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RESEARCH PAPER

Geochemical Indices for the Assessment of Chemical Contamination Elements in Sediments of the Suches River, Peru

Dante Salas-Mercado[1], Marian Hermoza-Gutierrez[1], Germán Belizario-Quispe[2], Fermín Chaiña[2], Edgar Quispe[2] and Dante Salas-Ávila[2*]

1. Escuela de Posgrado, Programa de Doctorado en Ciencia, Tecnología y Medio Ambiente, Universidad Nacional del Altiplano de Puno, Puno, Perú
2. Instituto de Investigación en Metalurgia, Materiales y Medio Ambiente, Universidad Nacional del Altiplano de Puno, Puno, Perú

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ABSTRACT
The purpose of this study was to evaluate the concentrations of potentially toxic elements in the Suches river using standardized geochemical indices and to identify the main sources of contamination in the section from the Suches lagoon up to 33.8 km downstream of the effluent river, in the district of Cojata, Puno, Peru. The concentration of Al, Ba, Co, Fe, M, Ni, P, V and Zn in sediments of the Suches river was determined by means of mass spectrometry from October 2019 to February 2020. The values of Co, Fe, Mn, Ni, P and Zn exceeded the base values of contamination according to the general geological references while Al, Ba and V, did not surpass them. The contamination factor showed that the elements Co and Ni revealed a very high level of contamination, while the Zn, a considerable level. The area has an average pollution load index value of 2.24, indicating moderate general pollution. The elements Co, Ni, Al and Zn were within the moderate and extreme classification according to the pollution index. The Spearman's correlation analysis allowed determining the association between Al, Fe, Mn, P and V, which share a natural origin and the accumulation of these elements is due to the effects of weathering and soil erosion. The evaluation of the contamination indices and the correlation confirm that Cobalt, Nickel and Zinc are toxic elements associated with gold mining and agricultural activities.
Keywords: Sediment pollution, water quality, freshwater, mining.

INTRODUCTION

Human activity and continuous expansion of industrial production cause the accumulation of polluting chemical elements in water, soil, plants, animals and even in microorganisms (Londoño et al., 2016). These elements produce adverse effects for life in general (Kusin et al., 2019; Su et al., 2014; Yi et al., 2020) due to their wide availability, diverse transport dynamics and interaction with organic and inorganic substances (Mandeng et al., 2019). Some chemical elements are found in the soil naturally but in low concentrations (Siqueiros-Beltrones et al., 2014) and these influence the chemical composition of the surrounding aquatic ecosystems (Mulholland et al., 2012). However, environmental imbalances are mainly produced by the intervention of anthropogenic activities related to mining, water discharges residuals and agricultural activities (Yan et al., 2018), causing the alteration of water quality in natural áreas (Kusin et al., 2019b; Su et al., 2014). Mining operations in the basins derives mainly from the continuous removal of large volumes of land that are accumulated in the

* Corresponding author Email: dsalas@unap.edu.pe

open in different surrounding areas which are considered as mining waste. Due to weathering, acid rock drainage of the waste occurs generating a deterioration in the quality of the soil (Karbassi et al., 2014). These deposits are potential sources of contamination due to their high concentrations of metals and other elements (Karbassi, et al., 2016), that are transported in greater quantities during the rainy season to rivers, lakes and other aquatic systems where a series of interactions with other compounds and elements take place (Santos-Francés et al., 2017).

Physical and chemical processes such as sorption, ion exchange, complexation, precipitation, oxidation-reduction reactions, desorption and bioaccumulation, can occur in aquatic environments of water; however, when environmental conditions change due to natural or anthropogenic processes, the accumulated chemical elements can be mobilized again due to interaction with sediments (Salomons and Stigliani, 1995). Physicochemical modifications or hydrodynamic erosion of the sediment-water interface can re-transfer these elements in the water column (Copaja et al., 2020; Yi et al., 2020). Sorption-desorption is considered a key process in the transfer of metals within rivers, playing an extremely important role and considerably increasing the downstream pollution load (Alahabadi and Malvandi, 2018; Londoño et al., 2016). Metal ions in water generate hydroxides by hydrolysis which react with inorganic ions to form chelates, sulfur complexes, carbonates and phosphates due to their low solubility, their complexes are easy to precipitate in sediments. The highest concentrations of chemical elements are found in sediments (Mendoza et al., 2020) because they adhere to solid particles becoming future sources of contamination due to their displacement to other environmental bodies (Yacoub et al., 2015) (Rügner et al., 2014), where their entry into the food chain could generate serious problems for nearby populations (Karbassi et al., 2014).

At the basin of the Suches river, the residuals are due to the small-scale mining and meteorological fluvial conditions which produce infiltrations and superficial runoffs in the surrounding environments where the sediments behave as a reservoir to the chemical specie s (Zhang et al., 2018), which could be a threat to the health of the population (Saiful et al., 2018). The tailings produced by the small-scale mining exhibit high concentrations of inorganic chemical elements and they are released to the Suches river through infiltration, precipitation, weathering and affluent leaks (Ministry of the Environment and Water, 2019).

In Peru there are no set standards of quality environment that allow the evaluation of concentrations of chemical elements in sediments. Generally what is used are the Canadian guidelines (CCME, 1998) to do the evaluations; however, these guidelines do not include appropriate classifications that contribute to decision making. Because of this, it is important to complement the evaluation of chemical elements in sediments using validated indicators.

Krika and Krika (2018) proposed to apply the Contamination Factor (CF), Geo-accumulation Index (Igeo) and Pollution Load Index (PLI) to evaluate the contamination of sediments along with international norms, determining that the metals were below these norms. However, the results based on indicators revealed that there is an important accumulation in the sampling sites. Other studies, such as the ones developed by Li et al. (2020), suggest that the Enrichment Factor (EF), PLI and Igeo can help determine the degree of alterations due to the anthropic activity, as well as the identification of possible predominant sources of contamination and what could cause this contribution, (Agah, 2021). On the other hand, (Agah, 2021) suggests using the contamination index (IPoll) instead of Igeo, since more significant results are obtained concluding that the evaluation with geochemical indices helps defining whether there is contamination in soils and sediments.

Furthermore, it is important to evaluate the chemical contamination with normalized indices, incorporating principal elements and trace elements given that the evaluation rules consider only heavy metals (Marra et al., 2021) and these do not include other elements such as nutrients, which can provide further information and explanation of its origins (Buscaroli et al., 2021). The purpose of this study is to evaluate the concentration of potentially toxic elements in the Suches river through normalized geochemical indices to classify contaminants and the identification of contamination sources.

MATERIALS AND METHODS

The lagoon Suches is a body of water that originates due to the melting of the Andean glaciers, in the Region of Puno, located in the southeastern part of Peru, at 4,605 meters above sea level with an area of 14,2 km² (ANA, 2014). This lagoon is the source of the river with the same name which is 164 km long (Iltis et al., 1991), it is an important water source for Puno because it drains its water to Lake Titicaca (Gammons et al., 2006), forming a natural border between Peru and Bolivia Fig 1. The study area is comprised of a 33.8 km stretch, where PM1 is the area of origin of the Suches River; PM2 is the mining discharge area; PM3 is the zone of agricultural activity; PM4 is the entry zone of the effluents, and finally PM5 is located 120 m downstream from the Castilla bridge, near the town of Cojata. **Error! Reference source not found.** shows the coordinates of the sampling points, established from the recommendations of the Guide for Soil Sampling of the Ministry of the Environment of Peru (MINAM, 2014).

The Suches River is located inside the Suches basin which has a complex geology since it is made up of 20 lithostratigraphic units (Gobierno Regional de Puno, 2015) from the geotectonic domain of the eastern altiplano of the Cenozoic era with a neogene system (Tapia et al., 2019). The lithostratigraphic units with the highest percentage of occupied area in the basin are the Upper Vilquechico formation (14%), Ambo group (13%), Sandia formation (12%) and the Morrénicos Deposits (12%). The Suches river basin is located in a high Andean ecosystem called Pajonal de humid puna (MINAM, 2019), made up of short grasses and grasslands, that limit the development of agricultural activity. Therefore, one of the main activities in this area is the breeding of alpacas, llamas and vicuñas (MINAGRI, 2018). Besides that, another main activity is open cast artisanal mining (INGEMMET, 2009) which takes place in the Peruvian and Bolivian zones using traditional technologies for the extraction of gold mineral (Salas-Ávila et al., 2021).

Table 1. Geographic coordinates of the sampling sites.

Sampling Sites	South Latitude	West Longitude
PM1	14° 47’44.57”	69° 20’ 24.85”
PM2	14° 54’28.74”	69° 21’ 48.33”
PM3	14° 54’48.81”	69° 22’ 8.03”
PM4	14° 55’30.04”	69° 22’ 13.8”
PM5	14° 59’ 1.22”	69° 22’ 4.08”

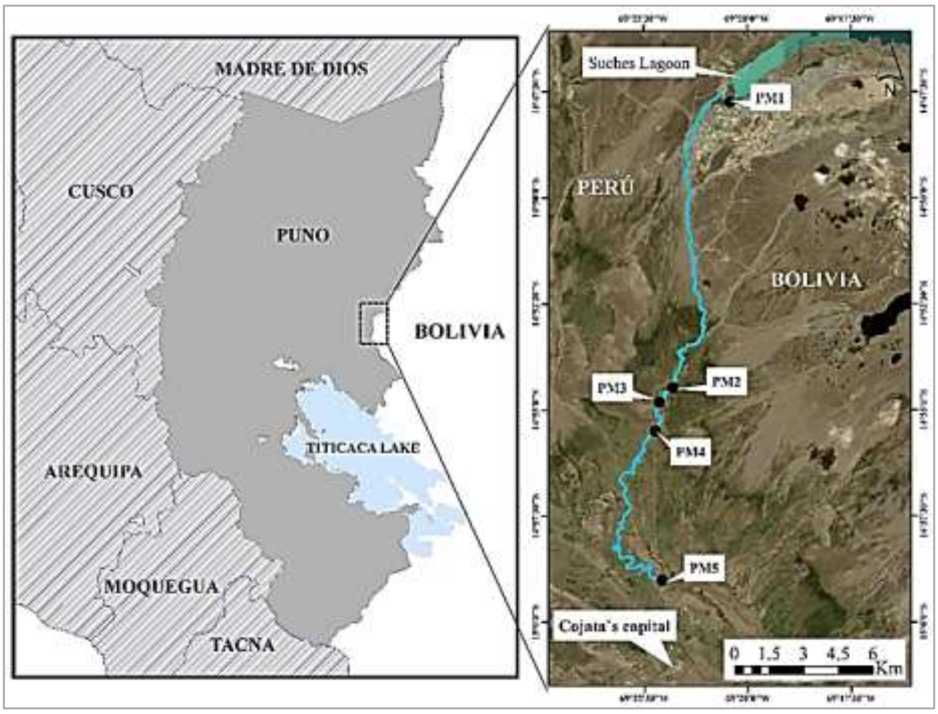

Fig 1. Map of the study area of the Suches river (Frontier Peru - Bolivia).

To investigate the presence of contamination, identification sampling was applied by obtaining representative samples composed of surface sediments at each sampling point between October 2019 and February 2020. The samples consisted of 250 g of sediments collected at each sampling site at 5 cm beneath the surface. The samples were stored in airtight bags at a temperature of 4° C to ensure its preservation until its transfer to the accredited laboratory ALS Global Perú (Arequipa branch), which has an global Quality Control and Analytics Control Integrated System (AQ/QC). The procedures were executed under the guidelines of the norms ISO/IEC 17025 y ISO 9001:2000.3. The concentration of nine chemical elements were determined in the matrix of the collected sediments: Aluminum (Al), Barium (Ba), Cobalt (Co), Iron (Fe), Manganese (Mn), Nickel (Ni), Phosphorus (P), Vanadium (V) and Zinc (Zn), by an inductively-coupled plasma mass spectrometer (I CAP Q, Thermo Scientific), using the guidelines of EPA Method 3050B (1996). To calculate the contamination of chemical elements in sediments the base values were used according to the predominant type of sandstone rock in the study area (Gobierno Regional de Puno, 2015; Turekian et al., 1961).

The contamination Factor (CF) was calculated as an indicator of the levels of contaminations in sediments for each element examined in the area (Hakanson, 1980), with the following equation:

$$CF_i = \frac{C^i_{melement}}{C^i_{base}}$$

where $C^i_{element}$ is the concentration of the chemical element and C^i_{base} is the base value of the element explored. The degrees of contamination of each element are: Low (CF <1), moderate $(1 \leq CF < 3)$; considerable $(3 \leq CF < 6)$ and very high degree $(CF \geq 6)$. Furthermore, the Pollution Load Index (PLI) of each area was determined in order to obtain the combination of the contaminants and to conduct a comparison of the environmental condition (Tomlinson et al., 1980), using the following equation:

$$PLI = \sqrt[n]{CF_1 x CF_2 x CF_3 x \ldots\ldots x CF_n}$$

where n is the number of contamination factors. The Pollution Load Index is classified in seven levels (El-Said et al., 2014; Singh et al., 1999): When PLI=0, the contamination load is the same as the base; (0<PLI≤1) unpolluted; (1<PLI≤2) unpolluted to moderately polluted; (2<PLI≤3) moderately polluted; (3<PLI≤4) moderately to highly polluted; (4<PLI≤5) highly polluted; and (PLI≥5) extremely polluted.

Subsequently we used the contamination index (I_{POLL}) suggested by Karbassi et al. (2008) to evaluate the contamination of chemical elments in sediments comparing them with the base values (Farkas et al., 2007; Haynes et al., 2000; Karbassi et al., 2016; Organismen & Ausbreitungswege, 1974), through the following equation:

$$I_{POLL} = log_2 \left[\frac{C^i_{element}}{C^i_{base}}\right]$$

where e, $C^i_{element}$ is the concentration of the element studied, C^i_{base} is the base value of the element studied present in lithology. The classification suggested by (Salehi et al., 2014)was used which considers a state without contamination ($I_{POLL} < 0.42$); low contamination ($0.42 \leq I_{POLL} < 1.42$); moderately contaminated ($0.42 \leq I_{POLL} < 1.42$); heavily contaminated ($0.42 \leq I_{POLL} < 1.42$); extremely contaminated ($0.42 \leq I_{POLL} < 1.42$) and finally, to determine the impact of the anthropogenic activities the Enrichment Factor (EF) was used, utilizing the following formula (Sinex & Wright, 1988).

$$EF = \left[\frac{\left(\frac{C^i_{element}}{Fe^i_{element}}\right)}{\left(\frac{C^i_{base}}{Fe^i_{base}}\right)}\right]$$

Where $\left(\frac{C^i_{element}}{Fe^i_{element}}\right)$ is the relation between the concentration of the element and the FE explored in the study area, while $\left(\frac{C^i_{base}}{Fe^i_{base}}\right)$the relation between the values of the elements and the Fe existing in the earth's crust. Iron (Fe) was established as the standardization element since it is predominant in Peru (Acosta et al., 2009) and two categories were established to determine the origin of the contamination: When EF <1.5, its origin is naturally as suggested by (J. Zhang & Liu, 2002) and when EF> 2, there is a level of contamination from anthropogenic activities (Nguyen et al., 2016).

In order to determine the association of the chemical elements the normality of the concentrations was verified with the Shapiro-Wilk analysis. Later, the data was standardized with the Z scale in order to avoid bias and loss of data. Also, the Spearman´s Correlation Index was applied because the data did not have a normal distribution. The R software version 4.0.2 was utilized (Team, 2020).

RESULTS AND DISCUSSION

Table **2** shows the average concentrations of the chemical elements detected at the sampling sites of the Suches river. The average values of AL, Ba and V do not exceed the base values; while the averages of Co, Fe, Mn, Ni, P y Zn do present high values. The total concentrations of these elements present in the sediments, in relation of the sample sites, are in the following order PM3 > PM1 > PM2 > PM5 > PM4, indicating that the higher concentration of the total elements is located in PM3. This site is the closest one to mining waste discharges that are produced close to site PM2. It is inferred that the river flow and the discharges could have influenced the accumulation of the chemical elements transported by the sediments in this site since downstream effluents connect to small rivers and creeks, causing a new decrease of the concentration due to the changes in volume, nature and flow of the water. The site PM3 was above these confluences therefore it was not affected. The site of origin of the Suches river (PM1) has the second highest average concentration of the total evaluated elements, which could be attributed to the extraction work done due to the small-scale mining that is performed in the areas surrounding the Suches lagoon and very close to the river mouth.

Table 2. Concentration of chemical elements in sediments.

Sampling Sites	Al (mg/kg)	Ba (mg/kg)	Co (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	P (mg/kg)	V (mg/kg)	Zn (mg/kg)
PM1	11604.4 ±394.0	19.3 ±1.3	12.54 ±1.5	28609.4 ±1,425.1	291.72 ±17.8	23.04 ±2.0	455.4 ±41.6	15.5 ±0.7	63.9 ±2.4
PM2	10897.4 ±1,507.9	35 ±9.9	11.7 ±1.5	27906 ±2,830.1	363.78 ±61.8	19.58 ±1.7	412.38 ±59.3	17.3 ±2.2	58.9 ±5.3
PM3	11630.8 ±959.3	43.46 ±6.6	12.92 ±1.5	29928.8 ±1,528.3	405.16 ±35.2	20 ±2.2	436.88 ±66.2	16.5 ±1.2	56.7 ±3.6
PM4	10187.4 ±291.8	39.52 ±2.9	11.94 ±1.3	26521.8 ±654.2	307.14 ±23.2	17.92 ±1.5	386.62 ±35.8	15.7 ±0.6	50.8 ±1.5
PM5	10378.6 ±187.8	61.12 ±6.1	11.9 ±1.7	27151.8 ±1,659.1	383.94 ±31.5	20.54 ±1.8	393.14 ±30.5	14.8 ±0.5	67.1 ±2.4
Average	10939.72	39.68	12.20	28023.56	350.35	20.22	416.88	15.96	59.48
SD (σ)	671.20	15.09	0.51	1323.09	49.03	1.86	29.08	20.02	6.34
Max.	11630.8	61.12	12.92	29928.8	405.16	23.04	455.4	436.88	67.1
Min.	10187.4	19.3	11.7	26521.8	291.72	17.92	386.62	386.62	50.8
Base [a]	25000	170	0.3	9800	200	2	170	20	16

[a] (Turekian et al., 1961)

Table 3 presents the concentration of the elements of this study compared to the findings from other investigations performed around the world in areas with mining and agricultural influence.

Table 3. Comparison of the average concentrations of elements of this study with other investigations.

River	Fe	Al	P	Mn	Zn	Ba	Ni	V	Co	References
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	
Calore	33650	40650	2400	2952.5	378.6	728.4	44.5	116.0	30.8	Zuzolo et al., 2017
Gomti	9894	-	-	450.2	176.1	-	40.4	-	-	K. P. Singh, Malik, Sinha, Singh, & Murthy, 2005
Lluta	20776	14208	11.4	1583.0	231.5	-	-	-	-	Copaja & Muñoz, 2018
Malasia	2042	1918	-	38.1	10.9	-	1.7	-	1.2	Kusin et al., 2019
Paracatu	78150	77650	-	1050.0	1053.5	566.0	-	-	12905	Mulholland,

River	Fe	Al	P	Mn	Zn	Ba	Ni	V	Co	References
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	
										Boaventura, & Araújo, 2012
Haraz	17300	-	-	-	73.8	-	43.5	-	9.5	Nasrabadi et al., 2010
Suches	28023	10939	416.9	350.4	59.5	39.7	20.2	16.0	12.2	This study

As it is shown in Fig 2, the sediments of all the sampling sites present a degree of very high contamination of the potential toxic elements such as Co and Ni, followed by Zn which present a considerable degree while Fe, Mn and P show a moderate degree. Likewise, the metals that were found in a low degree of contamination are Al, Ba and V. Cobalt has a mainly geological origin since it is a typical trace element from pyrite and phyllites chlorite/sericite (Mulholland et al., 2012; Zuzolo et al., 2017); it is not observed considerable variants of concentration of cobalt among all the sampling sites. On the other hand, even though the tendency denotes a major storage capacity of Ni and Zn in the area of origin and the last site of the study area, these differences are not significant. The weathering and erosion of the geological materials seem to be the reason of the release of both elements to the environment due to the sedimentary transport (Chau and Kulikovsky-Cordeiro, 1995).

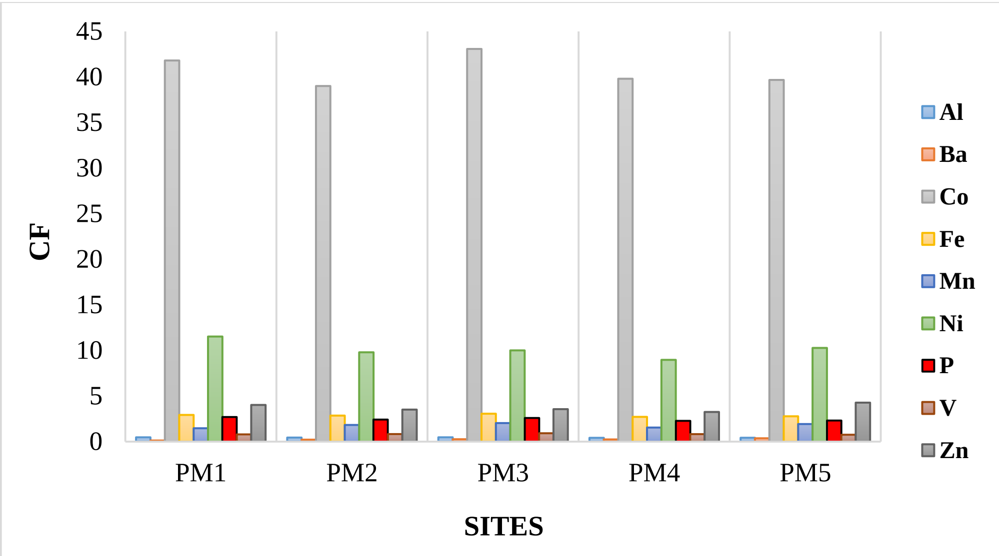

Fig 2. Degree of metal contamination in the sampling sites.

The average value of the contamination load in the areas of study was of 2.24, this is why it is considered that all the areas are moderately polluted Fig 2. The tendency of the pollution load from the sample sites, in descending order, are the following PM3 (2.40) >PM5 (2.37) >PM2 (2.21) >PM1 (2.13) >PM4 (2.11), finding that the PLI value in all its points/degrees/sites are high and at the same time superior to the values of other studies performed in Andean areas in Peru where anthropogenic activities such as cattle and agriculture whose range was of 0.66 to 1.48 (Mendoza et al., 2020). The values of the CF of Co, Ni and Zn provide a mayor contribution in the determination of the PLI in the study area (**Fig 3**). These results indicate that the sediments are generating a possible ecological risk in the Suches river, affecting the towns located downstream (Hasimuna et al., 2021).

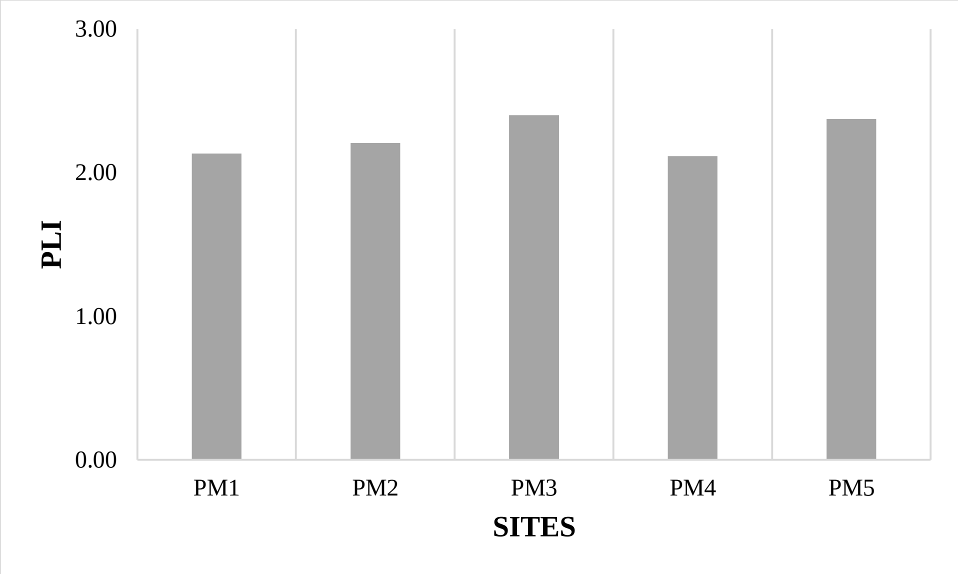

Fig 3. Pollution load per area.

Error! Reference source not found. shows the he I_{POLL} values of chemical elements in sediments at each sampling point. In decreasing order the averages are presented as follows: Co (5.29 ± 0.06) > Ni (3.31 ± 0.13) > Zn (1.88 ± 0.16) > Fe (1.5 ± 0.07) > P (1.26 ± 0.10) > Mn (0.77 ± 0.20) > V (-0.32 ± 0.10) > Al (-1.21 ± 0.09) > Ba (-2.26 ± 0.61). Al, Ba and V are within the uncontaminated class; Mn and P are slightly contaminated; Fe, Zn, Ni are moderately contaminated and Co is extremely contaminated. The main chemical elements that generate contamination are Co, Fe, Ni and Zn, suggesting that there is a contribution from the mining sector due to the removal of volumes of soil in the extraction process (Zuzolo et al., 2017) and the agricultural activity in the use of agrochemicals in cattle with the intention to accelerate its growth and the complementation of the food (Saiful et al., 2018).

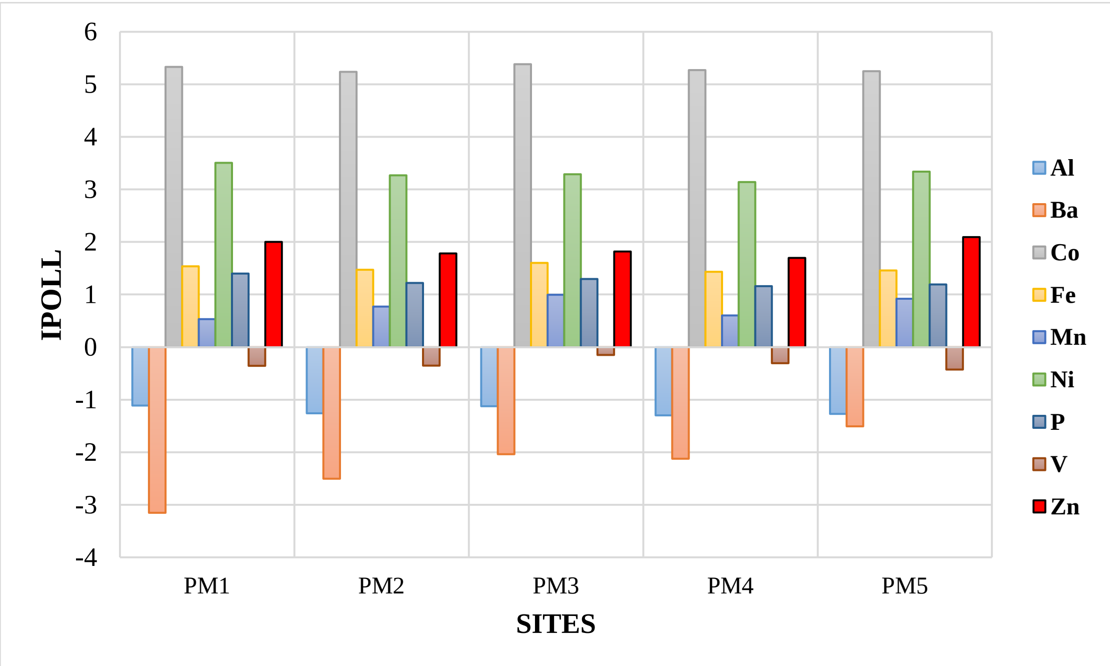

Fig 4. Pollution Index of metals in the sample sites.

Table shows the Enrichment Factor (EF) values of the chemical elements present in the Suches River, whose average values of Al, Ba, Mn, P, V and Zn are below 1.5 which would indicate that its origin is natural. While elements such as Co and Ni exceed the value of 2, which would suggest that the contamination caused by these metals is of anthropogenic origin. The concentrations of these heavy metals could have increased due to population growth and socio-economic activities (Nguyen et al., 2016) such as mining and raising livestock (MINEM, 2001; DRAP 2014). Artisanal mining activities have increased exponentially in recent years in the area (Malone et al., 2021) and have developed its operations without using adequate technologies. Also, the demand for alpaca breeding has grown due to the economic benefit of wool (Paredes, 2016) because the higher the altitude, the better the quality of the wool fiber.

Tabla 1. Descriptive values of the enrichment factors estimated/calculated based on the chemical elements of the sediments.

Element	Mean	Min	Max	SD
Al	0.15	0.15	0.16	0.00
Ba	0.08	0.04	0.13	0.03
Co	14.24	13.93	14.63	0.30
Mn	0.61	0.50	0.69	0.08
Ni	3.54	3.24	3.94	0.29
P	0.86	0.83	0.92	0.04
V	0.28	0.27	0.30	0.01
Zn	1.31	1.16	1.55	0.16

Table shows the analysis of the Spearman´s correlation to identify the association levels among chemical elements (Wang et al., 2012). All the correlations had positive results, which could indicate that the chemical elements originate from common sources (Yang et al., 2020). Element Al has a strong association with Fe, Mn, P y V (($r>0.70$ - 0.87; $p<0.01$); Fe with V ($r>0.79$; $p<0.01$); Mn with V ($r>0.76$; $p<0.01$) and P with V ($r>0.77$; $p<0.01$). According to Haxel and Boore (2015), the combination formed by Al, Fe, Mn and V have natural origins since these chemical elements are abundant in the soil, which would suggest that their accumulation in the areas of the study are the result of weathering and erosion in the soils (Siqueiros-Beltrones et al., 2014); while, on the other hand, Co with Ni ($r>0.78$; $p<0.01$); Ni with Zn ($r>0.76$; $p<0.01$), according to the contamination indices analyzed are toxic elements (Fashola et al., 2016) that could come from mining activity due to the release of sulfide minerals such as pyrite, chalcopyrite and galena in the gold mineral extraction process (Alonso Carballo, 1979; Villegas et al., 2012), as well as from livestock due to the agrochemicals (Saiful et al., 2018). On the other hand, these toxic elements present an association with phosphorus ($r>0.82$ – 0.83; $p<0.01$), since this element performs an important role in the process of transportation and deposition of chemical elements (Shen, Tang, Li, Liu, and Hu, 2020). Additionally, phosphorus is considered an important nutrient for livelihood because it is part of the development and growth of vegetation, which could allow that the associated toxic chemical elements enter in the food chain (Fernández, 2007; Griffith et al., 1977).

Table 5. Matrix of the Spearman´s correlation of the metal concentrations in sediments of the Suches River.

Element	Al	Ba	Co	Fe	Mn	Ni	P	V
Al								
Ba	0.34							
Co	0.50*	0.16						
Fe	**0.70****	0.08	0.50*					
Mn	**0.71****	0.65**	0.62**	0.60**				
Ni	0.57**	-0.03	**0.78****	0.69**	0.44*			
P	**0.78****	0.25	**0.82****	0.58**	0.63**	**0.83****		
V	**0.87****	0.38	0.62**	**0.79****	**0.76****	0.55**	**0.77****	
Zn	0.50*	0.23	0.41*	0.63**	0.40	**0.76****	0.51**	0.36

Note. * indicates p <0.05. ** indicates p <0.01.

Co, Ni and Zn are rooted in the studied areas naturally since they are present in the lithology of the Suches basin (Acosta et al., 2009; Alloway, 1990; Santos-Francés, Martínez-Graña, Alonso, et al., 2017). However, the evaluation with geochemical indices such as CF, IPOLL and EF, reveal that there is contamination of moderate to considerable level that could be caused by natural erosion due to weathering (Siqueiros-Beltrones et al., 2014). Also, the anthropogenic activities carried out in the area such as artisanal open cast mining (INGEMMET, 2009) contributing to the increase in concentrations of these elements in the sediments due to the gold mineral extraction processes in which large volumes of soils are removed (Zuzolo et al., 2017) releasing sulfide minerals such as pyrite, chalcopyrite and galena (Alonso et al., 2020). In addition, there are innumerable sedimentation ponds that are the final discharge point of the removed material and these do not have any type of design to prevent overflows produced during seasons with intense rainfall (Salas-Ávila, 2021).

Moreover, there is also a contribution of these elements through livestock activity due to the prevalence of ruminant livestock rearing in the area (MINAGRI, 2018). These types of cattle periodically show vitamin B12 deficiency (Underwood & Suttle, 1999) and because of this, producers are forced to use different types of agrochemical products with Co (Saiful et al., 2018) and Zn content to complement their feeding (Wilson, 2018). These products are given to the livestock through the spraying of agrochemicals in the soil and pastures and this would suggest that the increase in the concentrations of these elements would come from this activity as well as from the excreta in grasslands.

Due to its high altitude and extension, the basin of the Suches plays a key role in the hydrology of the border region between Peru and Bolivia, with its complex interaction in the atmospheric, geological and environmental processes, having positive effects in the biodiversity and in the different towns that are supplied by the water that runs in the area (Donaires, 2017). Due to human activities in the region, the outcome of the study in the Suches river contribute to the establishment of the necessary baseline for the monitoring and evaluation of the anthropogenic impacts on the quality of the soil and water in relation to the presence of elements potentially toxic with spatio-temporal characteristics.

It is worth noting that it is necessary to perform studies in extensive stretches of the river and its effluents, which could display a broader view to assess whether the results of the evaluations done with the index of pollution have been influenced mainly by the lithology of the basin or by the local anthropic activities that influence changes in the use of the soil and agricultural activities. Additionally, another driving force of environmental change that could affect and be reflected in the chemical properties of the sediments is climate change. King et al. (2017) determined that the increase of extreme weather and the rapid melting of glaciers have had an impact in the hydrology of the rivers. The geochemistry can provide valuable information about the changes of these environmental conditions as well as enable a diagnosis and projections based on chemical transport models of elements in the geographic areas (Kang et al., 2019).

The water resources of high Andean areas are fragile ecosystems and of great concern, especially for their contributions to human well-being. Understanding the behavior of its components through the study of geochemistry in sediments will allow evaluating at large scale the environmental changes, studies that are insufficient without proper management of these resources. The design and implementation of environmental regulation standards for sediment will make it possible to regulate anthropic activities in vulnerable areas and to avoid the unwanted effects on life in general.

CONCLUSION

As result of the methods applied in the process of evaluation in the presence of chemical elements in the sediment in a portion of the Suches river, the degree of concentration of the same, they ascend from moderate to high, where the potentially toxic elements such as Co, Ni, Al and Zn, would be generating possible ecological risks in the study area and in the towns downstream.

According to the chemical analysis of the sediments, the accumulation of chemical elements evaluated are produced at PM3, which have a relation with the dumping transport that occur upstream due to the small-scale mining that is carried out in PM1 and PM2.

In line with the contamination factor, a very high degree of contamination of Co was found in sediments, which have a geological origin typical of the mineralogical strata of pyrite and phyllites chlorite/sericite; similarly, Ni and Zn present a very high degree and considerable degree of contamination, respectively, which could be related to the weathering and erosion of the geological materials in the environment because of the transportation of sediment.

The average value of the PLI allowed to identify that the study area is moderately contaminated. The value of all sampling sites is higher than those similar studies in Andean areas of Peru.

The IPOLL of the elements Co, Fe, Ni and Zn in sediments indicate that they are within the classification of moderate to extreme contamination which would imply that there is an ecological risk in economic-productive activities, mainly agricultural and livestock.

The Spearman´s correlation analysis helped determine that AL, Fe, Mn, P and V share the natural origin and that their accumulation is due to the effects of weatherization and erosion in the soils. In addition to the evaluation of the contamination indices, the correlation confirms that Co, Ni and Zn are toxic elements associated to the extraction of gold minerals and to the agricultural activities in the area.

Finally, considering that in Peru there are no set standards of quality environment that allow the evaluation of concentrations of chemical elements in sediments, this study constitutes a necessary reference as a baseline to monitor and assess the anthropogenic impacts (mining and agricultural activities) in the quality of the soil and water with regard to the presence of potentially toxic elements.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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