moderate	3
Mera Formation	Moderate	3
Napo Formation	Moderate	3
Cofanes Group	Moderate	3
Metamorphic rocks	Moderate	3
Alluvial deposits	high	4
Alluvial deposits (ejection cone)	high	4
Alluvial deposits (terraces)	high	4
Alluvial colluvium deposits	high	4
Volcanic (lahar) deposits	high	4
Volcanic deposits (pyroclasts)	high	4
Hillside deposits	Very high	5
Hillside deposits (colluvial)	Very high	5

Therefore, with the results obtained, by combining all the factors mentioned above in equation 1, the value of the indicator of the threat of landslide HI can be classified and evaluated based on the values in Table 7 [31], [36]. In effect, the susceptibility index for the basin in question is calculated by adding the two maps [20], [24], [37], as shown in equation 3.

$$H = H_s + H_p \quad (3)$$

TABLE III
THE THREAT OF LANDSLIDE HI, BASED ON [69]

Equation value HI	Class	Slip hazard classification
< 6	I	Very low
7 - 32	II	Low
33 - 162	III	Moderate
163 -512	IV	Medium
513 - 1250	V	Tall
>1250	VI	Very high

2) Coca River Water Sampling: The sampling was carried out in a simple random probability type of the Rio Coca water body, the sampling was carried out 3 days after the oil spill caused by the rupture of the (SOTE) and (OCP) transfer line. Therefore, the river was divided into five points under the criteria of accessibility of the place for the sample, housing on the riverbank and the point of water collection of the canton Francisco de Orellana (El Coca) the samples were sent to the AqLab laboratory. The monitored points are detailed in the Table 4. Therefore, to know the state of the water, the terminology of compliance is assigned, which means that it is within the allowable limits with a green color, and it does not comply with red when the parameter does not meet the established permissible limits.

TABLE IV
COCA RIVER SAMPLING POINTS

Points	Coordinates	Parameters	Location
1	X: 0270532 Y: 9974358	Oils and fats, Ba, Cd, Cr, DBO, DQO, TPH, OD, Pb y SST	San José de Guayusa extraction of stone material.
2	X: 0271485 Y: 9969422		San José de Guayusa 8 km from point 1
3	X: 0276590 Y: 9962095		San Sebastián del Coca Puente
4	X: 0278705 Y: 9952340		La playita - 100 m from the water catchment point (El Coca)
5	X: 0278705 Y: 9952340		After the Coca River Gas Station

III. RESULTS AND DISCUSSION

A. Areas Susceptible to Landslide

In order to determine the areas susceptible to landslide in the Quijos-Río Coca basin (Fig. 2), information that allowed knowing the exposure areas that would present an alteration in the water quality due to the contribution of sediment mass and the presence of oil, due to landslide, the study basin was delimited to calculate the slope factor (Sr) and determine the characteristics of the terrain.

Fig. 3 Road situation due to the erosion of the river - road from Baeza to Lago Agrio. Hereby, from 1 to 4 are indicated the Chronological events in the river morphology: 1, Track loss at km 66 (22/08/2020); 2, Provisional variant for km 66; 3, Cracking of the track at the Bridge over the River Montana (04/06/2020) Track variation over the River Montana; 4, Large-scale landslide which partially dammed the Coca River. (20/07/2020)

Thus, to calculate the types of materials, sediments and rocks in the activity of sliding and to perform the classification based on the lithology (Sl) of the study area and assign the factor, the categorization was used based on the criteria issued by the national monitoring system (Fig. 3 and 4) for the instability of the slopes [25], [29], [33]. To determine the soil moisture (Sh), the limit values of 125 mm precipitation in ten days were used. The precipitation data were obtained from the precipitation raster of the historical data Global climate and weather data WorlClim through which it was possible to calculate the factor.

The seismic intensity (Ts) was calculated based on the historical records provided by the national monitoring considering a period of 10 years represented in Figure 5. Similarly, the intensity of the rain (Tp), calculated the maximum daily rainfall of a 10-year period from historical data from Global climate and weather data WorlClim as shown in figure 6, in the same way, to calculate the influence of rain over time and know the intensity of rain (Tp), which is one of the triggers that influence landslides, information was calculated from a 10-year period that will allow us to know the classification and the Tp factor [38]–[40]. Finally, by combining the data obtained from Sr, Sl, Sh, Ts, Tp and applying equation 1, a relative level of threat (HI) is obtained for the section of the study, for calculating the susceptibility index for the basin under study is calculated by adding the two susceptibility maps associated with the earthquake trigger factors (Ts) and the maximum precipitation trigger factor (T) as indicated in Figure 7, susceptibility index.

The areas susceptible to landslide hazard HI with a total of 936.19 km2 are observed (Fig. 7), showing that 61.17% have an average susceptibility that corresponds to 572.68 km2, while 26.72% high that corresponds 250.12 Km2, 11.82% moderate, 0.25% very high, comprising an area of 2.34 Km2, and 0.04 low, comprising an area of 0.34 Km2. It can be pointed out that in the study area, the state road network, the National System of Protected Areas SNAP, found over the Quijos river basin, was identified, however, due to the lack of availability of spatial information on the transfer lines of (SOTE) and (OCP) did not allow records in the susceptibility area [9], [41]–[43].

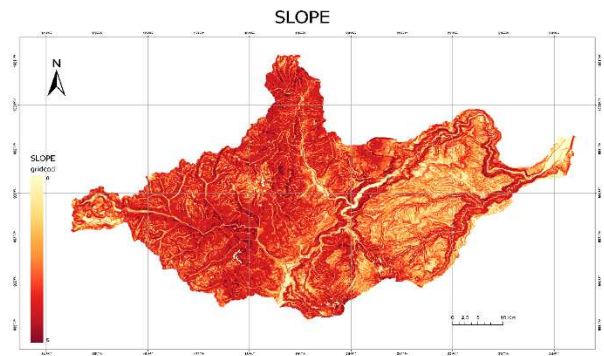

Fig. 4 Susceptibility of passive and active elements based on data of the Ministry of Agriculture and Livestock, United States Geological Survey, National Seismic Monitoring System and Global climate and weather data. In this figure are the passive and active elements susceptible, represented by the slope (Sr) with the assigned weight of 1 which means that the conditions and characteristics of the terrain are flat or almost completely and a value of 7 extremely scratchy.

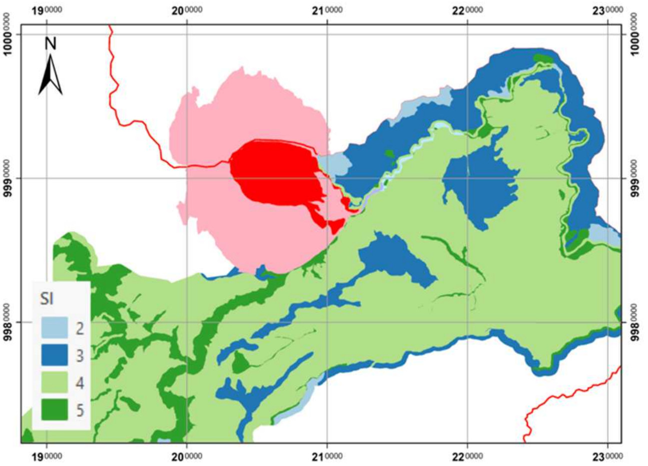

Fig. 5 The lithology represented in this figure presents a factor of 2 moderate classification, table formation, 3 medium, metamorphic rocks, 4 high volcanic deposits (lahars) and 5 very high that are slope deposits (colluvial)

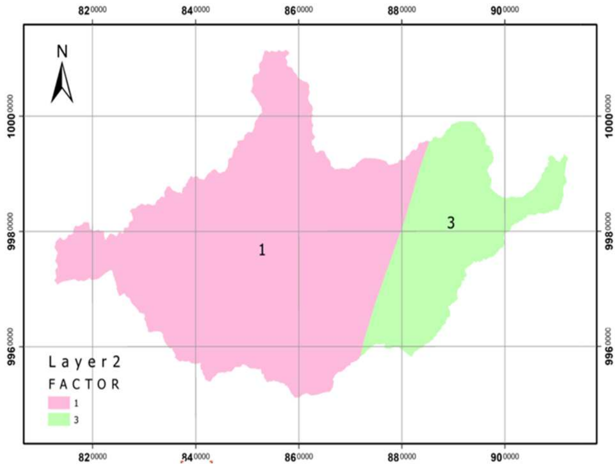

Fig. 6 In this figure a seismic intensity (Ts) of 8 strong and 9 very strong is represented in the corresponding colors or violet and green

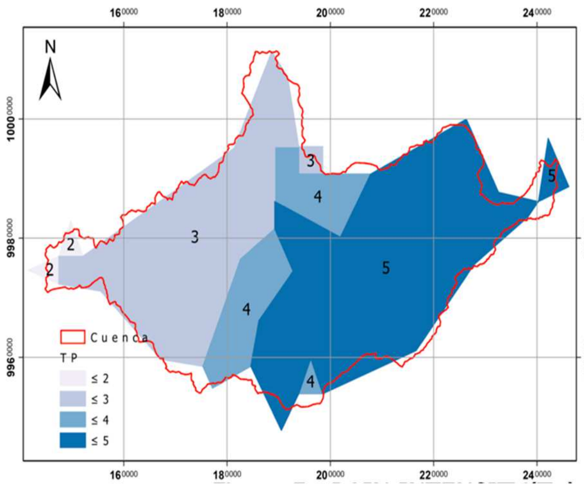

Fig. 7 This figure represents the intensity of rains (Tp) presents factors of 2 low in the 10 years the precipitation 51 to 91 mm, 3 medium presents precipitation 91-130 mm, high 131 to 175 mm and 5 very high, the precipitation is greater than 175 mm of rain in the last 10 years

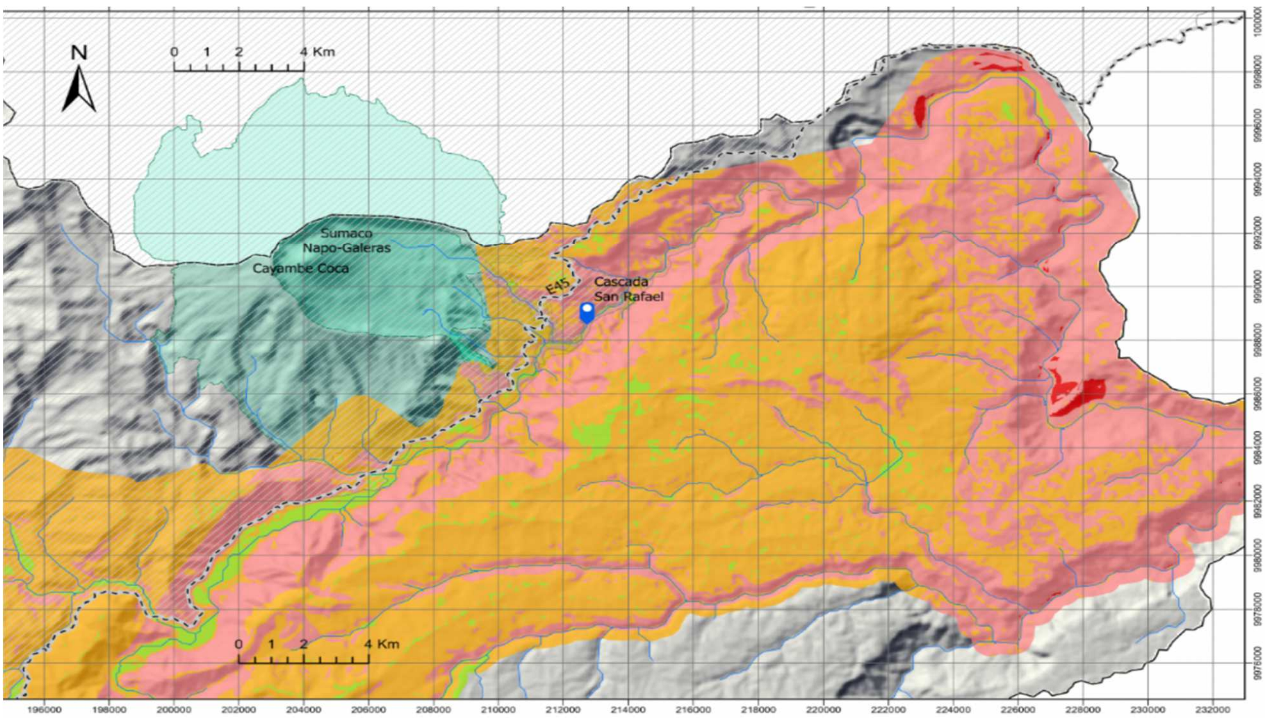

Fig. 8 Overview map with the susceptibility of slippery areas. Scaled colors where red is high and green is low susceptibility.

B. Analysis of the Water from the Coca River

From the samples analyzed, the results will be compared with criteria of water quality of water sources for human consumption, AM 097 A, Annex 1. The samples were analyzed on the basis of the EPA standard and reported by test No. 12778, 14003a, 14003 b, 14003 c, 14003d, the results are detailed below in Table 5.

As a result of the ten parameters analyzed, four parameters are within the permissible limits that correspond to Ba with 0.70 mg / L, OD 7.4% saturation, BOD5 2 mg / L, and COD with 25 mg /L. The parameters oils and fats, Cd, total Cr, TPH, Pb, and SST, are outside the permissible limits, which means that there is an alteration in water quality due to the contribution of sediment in SST and the presence of oils and fats, yielding Cd 0.05 mg / L, total Cr 0.45 mg / L, TPH 0.20 mg / L, Pb 0.20 mg / L, and SST 20% increase in natural condition. In effect, the presence of these heavy metals Cd, Cr, and Pb would present effects on the aquatic ecosystem, being a threat to flora, fauna, and even to humans due to bioaccumulation. In living organisms, the presence of Cd in dozens elevated would present hyperkeratosis of the epithelium of the stomach and degenerative anomalies [44]–[47].

The absorption of Pb is a serious risk to public health, causing delayed mental development in children. Due to hypertension and cardiovascular diseases in adults, it can trigger teratogenic effects and impede normal development in the nervous system of the fetus. Moreover, Cr in high concentrations can generate alterations such as hypochromic anemia, slow the growth rate, diarrhea, changes in hair color, infertility, and heart failure [14], [48]–[50]. Lastly, oils and grease, TPH in aquatic environments induce changes in chemical properties, decreasing pH, conductivity, and cation exchange capacity, which makes the functional structure of the bacterial community of water and soil less diverse [16], [51]–[53]. Another serious effect on the health of the population due to the fact that they are concatenated polynucleated components of

petroleum and are relatively resistant to biodegradation, and can be accessed by the food chain [2], [34], [35], [54]. The lack of geological studies allows predicting the hazards and areas susceptible to mass slippage in the incidence of the Quijos - Coca River basin through which the SOTE and OCP transfer lines pass. It presents environmental risks of natural events that alter the quality of the abiotic (water, soil), biotic (aquatic fauna), and social components (people who live on the riverbanks and at the point of water collection of the Francisco de Orellana canton). To determine areas susceptible to landslide, the Mora-Vahrson Method and the use of GIS were applied. It presents values of slope (Sl) 7 extremely steep and 1 plane, lithology (SI) factors 2 moderate and 5 very high that are detailed in Table 2. It presents a seismic intensity (Ts) with characteristics of 8 strong and 9 very strong, and precipitation or intensity of rain (Tp) of 2 low that includes precipitation 51 to 90 mm and 5 very high that it ranges from 175 mm of maximum daily precipitation.

The sum of the maps associated with the seismic detonating factors (Ts) and the maximum precipitation detonating factor (TP) shows that the study area presents a mean landslide susceptibility with 61.17%. It is important to indicate that in the study section no houses were found, but the state road network, SNAP protected areas, the San Rafael waterfall and the Quijos river basin were found. Due to the landslides in the sector of the Río Quijos - Río Coca basin, there is an alteration in the quality of the water. All the monitored points have heavy metals that are outside the permissible limits. This means that the water is not an act for human consumption or for preserving aquatic life in the Coca River. If this event constantly occurs, it could cause adverse damage to the benthic and epibentic organisms of the river [1], [55]–[57].

TABLE V
COCA RIVER WATER QUALITY, SAMPLE # 12778, 14003A, 14003 B, 14003 C, 14003 D

Parameters	**Unit**	**Allowed limit**	**Points - Results**					**State**
			1	2	3	4	5	
Oils and grease	mg/L	0.3	< 0.6	< 0.5	< 0.5	< 0.5	< 0.5	Fails
Ba	mg/L	1.0	<0.70	<0.70	<0.70	<0.70	<0.70	Complies
Cd	mg/L	0.001	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	Fails
Cr Total	mg/L	0.032	<0.45	<0.45	<0.45	<0.45	<0.45	Fails
DBO_5	mg/L	20	< 2	< 2	< 2	< 2	< 2	Complies
DQO	mg/L	40	< 25	< 25	< 25	< 25	< 25	Complies
TPH	mg/L	0.5	< 1.2	<1.2	< 1.2	<1.2	< 0.20	Points 1 to 4 do not comply
OD	% Satur.	>80	7.4	7.4	7.4	7.4	7.4	Complies
Pb	mg/L	0.001	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	Fails
SST	mg/L	Max. 10% increase in natural cond.	20	20	20	20	20	Fails

Similarly, in the section of the Quijos - Coca river basin through which the SOTE and OCP transfer lines pass, there is a lack of information that the state has inventoried the previous spills that have occurred due to the rupture of the SOTE transfer lines and OCP, which does not happen in the case of the environmental risks generated in the hydrocarbon activities [15], [58], [59]. The spills caused are inventoried by the Environmental and Social Repair Program PRAS, where it monitors the comprehensive repair plan of the Amazon district with a percentage of 39% compliance up to the year 2017. There has been no follow-up of the monitoring goals for the years 2018 and 2019 [60]–[62].

The International Hydrocarbon Pollution Compensation Fund (IOPCF) indicated that from $ 51,437 / ton of oil spilled by applying the conversion factor to the state, it would cost it to remediate the existing environmental liabilities about 46.8 million / year as a reference value. There are studies of spatial analysis of accidental oil spills in the Amazon by type of infrastructure, in which 82% correspond to wells, 15.2% battery separation, 2.8% transfer lines from SOTE and OCP, but there are no studies of spills caused by the rupture of the transfer lines [63]–[65].

The analysis of the environmental risk of natural events presents limitations due to the fact that data from the study area of the slopes, lithology, soil moisture, intensity of rainfall, maximum and minimum rainfall of the last 10 years are required, sequentially, we are not has studies of the water quality of the Coca river, the PDOT Development and Territorial Planning Plan of the study area does not record the biodiversity of the area where the areas with the greatest diversity of trees, insects and amphibians in the world and other species are indicated, because in the Amazon amphibians are of concern because they are threatened as well as macroinvertebrates that are considered as biological indicators of the ecological quality of the water, which did not allow registering information on the biotic component of the study area [66], [67].

This information was from the analysis of environmental risk due to a natural cause as susceptible to landslide danger. It can be used as a baseline for the local governments in order to conduct analyzes, evaluation of the environmental risk and the risk management that allows the elaboration of prevention measures against natural events [63]–[65], [68]. Besides, the provision of statistical analyzes for the evaluation of landslide susceptibility at the local level and may have a computer system that records the statistical data of the water analysis of the Coca River. Future research lines may be presented in the environmental risk assessment of heavy metals in water and sediments, heavy metal removal technologies. Upcoming research can also be in the determination of heavy metals and TPH in bioindicator organisms and the ecotoxicological effects of oil in the aquatic environment and the population is near the riverbank.

IV. CONCLUSION

The current study determined areas susceptible to landslides caused by the erosive process located in the San Rafael waterfall. In effect, the landslide puts at risk the contamination of the Coca River by sediment, Coca Codo Sinclair Hydroelectric, and the transfer lines (pipes) of (SOTE) and (OCP). From the water analysis made to the Coca River, it was determined that some of the given parameters are outside the permissible limits. Thus, there is an alteration in water quality due to the contribution of sediment in TSS and the presence of oils and fats. This puts at risk the population located on the banks of the Coca River and the water catchment point of the Francisco de Orellana canton.

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