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DETERMINATION OF VULNERABLE POPULATIONS IN CRITICAL SECTORS OF THE ROCHA RIVER BASIN IN BOLIVIA

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Rivers are ecosystems that are constituted as indicators of environmental quality thanks to the different types of environmental, and socioeconomic services they offer. Due to the constant expansion of cities, the pollution of rivers is becoming increasingly critical, especially in those rivers that cross or are close to urban centers. In developing countries, such as Bolivia, rivers are an accessible and invaluable source of water for use and consumption, so preserving their quality is essential. There are numerous studies of the water quality of the Rocha River carried out by various institutions that verified the increase in contamination in the body of water. However, the vulnerability for populations and ecosystems have not yet been identified for the entire basin. This research compiled and crossed the available information on anthropogenic activities, water quality, and population distribution to expose the impact on water quality and thus identify vulnerable populations in critical sectors of the Rocha River basin. This study is the base for formulating mitigation actions in the identified areas, to reduce the risk to public health and ecosystems.

Keywords: sensitive ecosystems; public health; environmental degradation

DETERMINACIÓN DE POBLACIONES VULNERABLES EN SECTORES CRÍTICOS DE LA CUENCA DEL RÍO ROCHA EN BOLIVIA

Los ríos son ecosistemas que se constituyen como indicadores de la calidad ambiental gracias a los diferentes tipos de servicios ambientales, socioeconómicos que ofrecen. Debido a la constante expansión de las ciudades la contaminación de ríos se está volviendo cada vez más crítica, en especial en aquellos ríos que atraviesan o son cercanos a centros urbanos. En países en vías de desarrollo, como Bolivia, los ríos son una fuente accesible e invaluable de agua para uso y consumo, entonces la preservación de su calidad es fundamental. Existen numerosos estudios de la calidad del agua del Río Rocha realizados por diversas instituciones que comprobaron el aumento de la contaminación en el cuerpo de agua. Sin embargo, la vulnerabilidad para poblaciones y ecosistemas aún no se han identificado para toda la cuenca. Esta investigación recopiló y cruzó la información disponible sobre actividades antropogénicas, calidad del agua y distribución de la población para exponer el impacto en la calidad del agua y así identificar poblaciones vulnerables en sectores críticos de la cuenca del río Rocha. Este estudio es la base para formular acciones de mitigación en las áreas identificadas, y así reducir el riego para la salud pública y los ecosistemas.

Palabras clave: ecosistemas sensibles; salud pública; degradación ambiental

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1. Introduction

Rivers are ecosystems that provide different environmental, sociological, and economic services, and make them important for the life balance on Earth (Arthington et al., 2010). Water resources in rivers not only can promote socio - economic development, but also provide a living environment. Thus, maintaining river ecological health can improve the human living environment (Cheng et al., 2019). Due to rapid economic development, population growth and climate change (Huang et al., 2017), the problem of river pollution is critically increasing, especially in urban centers (Wang et al., 2012) and pollution of river water is one of the biggest environmental problems in developing countries (Md Anawar and Chowdhury, 2020). Protecting and restoring ecosystems related to water, such as rivers, is presented as a priority in Goal 6, "Clean Water and Sanitation", within the Sustainable Development Goals (SDG) that frame the 2030 agenda (United Nations, 2015).

In the city of Cochabamba in Bolivia, the uncontrolled expansion of the urban sprawl together with the continuous population increase, leading to the release of solid and liquid waste from domestic, agricultural, and industrial activities in the Rocha River (d'Abzac et al., 2020). According to the 2012 environmental audit report presented by the Cochabamba Autonomous Departmental Government (GADC), the contamination of the Rocha River has increased since that was reported in 1998. In the report, 37 industrial activities or projects were identified. that operated in its course, and 10 of these industries did not have an environmental license and discharged their effluents into the Rocha River. Moreover, some of the companies, that had an environmental license, released effluents that exceeded the permissible limits indicated in the standard. The audit presented 44 recommendations to the municipalities and government to improve the riverbed, mainly seeking to develop an emergency plan that includes actions to safeguard it; among them the implementation of decentralized water treatment plants in each municipality and the development of annual monitoring of the entire river basin.

In 2015, the first monitoring of the entire basin was carried out, analyzing physicochemical, metallic, organic, and microbiological parameters at various points along the 68 km of the channel of the river. Due to the high level of contamination, the environmental services offered by the Rocha River are limited. As a water resource, the Rocha River is of vital importance to Cochabamba, especially in the dry season. During this time of the year, water scarcity causes constant conflicts as it serves as a water supply for farmers, cattle ranchers, car washers and irrigators of the city's green areas. These conflicts are related to the quantity and poor quality of water, which represent a danger to activities and direct and indirect water stakeholders (Servicio Departamental de Cuencas, 2015).

The inadequate environmental management system and the unsustainable anthropogenic activities in the Rocha River basin have caused a water crisis concerning Rocha River quality. This research aims to compile the available information to expose the impact of anthropic activities on water quality and thus identify vulnerable populations in critical sections of the Rocha River basin. The foregoing provides relevant information for decision-makers to propose actions to mitigate pollution in specific parts of the Rocha River basin, to reduce the degradation of ecosystems and the risk to public health.

2. Goal

Determine vulnerable populations in critical sections of the Rocha River basin in Bolivia.

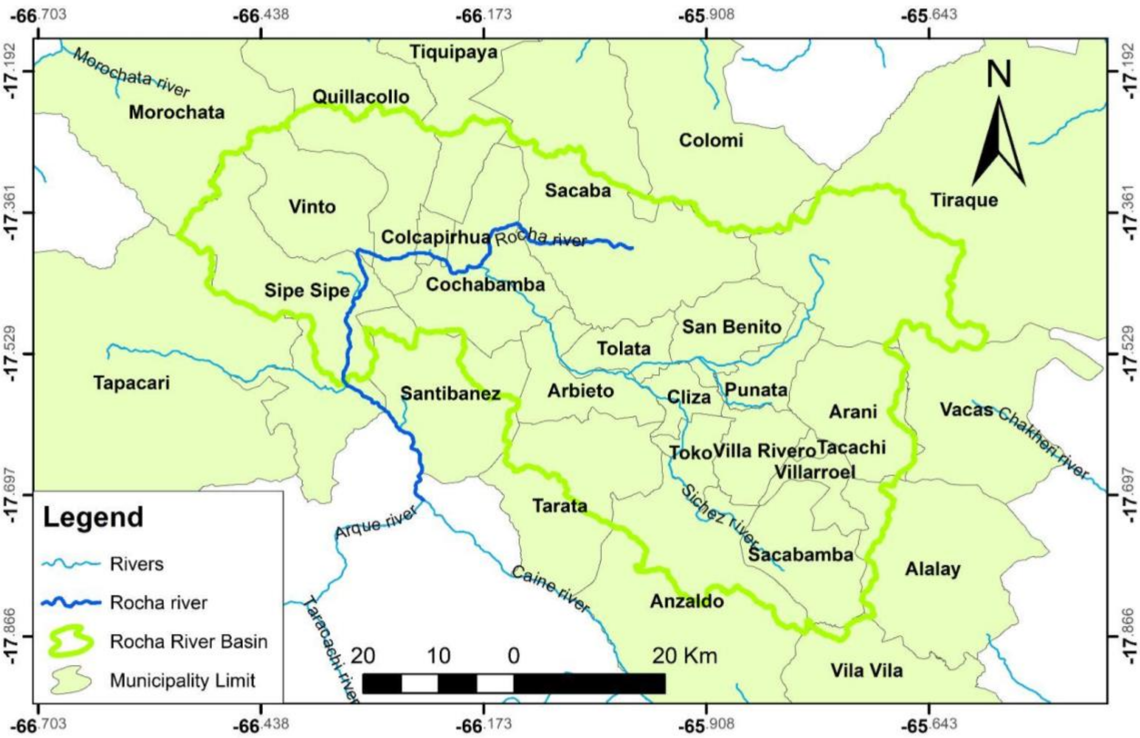
3. Material and Methods

This section has two parts, the first describes the study area, and the second exposes the research methodology.

3.1. Study area.

The Rocha River basin is located in the Department of Cochabamba, beginning in the TiraqueIgando mountain range and extending to Capinota, to finally join the Tapacarí and Arque Rivers to form the Caine River (Departmental Service of Basins, 2015). Figure 1 shows the course of the Rocha River through the basin.

Figure 1. Rocha River route



Source: own elaboration, 2023.

The Rocha River basin is divided into 68 micro-basins, with extensions of 10,000 ha. Likewise, the basin area includes 24 of the 47 municipalities of the Department of Cochabamba, with a population within the area of 1,271,402 according to the last census in 2012 (INE, 2012).

The climate of the Central Valley of Cochabamba, where this body of water is found, is semi-arid and temperate, with average temperatures between 14 and 17°C and average annual rainfall between 400 and 600 mm. In the dry season, the riverbed decreases, taking on the characteristics of a stream, and in the rainy season, it presents short-term floods due to the contributions of the basin (CINER, 2006).

The Rocha River is an important regulator of the hydrological cycle of the basin, being a space for infiltration, evaporation, runoff, and even as a groundwater course, which helps to control floods and droughts (d'Abzac et al., 2020).

3.2. Methodology

This study was carried out with the ArcMap platform and the ArcGis software and was developed in 4 stages, which are described below.

3.2.1. Identification of Municipalities in the basin with the greatest anthropogenic activity

Information was collected from the study area regarding geomorphological characteristics, and division of micro-basins to identify specific and relevant characteristics of the basin; In the same way, information was collected from municipalities and productive activities (agriculture, irrigation systems, and mining). The above information was for 2017 and 2018 because they were the closest available years (Portal Geo Bolivia, 2023). Then, a crossing of the information layers was carried out, which allowed the identification of the municipalities that could have greater vulnerability within the basin due to anthropogenic activities.

3.2.2. Determination of vulnerable populations about water quality in the Rocha River

To determine the vulnerable populations in the Rocha River basin, the available information on population settlements in the basin (Portal Geo Bolivia, 2023) was crossed with data on water quality obtained from the "Ecotoxicological Diagnosis of the bioavailability of pollutants in the Rocha River" (d'Abzac et al., 2020). It should be mentioned that the ecotoxicology study only has data referring to the Rocha River and not the entire basin. The crossing of information allowed to identify the communities that receive the highest load of contaminants and therefore are more vulnerable to the poor quality of water to which they have access.

3.2.3. Evaluation of the most vulnerable areas in the Rocha River basin

The evaluation carried out was based on the anthropogenic activities carried out in the basin (Portal Geo Bolivia, 2018), and the quality data obtained from the water quality monitoring carried out in 2020 at 5 points of the river was taken as a quality reference (d'Abzac et al., 2020). The product of this evaluation was a map where the results of sections 3.2.1 and 3.2.2 were crossed. In the map, the areas with the greatest vulnerability to exposure to inadequate water quality caused by unsustainable anthropogenic activities were identified.

3.2.4. Determination of critical sectors in the Rocha River basin

Finally, data on water quality, population distribution, and anthropogenic activity were crossed to identify in a georeferenced manner which sectors of the Rocha River basin are the most critical concerning water quality. This is due to the systemic nature of the basin as a planning and development entity. The geographical distribution allowed to visualize which micro-basins are the ones that receive the highest impact on their aquifers regulation capacity and the degree of vulnerability that they present to threats in their buffering capacity for water resources conservation.

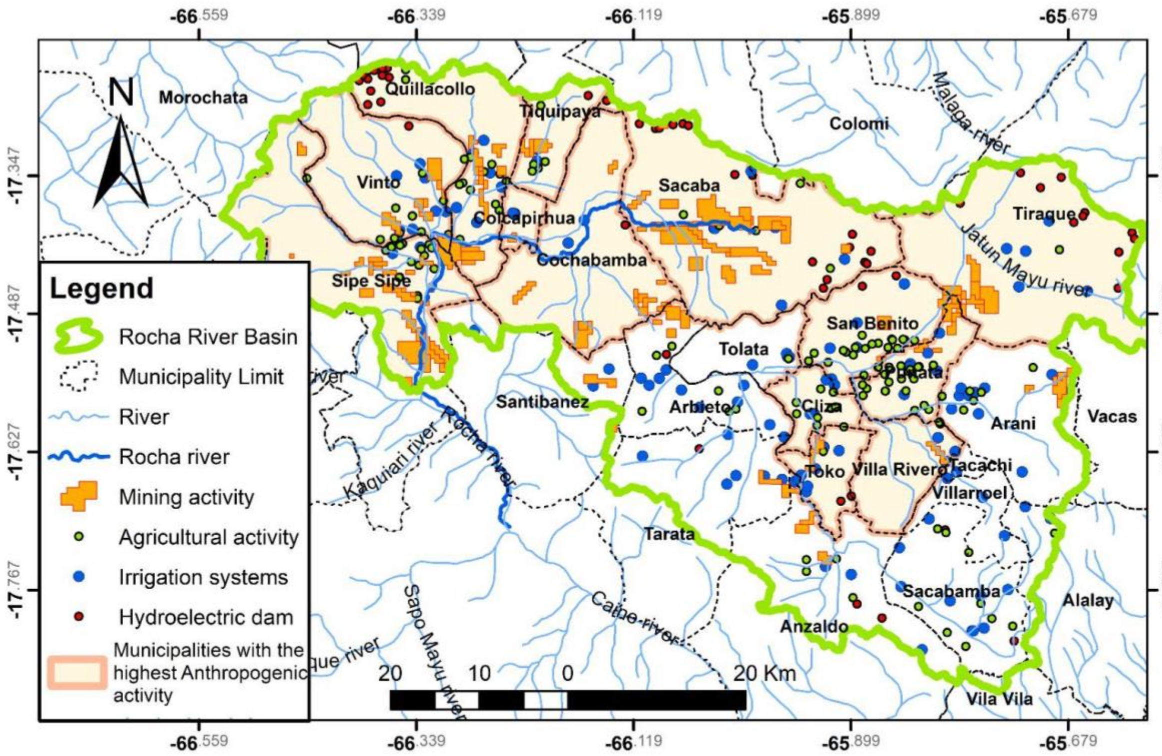
4. Results and discussions

The results obtained and their discussion are presented below.

4.1. Municipalities with the highest anthropogenic activity in the Rocha River basin.

The result of the information crossing reveals that the highest concentration of anthropogenic activity takes place in the municipalities of Tiraque, San Benito, Sacaba, Cochabamba, Colcapirhua, Quillacollo, Tiquipaya, Vinto, Sipe Sipe, Cliza, Punata, Toko, Villa Rivero, and Punata. The municipalities have a population growth that extends the urban area without control and generates pollution by mining and agricultural production. Figure 2 shows the municipalities in the basin with the highest anthropogenic activities.

Figure 2. Municipalities with the highest anthropogenic activities



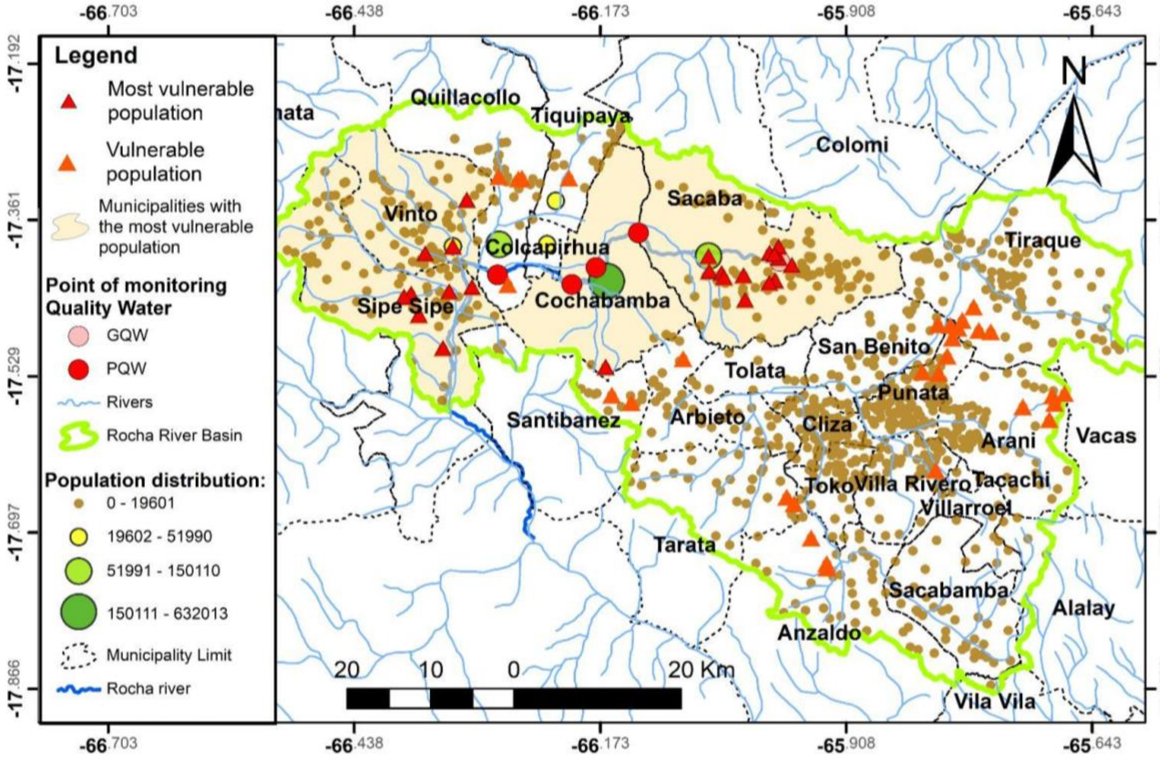
Source: own elaboration, 2023.

Mining is an activity with a considerable environmental impact, specifically due to its acid drainage that deteriorates the quality of surface bodies such as rivers (Huang, 2010; Jhariya, Khan, & Thakur, 2016; Emmanuel, Jerry, & Dzigbodi, 2018). Areas with unsustainable mining activities must be monitored to avoid ecological disasters and public health risks. It is also known that livestock and agricultural activities generate pressure on ecosystems as they are extensive land use activities, as mentioned in the study by Romo-Leon, Van Leeuwen, and Castellanos-Villegas (2014). Agricultural activities can affect water resources, both in terms of their availability for consumption, due to the essential and necessary irrigation to carry out these activities, and in the degradation of water quality due to the use of agrochemicals, which are dangerous compounds (Bhushan & Pathma, 2021).

4.2. Vulnerable populations in relation to water quality in the Rocha River

Knowing that access to water of sufficient quality is essential for adequate development in the quality of life of people (Tanck, 2017), it is important to identify the most vulnerable populations on the Rocha River about the water quality water they consume or have access to use. As a result of crossing the available data, the most vulnerable populations exposed to water with inadequate quality are identified, these populations are located in the municipalities of Sipe Sipe, Vinto, Cochabamba, and Sacaba, as shown in Figure 3.

Figure 3. Municipalities with the population most vulnerable to poor water quality

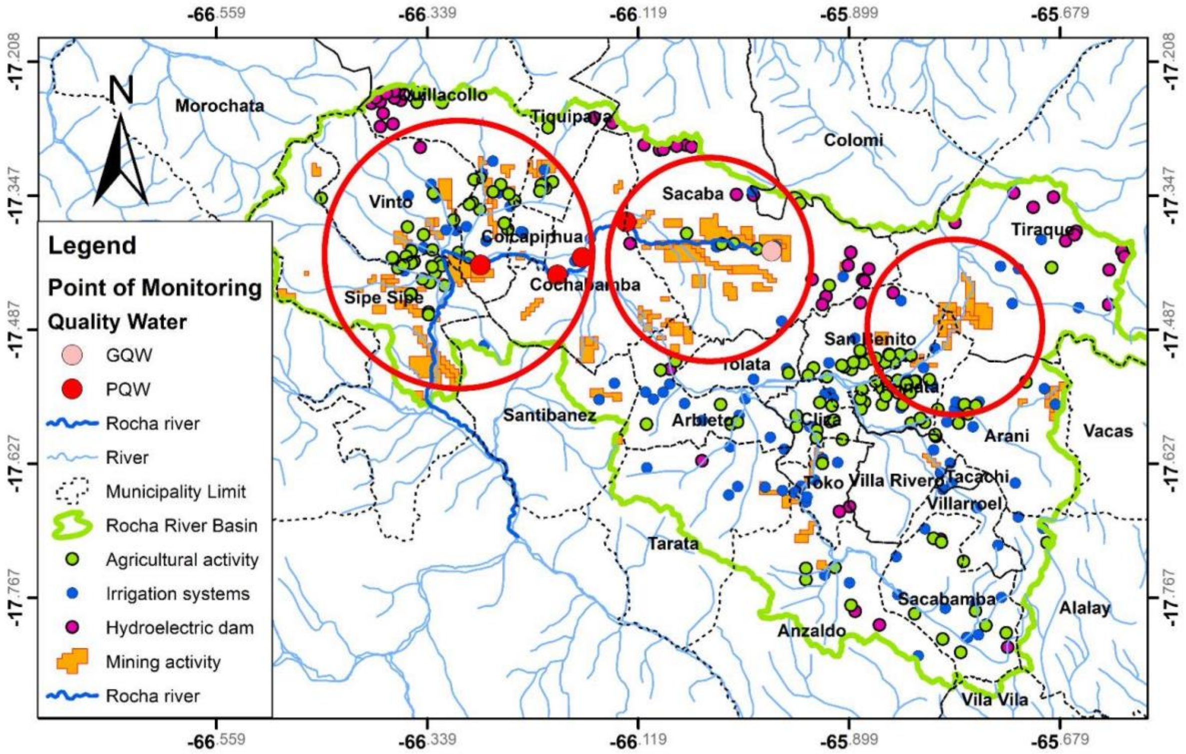


Note: PQW = Poor Quality Water, GQW = Good Quality Water.
Source: own elaboration, 2023.

4.3. Areas with the highest vulnerability in the Rocha River basin

The information obtained in sections 4.1. and 4.2. was crossed, and it was possible to identify the areas of the basin with the highest vulnerabilities to water quality. The vulnerable areas are the conglomerate of several points contained in the different layers of crossed information that coincide in close distances; these areas are found in red circles and are shown in Figure 4.

Figure 4. Areas with the highest vulnerability in the Rocha River basin



Note: PQW = Poor Quality Water, GQW = Good Quality Water.
Source: own elaboration, 2023.

The correlation of information is essential to identify the areas that do not yet have specific water quality studies but are vulnerable due to their land use. It is presumed that the aquifers of the identified areas may be impacted and interrupted in their recharge, this affects their conservation capacity in the event of contamination. Thus, it can also be pointed out that, in the most vulnerable areas, the natural processes of pollution buffering are oversaturated, which avoids a natural attenuation of pollutants.

4.4. Critical sectors of the Rocha River basin

Finally, the critical sectors of the basin were determined, identifying the populations and rivers with the greatest threat of contamination due to existing anthropogenic activities. It was found that 52 of the 925 communities within the basin are the most vulnerable because they are exposed to poor water quality as a result of mining activity in the area and overexploitation of soils for productive activities. Of the 52 most vulnerable communities, 22 are in the most critical areas of the basin. Nine of the 68 micro-basins that comprise the Rocha River Basin were identified as critical. The micro-basins, municipalities, populations, number of inhabitants, and rivers identified as critical are shown below in Table 1.

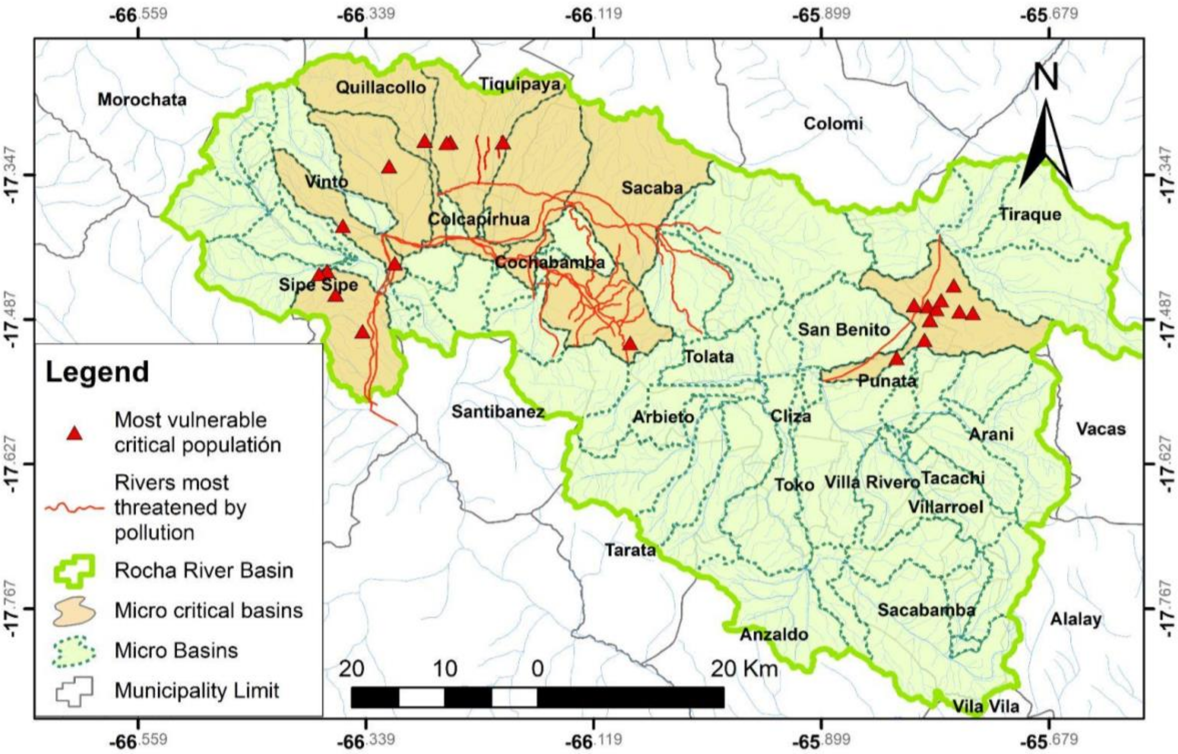
Table 1. Details of critical sectors in the Rocha River basin

N° Micro Basins	Micro Basin code	Municipality	Rivers most threatened by pollution	Most threatened communities	Population
1	4669851	Sipe Sipe	Rocha, Chaquimayu, Kolpa, Kasamayu, Colera, Sacani	Sique Sique, Chahuarani, Linko, Cuticollo	16631
2	4669855	Vinto	Chulla. Huayllaquesa, Buena Vista	Higuerani y Payacollo	13139
3	4669857	Vinto	Kollpa Mayu	Buena Vista,	123014
4	4669858	Quillacollo	Chapare, Tamst	Chocaya Rocha	963
5	4669862	Tiquipaya	Suti, Kosur, Apote	Rancho water, Jove Rancho	116872
6	4669864	Tiquipaya, Cochamaba	Rocha, Andrade	Tiquipaya, Mayorazgo Molinos	19601
7	4669865	Sacaba	Rocha, Lagunillas, Maylanco,Molino Mayu	Capujio, Sacaba	2565
8	46698799	Cochabamba	Millumayu, Ichimayu, Suti	Taco Loma	2919
9	4669895	Tiraque	Paracamaya, Morro, Cruz Mayu, Atojmayu	Illuri Bajo, Vinto, Jarcanayu, Chaqueri, Illuri Chico, Cursani, Huayra Punku	1890

Source: own elaboration, 2023.

Below in Figure 5, the most critical sectors within the basin are exposed.

Figure 5. Critical sectors of the Rocha River basin



Source: own elaboration, 2023.

5. Conclusions.

This research compiled and crossed the available information on anthropic activities, water quality, and population distribution to expose the impact on water quality and thus identify vulnerable populations in critical sectors of the Rocha River basin. 9 micro-basins were identified as the most critical sectors of the basin, in which mining and agricultural activities stand out, which contaminate the water with heavy metals and agrochemicals, which are considered highly toxic and dangerous. Some micro basins identified as critical have already been exposed previously in recent studies, corroborating the urgency of formulating and executing mitigation measures for these sectors.

Until now, no updated study relates water contamination to ecotoxicological risks for all the critical sectors identified in the Rocha River basin. In this sense, the real danger to public health and pollutants is not fully determined. Future research should prioritize water quality control monitoring in the areas that were identified as most critical. Monitoring the length and breadth of the different rivers within the basin may expose the dispersion of pollutants in the basin. The above will allow an exact diagnosis of the existing risks for communities and ecosystems, and thus seek to reduce, recover and conserve the water resources of the Río Rocha basin.

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