Heliyon 10 (2024) e30552

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Water quality assessment methods of the highland Andean rivers: A scoping systematic review

Carlos Matovelle [a,b], María Quinteros [a], Karen Sofía Quinteros [a,*], Karla Jaramillo [a]

[a] Universidad Católica de Cuenca, HYDROLAB, Centro de Investigación, Innovación y Transferencia de Tecnología (CIITT), Ecuador
[b] Universidad Católica de Cuenca, Grupo de Investigación, Ambiente Ciencia y Energía, Ecuador

ARTICLE INFO

Keywords:
High mountain
Water quality
Scoping review
Andean rivers

ABSTRACT

Water is a resource that influences sustainable development in different ways in social, economic, and environmental aspects, being the Andes the major provider of this resource. However, they have been affected mainly by anthropogenic activities due to the proximity of settlements in the watersheds, so they tend to have more significant contamination, and their evaluation is essential to mitigate problems for those who consume them. However, despite being a fundamental resource and one of the main contributors of water, it is not so studied, so the present study aims to determine the studies based on the water quality of the high mountain rivers of the Andes by using a PRISMA methodology with the scoping review extension, based on search techniques, inclusion and exclusion criteria, and monitoring tables, in order to maintain a line of research attached to the objective of the study. After using the methodology, ten articles were obtained, which were analyzed after a bibliometric analysis to determine features of interest, such as countries in which the studies were carried out, years of publication, methodologies used, and authors' consensus. High Andean rivers' importance, the need for more studies within these areas, and the lack of suitable indexes for these unique ecosystems are highlighted.

1. Introduction

Surface water refers to anybody of liquid water found on the Earth's surface, including the ocean water and water stored in the inland repositories, such as rivers, streams, lakes, wetlands, reservoirs and creeks [1]. Earth's hydrosphere covers more than 97 % of the globe, with only 1,1 % being fresh water [2]. Of this, 1,1 % de freshwater, the 99 % is found underground, leaving only 1 % as surface water [1,3]. Nevertheless, water is an essential component of the environment, as it is one of the most indispensable natural elements, sustaining various forms of life on the planet [4], It is fundamental to all living organisms, to human health, food production and the industrial processes [4,5].

This valuable resource is extensively used for the majority of human activities such as drinking, domestic use, industrial and research activities, irrigation and agricultural production, horticulture, livestock farming, and aquatic life management as fish and fisheries [4,6]. Due to its significant importance and widespread use, society has to afford this issue of pollution affecting this vital resource. Pollution arises from various factors, spanning natural causes to human-induced processes [7]. Natural factors influencing water quality include hydrological, atmospheric, climatic, topographical, and lithological factors [8]. Nevertheless, the rapid proliferation of populations and the expansion of socio-economic activities, have led the use of the limited fresh surface water are increasing

* Corresponding author.
E-mail address: hydrolabciitt@ucacue.edu.ec (K.S. Quinteros).

https://doi.org/10.1016/j.heliyon.2024.e30552
Received 17 July 2023; Received in revised form 26 April 2024; Accepted 29 April 2024
Available online 3 May 2024

hastily [1,9].

Furthermore, human activities have a significant impact on water quality, and this impact is often exacerbated by changes in land use that expose the water with contaminantes and pollution decreasing their quality [4]. For example, mining can pollute water bodies with heavy metals; livestock farming and agriculture can lead to nutrient, fertilizers and pesticide residues (e.g., organophosphates, carbamates, and organochlorine groups) [10,11]. runoff; production and disposal of effluent (e.g., industrial, municipal, and agricultural) that increase sediments in the run-offs or soil erosion caused by the modifications in land-use [12–14]. In the recent years, the aparition and increase of emergent contaminants in water bodies are a potential risk for its ecosystems and humans health, the presence of pharmaceutical and selfcare products and endocrine-disruptting chemicals are causing concern [15], even more, because WQI models do not consider any toxic or radioactive constituentes to evaluate water quality [16], few models as Oregon index, the Dojildo index, Liou index, Almeida index and the West-Java WQI recommended to include toxins (detergent, phonels), pestices and trace variables (e.g. Pb, Cu, Zn, Cd, Hg, Mn, Fe) for evaluating water quality in a water body.

A substancial portion of the global populations, precisely a fourth part, faces the issue of not having access to a safe water supply, besides the half of the world's population contends with insufficiente sanitation facilities [2], that reality translates to over 5 million deaths annually attributed to waterborne diseases [1].

The Andes Cordillera exhibits a diverse range of mountain climates, spanning from highly humid conditions in the extra tropics to hyper-arid conditions in the subtropics. This variation is attributed to its extensive latitudinal expanse and distinctive topography. These climatic gradations contribute significantly to the provision of essential ecosystem services. The Andes Cordillera acts as a crucial carbon sink and boasts a substantial water retention capacity, giving rise to the formation of vital wetlands. These wetlands, in turn, play a critical role in interacting with the ecosystems downstream in the Andean slopes [17]. Moreover, the Andean paramo region stands out as one of the most noteworthy biodiversity hotspots [18]. This is underscored by the increasing focus on research in the area, highlighting its ecological importance and the need for a deeper understanding of its complex dynamics [19].

The Andes comprehends more than 99 % of the world's tropical glaciers, so water is essential for the three dimensions of sustainable development since it provides in the social, economic, and environmental ambit [20]. Also, the Andean paramo is the primary provider of fresh water to near 90 million people the Andean highlands of Venezuela, Colombia, and Ecuador, extensive parts of adjacent lowlands, and the arid coastal plains of North Peru [21,22]. So, the population depends on these resources captured, stored, and purified in mountain areas the rivers that descend from the paramo, providing a high and sustained base flow of excellent water quality.

Meanwhile, the establishment of humans in mountains areas causes stress in these ecosystems and deterioration because it generates the loss of biodiversity, increase of erosion, and changes in land use that also impacts the water cycle [23–25], the run-off in a river basin can deposit large quantities of sediments in rivers, directly affecting water quality.

According to Calvin et al. (2023) [26] the mountain ecosystems declared in the Panel on Climate Change (Cross-Chapter Paper 5: Mountains, 2023) and their azonal flooded and floodable areas [27] are especially vulnerable to climate chance. Like other parts of the world, the Andean Mountain ranges are susceptible to global climate change, so it is necessary to have effective land use planning to ensure optimal water supply to cities and rural areas. For these reasons, it requires a good understanding of the hydrology in the paramo; unfortunately, few waters quality studies have been developed in the high Andean streams to analyze these factors and their downstream evolution.

Recognizing the urgency of this situation, the continuous monitoring and regulation of freshwater quality have emerged as critical imperatives for nations worldwide [6,28]. By effectively assessing, predicting, and controlling water pollution, we can safeguard water resources and also lay the foundations for their sustainable use [29]. In developed countries, nutrient enrichment and eutrophication of water resources are issues that have to face as a challenge [30,31]. Meanwhile, developing countries contend with a set of problems, where they seek to balance the preservation of water quality with the current efforts to enhance water supply and santitation insfraestructure [29,31,32].

Thus, the management and maintenance of freshwater quality is essential for the sustainability of human civilization and the health of the environment. Given its relevance, research in this field has been extensive [1,16], but this particular study stands out by focusing on the water quality of high Andean rivers using the PRISMA-ScR methodology, which aims to improve the review process and provide a more complete and detailed view of water quality in rivers in the area.

The PRISMA-ScR methodology, by improving the systematic review process, adds value to the research by providing a more complete and detailed view of water quality in high Andean rivers. Most notably, this study stands out as distinctive in that it addresses a previous absence of literature reviews or systematic studies specific to water quality in these rivers.

The contribution of this work lies in providing an overview of the studies carried out over the last 21 years, which allows us to understand the evolution and current situation of water quality in high Andean rivers. In addition, the replicability of the study positions it as a valuable model for similar research in different contexts.

1.1. Water quality assessment

1.1.1. Water quality index

In this context, recognizing the importance of the water resource, the management of water quality has assumed a crucial role, requiring the collection and analysis of an extensive datasets related with water quality which, due to their magnitude can pose challenges in terms of evaluation and synthesis [16]. Various tools have been developed to assess water quality data, where this last one plays a key role in understanding ecological status. However, its applicability is context-dependent, and the evaluation of the parameters may differ based on regulations of each country [33]. Among these tools, Water Quality Index (WQI) models stands out as a

Table 1
Water Quality Index and models summary.

WQI model	Proposed year	Number of parameters and selection process	Rating scale	Number of studies in rivers (1960–2019)
Horton index	1960	8 parameters suggested. Parameters significance and data availability	Very good (91–100), Good (71–90) Poor (51–70) Bad (31–50) Very bad (0-30)	6
FIS	1960	Employs correlation studies of the parameters for setting the model parameters	Not specified	10
NSF index	1965	11 parameters. Used Delphi technique.	Excellent (90–100) Good (70–89) Medium (50–69) Bad (25–49) Very bad (0-24)	17
SRDD Index	1970	10 parameters. Used Delphi	Clean (90–100) Good (80–89) Good with treatment (70–79) Tolerable (40–69) Polluted (30–39) Several polluted (20–29) Piggery waste (0-19).	6
Dinius index (modified version of NSF index)	1972	11 parameters. Used Delphi technique.	Purification not required (90–100) Minor purification (80–90) Treatement required (50–80) Doutful (40–50)	1
Bascaron index	1979	26 parameters were suggested	Excellent (90–100) Good (70–90) Medium (50–70) Bad (25–50) Very bad (0-25)	3
Oregon index (refined version of NSF index)	1980	8 parameters used Delphi process	Excellent (90–100) Good (70–90) Medium (50–70) Ord (25–50) Very ord (0-25)	2
EQ index	1982	9 parameters recommended. Adopted Delphi method	Excellent (90–100) Good (85–89) Fair (80–84) Poor (60–79) Very poor (<60)	1
House index (refined version of SRDD index)	1986	9 parameters. Key personnel interview. Expert panel judgement process.	High quality (71–100) Reasonable quality (51–70) Moderate quality (31–50) Polluted (10–30)	1
Smith Index	1990	7 parameters. Used Delphi technique.	Not specified	2
British Colombia Index	1995	Used common monitorinf parameters. Open choice system. Al least 10 parameters	Excellent (0–3) Good (4-17) Fair (18–43) Borderline (44–59) Poor (60–100)	1
Dojildo Index	1994	26 parameters. Open (additional group) and close system (basic parameters group).	Very clean (75–100) Clean (50–75) Polluted (25–50) Very polluted (0-25)	1
CCME (reformed version of BCWQI)	2001	4 WQ parameters. Delphi technique	Excellent (95–100) Good (80–94) Fair (65–79) Marginal (45–65) Poor (0-44)	28
Liou Index	2004	13 parameters were used. Parameters were selected based on envorimental and health significance	Not specified	1
Malasyian Index	2007	6 parameters used	Parameters based individual rating scale used	6
Hanh Index	2010	8 parameters. Based on monitoring data availability	Excellent (91–100) Good (76–90) Fair (51–75) Marginal (26–50) Poor (<25)	1

(*continued on next page*)

Table 1 (*continued*)

WQI model	Proposed year	Number of parameters and selection process	Rating scale	Number of studies in rivers (1960–2019)
Almeida Index	2012	10 WQ parameters. Delphi technique	Excellent (91–100) Good (81–90) Medium (71–80) Poor (<25)	1

Based on Uddin et al. (2021) [16].

reliable instrument to determine water quality. These models are based on an aggregation function which enables the analysis of large temporally and spatially-varying water quality dataset to produce a single value [16].

In the review conducted by Uddin, G. et al. (2021) of the water quality index models and their application in assessing surface water quality, the most commonly WQI models were discussed. The WQI models are constructed on the analysis of an impartial amount of physical-chemicals, microbiological, and biological parameters, involving a four-step process: first, the relevant water quality parameters are selected. Second, the water quality data are read for each water quality parameter the concentrations are converted to a single-value dimensionless sub-index. Third, the weighting factor for each water quality parameter is determined and fourth, a final single value water quality index is calculated by and aggregation function (additive, multiplicative, combined. Square root of the harmonic mean function, minimum operator function, unique linear/non-linear aggregation function aggregations) using the sub-indices and weighting factors for a water quality parameter [16].

Although WQI models have been developed over the last 50 years, the first WQI represented in different scales was developed by Horton in 1965 and is a result of a function that includes 10 water quality parameters most common used to calculate water quality [34].

In 1970 Brown, with the support of the National SanitationFoundation (NSF), developed a new general water quality index (NSF-WQI) without considering the uses given to water resources [30]. This method is subjective since the opinion of experts in water quality was required to carry out the calculation procedures.

Several WQI models have since based on the NSF-WQI. The Scottish Research Development Department (SRDD) developed the own model the SRDD-WQI, which also is based in part with Brown's model and used it for assessment of river water quality [16]. Meanwhile, the Bascaron Index (1979) [16]and Dalmatian Index [35] are derivations of the SRDD-WQI. A later development the Environmental Quality Index model for the assessment of water quality in the Great Lakes ecosystems was proposed by Steinhart et al., in 1982.

Another model proposed was the British Columbia Water Quality Index (BC-WQI) and the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) are similar and were developed by the Canadian Ministry of Environment; these indices are developed for specific areas where different monitoring points are considered for evaluating multiple parameters [36]. Dinius Water Quality Index (DWQI) uses the Delphi method to consider water resources' possible uses [37].

According to the development of the WQI, these may have evaluation approaches with general parameters, which are considered by the type of consumption or water use and the management that water resource is going to be given; it is important to point out that it is not feasible a WQI general model since parameters depend on location, quantity and the use that water resource is going to be given.

To the date, more than 35 WQI models were introduced, each one of them have been developed with variations in model structure, the parameters used and their weight, the methods used for sub-indexing and aggregations [31,38–40]. Though, WQI have been applied to all major types of waterbodies, where 82 % of applications have been to assess river water quality. In Table 1 shows a summary of WQI model structures and applications in rivers study areas found in literature published from 1960 to 2019.

1.1.2. Biotic index (BI)

The development of a BI to assess water quality has been proposed since 1960, considering that living organisms are the first to have pollution problems. In the 70s, Chandler and later Cook proposed the Biotic Score, a pretty acceptable index to assess water quality simultaneously. In Europe, the saprobic system was used, an extended method that reflects precise results that require observing organisms' adaptability or tolerance to different pollution levels [41].

So, the BI has been developed to assess the effect of anthropogenic interventions on different ecosystems [42,43]; the use of a biotic index provides a quick and quantifiable response against various environmental disturbances [44]. In addition, they allow a better understanding of water quality alteration processes [45].

The BI was developed based on probity and considered the assignment of pollution tolerance values to different species communities, observing the species' quantity and diversity and obtaining a numerical value representing pollution in a biological community. Among biological index benefits, we can find multiple stress factors determination in multiple ecosystems; in limitations, the taxonomic identification can be found since subjective criteria use it and its results disagree with the different taxonomic levels; in addition, the little knowledge of particular taxa and the greater use of specific taxa hinders results quality [46].

Biological monitoring methods were mainly developed in Europe or North America, so their applicability can be debated [47]. For this reason, to solve this problem, many countries have developed their biological index, such as the Neotropical Lowland Stream Multimetric Index (NLSMI) to monitor rivers in Panama [48] and the Macroinvertebrate Multimetric Index to assess wetlands in southwestern Ethiopia [47].

1.1.3. Mathematical models

Mathematical models in water quality are used as analysis and prediction tools, contributing to the development of scientific knowledge of specific areas [7]. Predictions allow simulating and quantifying the impact generated by diffuse and point sources of water pollutants since it is a tool that has the possibility of understanding the behavior (cause-effect) of a specific water system that has been a receiving medium in different circumstances [7,49].

The basic parameters to model the aquatic environment are temperature, pH, dissolved oxygen, BDO, and solids. A mathematical model needs to be calibrated to reflect the observed behavior to simulate variables. It is necessary to specify different parameters that guarantee results and understand environmental processes to describe them through equations as a representation of reality. Mathematical models for evaluating water quality are modified and adapted to the requirements of the study area and vary according to the temporal or spatial scale to be analyzed [38]. Water quality models are used as management strategies in river sanitation, as they reproduce ecological processes and the effects of anthropogenic activities [50].

1.2. Water samples conservation

In Ecuador, according to regulation NTE INEN 2169 [51], the handling and conservation of water for analysis are administrated by various parameters, such as the characteristics of the collection container. These samples are stored at temperatures lower than the collection temperature, and freezing at −20 °C extends the storage period. Preservatives, such as acids, bases, diacids, or special reagents, may be used.

On the other hand, the national protocol for monitoring the surface water quality of water resources in Peru stipulates that water should be sampled at control points and a depth specified in the authorization for the discharge of treated wastewater [52]. The type of container, storage time, temperature conditions for each physicochemical parameter, nutrients, non-volatile and volatile organics, aromatic hydrocarbons, pesticides, microbiological agents, metals, and metalloids are specified in Annex VII of the national protocol.

In contrast, the water sampling manual in Colombia provides various protocols for cleaning, sampling, sampling order, sample volume, addition of preservatives, and their conservation at a refrigeration temperature of 4 °C, protected from light. This is achieved using portable coolers with ice packs, with the collection-to-laboratory arrival time being less than 24 h [53].

Overall, the water conservation protocols considered are from countries where studies on the water quality of high Andean rivers (some of those forming the Andes Mountain range) are conducted. The collection of water sources, preservation, transportation, and laboratory analysis of parameters to determine water quality are similar across different countries. The low-temperature preservation is crucial to prevent the degradation of compounds within the water sample.

This paper is organized as follow, in Section 2 a research rationale about the objective and related research is presented. Meanwhile, Section 3 details the PRISMA methodology. The findings, observations and commentaries are reported in Section 4. Section 5 has de limitations, novelty and replicability of the used method. Finally, the last arguments and conclusions are presented in Section 6.

1.3. Research rationale

The water quality assessment research is indispensable, underscoring the need to scrutinize existing academic literature to determine published research and identify potential critical research gaps [54,55]. To date, there are few or no systematic literature reviews especially addressing the assessment of water quality in rivers, particularly in highland rivers in the Andes. For instance, Uddin et al. (2021) [16], conducted a comparative discussion on the most important WQI models, delving into their structure, developmental stages, applications, and associated challenges. The study emphasizes future research directions, highlighting the limitations of current approaches in predicting future changes or addressing the root of the causes of water pollution. This is contingent on local water quality objectives and the availability of data- Similar investigations have been conducted by Lumb et al. (2011) [56], Poonam et al. (2013) [57] and Patil et al. (2012) [58].

On the other hand, the importance of physicochemical parameters in obtaining an accurate representation of water quality is paramount. These parameters play a crucial role in describing the significance of different factors for WQI- Studies, such as that conducted by Patil et al. (2012) [58], emphasize the influence of factors and geological conditions, highlighting the importance of physicochemical parameters. The research indicates that these parameters are essential for exploring parameter studies and are established by comparing the values of real water samples.

Meanwhile, the study conducted by Chidiac (2023) [59] is presented as a comprehensive review of the Water Quality Index. This review addresses the various stages of its development, the progression of the field of study, different indexes, as well as the benefits and limitations of each approach. The study advocates for the expansion and refinement of indices as scientific knowledge advances, suggesting the creation of updated WQIs that incorporate statistical methodologies, consider interactions between parameters, and align with scientific and technological advancements for future research. This approach is deemed crucial for guiding forthcoming investigations in the field of water quality.

While reviews have provided valuable insights, they have predominantly concentrated on a specific dominion-the assessment of surface water quality in the highlands of the Andes. However, these reviews often fall short of attempting to identify the most influential contributions over an extended time frame. The dearth to research focused on water in highland rivers of the Andes underscores the need for a systematic synthesis to achieve a more profound understanding of the subject.

This reaserch aims to address this gap through the application of the PRISMA-ScR methodology, by summarizing and structuring the existing body of knowledge in this particular domain, the intention is to raise awareness and encourage increased research actions in this area. The results of this synthesis are expected to unveil the current research landscape, trends, and hotspots, providing a comprehensive understanding of the monitoring of water quality in Andean rivers.

Furthermore, to fill the knowledge gap, this study employs the PRISMA-ScR methodology to conduct a rigorous quantitative and qualitative analysis of reported research at the intersections of river quality assessment approaches. It contends that the study contributes significantly to the literature by analyzing water quality in the Andes. The contributions are multi-fold: Firstly, by offering a background of previously reported river quality assessments: secondly, by establishing a foundational dataset with monitoring records of the WQI in highland Andean rivers, involving analyzing repositories, years of publications, methods, study locations and qualitative results.

2. Methodology

The study documents lack current research thorough its findings, thereby suggesting areas for further investigations. The primary objective of this work is to provide an initial evaluation of existing academic records on the study of water quality in high Andean rivers. It seeks to establish a baseline that encompasses past research, methodologies employed, qualitative results obtained and the inherent limitations of the subject. To facilitate a detailed assessment and guide future investigations, specific research questions aligned with these objectives have been formulated (Table 2). These questions aim to better develop and map the objectives they address.

To achieve the objectives of this study, an exploratory systematic review of the published scientific literature was carried out using the following methodology.

2.1. Scoping review

The guidelines taken for the respective exploratory systematic review followed, in part, the systematization criteria of Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) and, in turn, the criteria and theoretical framework of the methodology proposed by Arskey and O'Malley [60] and updated by Levac et al. [61].

Therefore, the reason for choosing the exploratory review methodology is because it is the first review to be carried out on water quality in high mountain Andean rivers; in addition, given the limited amount of available information by the few studies published on the subject, the lack of consensus information that exists and the variety of methodologies that could be used to assess water quality in Andean rivers, give as results heterogeneous studies. Thus, carrying out an exploratory review as a first point favors systematization, which allows the research and, in turn, justifies the need to investigate water quality in this region.

Hence, PRISMA is based on four main parts along many steps; the first part is planning, which aims to cover the focused research questions and the search strategy. The second part is selection, which aims to extrapolate and classify the data. The third part is extraction, which evaluates the data through a pre-established systematic evaluation. Finally, the last stage is known as data synthesis and aims to analyze the data to develop successive procedures. The previously mentioned parts are summarized in the following steps:

2.1.1. Identification of the research question

Once the study's objective has been established, the research question of the present work is: What studies were conducted to determine water quality in high-mountain Andean rivers, and what methods are used to determine the value of water quality in high-mountain Andean rivers?

2.1.2. Search strategy to classify relevant articles

The strategies used to search for the necessary terms, the sources for finding and locating the literature, and the search procedure have been detailed below.

2.1.3. Search terms

From the two research questions, a set of keywords was obtained to perform the searches, the same that could be found anywhere in the article. In addition, the Boolean operators "OR," "AND," and "NOT" were used to retrieve refined and precise results. Thus, the key terms to obtain the most coincident results were: "water quality" AND "Andean rivers."

Table 2
Study research questions and objectives.

Research Question	Objective
What is the current state of the literature regarding studies on water quality in high Andean rivers?	Formulate a PRISMA methodology tailored for the search of water quality in high Andean rivers, employing database for the protocol.
What are the recent research findings on the water quality of high Andean rivers, identified after applying search methods with inclusion and exclusion criteria?	Conduct an in-depth analysis of the articles obtained using previously established search protocol to explore the existing body of research within the fields of the high Andean River water quality.
What are the years of publications, methods, countries, repositories and other relevant aspects presented in the analyzed scientific literature?	Establish a comprehensive baseline of information regarding the studies, countries, methods, years and basic study information derived from the analyzed articles.

2.1.4. Use of bibliographic resources

Therefore, a previously structured search was conducted in 6 electronic databases: Scopus, Science Direct, Web of Science, Springer, Scielo, and Taylor & Francis. The search criteria were used in their respective navigation bars. These documents were consulted from March 2023 to May 2023.

2.1.5. Filtering

After obtaining the articles by using the key terms, in the next step for the selection of articles, the following inclusion criteria were used: a) quantitative and qualitative studies on water quality in Andean rivers using different methodologies; b) publications between 2002 and 2023; c) publications in Spanish or English. Exclusion criteria: a) studies that do not have complete accessibility to the text, and b) research conducted outside the countries that make up the Andean Mountain range.

2.1.6. Extraction

Then, from the search for information through key terms and inclusion and exclusion criteria; subsequently, an analysis was carried out through a brief reading of the document to select the remaining articles from the primary search. For this section, a checklist to be fulfilled was used, which lists key criteria to select articles according to the PRISMA-ScR methodology for the data extraction.

The data extraction process is referred to as "data charting," which provides the reader with a logical and descriptive summary of the results that align with the objective/s and questions of the scoping review to maintain the focus of the review study, thus granting that the chosen articles have the interest, reliability, and validity, thus giving relevance to the work.

The draft charting table was developed using some key information such as:

1. Author (s)
2. Year of publication
3. Origin/country of origin (where the source was published or conducted)
4. Aims
5. Population and sample size
6. Methodology/methods
7. Duration of the intervention
8. Outcomes in a qualitative result

- **Sort of selected articles**:

As a result, the data obtained is charting extracted in a Microsoft Excel spreadsheet was analyzed. Furthermore, information was synthesized that would be presented in the results section figures.

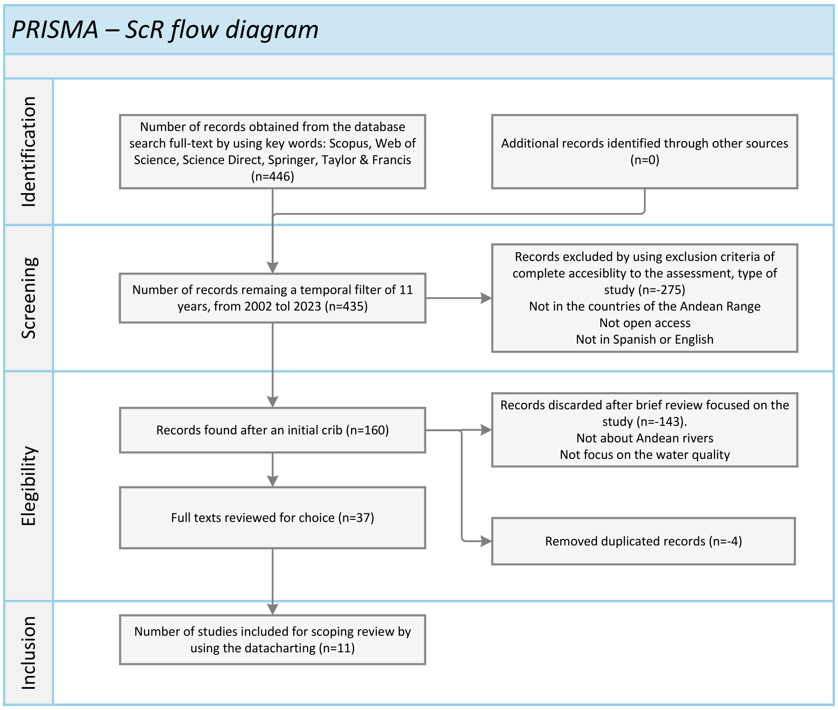

Fig. 1. PRISMA-Scoping review flow diagram of water quality in Andean rivers.

Table 3
Chart of analyzed articles after applying the inclusion and exclusion criteria.

#	DATABASE	AUTHORS	TITLE	YEAR	AIM	CUALITATIVE RESULT	LIMITATIONS
1	SD	Castillejo, P. et al. [62]	Response of epilithic diatom communities to environmental gradients along an Ecuadorian Andean River	2018	Test the hypothesis that diatom communities undergo changes in species composition along a downstream gradient of increasing eutrophication and organic pollution.	Moreover, the results obtained suggest a lack of concordance with the trophic values given to some of the epilithic diatoms in the literature. There were also species that seem to be sensitive to downstream nutrient increases that were not considered as bioindicators in previous studies. We concluded that the trophic values of diatom species available in the scientific literature are not directly applicable to their sites in the Pita River. Hence, it is necessary to establish a trophic diatom index for the Andean region of Ecuador	The method is not so valid given to the lack of information
2	SD	Damanik-Ambarita, M. et al. [63]	Ecological water quality analysis of the Guayas River basin (Ecuador) based on macroinvertebrates indices	2016	(1) To determine the ecological water quality of the Guayas River basin based on macroinvertebrates indices, (2) to identify physical–chemical variables significantly affecting the water quality in the area, and (3) to evaluate the relationship between the occurrence of benthic macroinvertebrates and physical–chemical variables. The results of this study can be used to support the future water management of the Guayas River basin and similar basins situated in tropical lowlands worldwide.	Two biotic indices were calculated to assess the water quality with an ecological approach: the Biological Monitoring Working Party Colombia (BMWP-Col) and the Neotropical Low-land Stream Multimeric Index (NLSMI). Both the BMWP-Col and NLSMI indicated good water quality at the (upstream) forested locations, lower water quality for sites situated at arable land and bad water quality at residential areas. Both indices gave relevant assessment outcomes and can be considered valuable for supporting the local water management. A correspondence analysis (CA) applied on both indices suggested that flow velocity, chlorophyll concentration, conductivity, land use, sludge layer and sediment type were the major environmental variables determining the ecological water quality. We also suggested that nutrient and pesticide measurements are important to study water quality in the area where intensive agriculture activities take place. The nutrient levels detected in agricultural areas were relatively low and illustrated that the types of crops and the current cultivation methods were not leading to eutrophication. The applied methods and results of this study can be used to support the future water	

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Table 3 (*continued*)

#	DATABASE	AUTHORS	TITLE	YEAR	AIM	CUALITATIVE RESULT	LIMITATIONS
						management of the Guayas River basin and similar basins situated in the tropics.	
3	SD	Carrera, P. et al. [64]	Ecology of a high Andean stream, Rio Itambi, Otavalo, Ecuador	2003	(1) Research and analysis of physical, chemical and biotic characteristics of Rio Itambi in order to understand and quantify the interaction of these parameters. (2) Adaptation and development of a new method for ecological evaluation of the structure of a high Andean stream with the purpose of having a tool in Ecuador, which would allow the monitoring the geomorphological quality of streams, and the management of these ecosystems. (3) Determination of fauna and flora biodiversity of Rio Itambi and correlation with physical and chemical parameters of Rio Itambi, learning this way its regulating factors as well as the ecological stream zoning. (4) Registration and evaluation of ecological quality of Rio Itambi with the objective of developing concepts for an adequate management of running waters.	The impact on quality is causes by human activities (sewage imput, cattle raising), by landslides with a remodeling of the stream bed and by a low oxygen concentration due to altitude. Flora of streams banks as well as diatoms, macrophytes and fauna of stream bed were determined, and within the stream, biodiversity is low. In the upper part of the stream, this seems to be an effect of low oxygen saturation values and of landslide that remodel the stream bed, and in the lower part of the stream it is due to anthropogenic damage by sewage imput.	
4	SC	Coayla-Peñaloza, P. et al. [65]	Benthic macroinvertebrate communities and water quality assessment in high Andean wetlands Callali-Oscollo, Arequipa-Cusco, Peru	2023	Assess the water quality in lotic environments located in the Callalli-Oscollo districts using the study of aquatic macroinvertebrate community.	Thirty families were recorded in lotic environments, the most abundant being Chironomidae, Naididae, Limnesiidae, Elmidae, Baetidae and Lumbriculidae. The ecological quality was good, except at the station associated to the dam, where it was doubtful. Twenty-six families were recorded in lentic environments, the most abundant being Cyprididae, Naididae and Corixidae. The macroinvertebrate communities in high Andean environments reflect ecosystem conditions. Environments associated to human activity have lower ecological quality	Uses high Andean wetlands
5	SC	Rey-Romero, D. et al. [66]	Effect of agricultural activities on surface water quality from paramo ecosystems	2022	Analyze whether different agricultural contaminants (nutrients, organic matter, sediments, and pathogens) affect water quality and could compromise its use for different purposes such as human consumption, irrigation, livestock watering, and aquatic life	The studied agricultural activities increased loads of surface water in quality in nitrates (0.02–2.56 mg N–NO3/L), potassium (0.13–1.24 mg K/L), and *Escherichia coli* (63–2718 FCU/100 mL), generating risks on the human health and promoting	Limited to the production activity

(*continued on next page*)

Table 3 (*continued*)

#	DATABASE	AUTHORS	TITLE	YEAR	AIM	CUALITATIVE RESULT	LIMITATIONS
					ambient freshwater, and (ii) to assess the influence of the rainfall regime on the water quality of surface sources.	eutrophication. Total nitrogen and organic matter in the rainy season were higher than dry. BOD5, COD, turbidity, and *E. coli* were above international standards for direct human consumption. However, water could be used for irrigation, livestock watering, and aquatic life ambient freshwater. The results show that a small land-use change of almost 15 % from natural paramo vegetation to agricultural uses in these ecosystems impairs water quality, limiting its uses, and the need to harmonize small-scale livelihoods in the paramo with the sustainability of ecosystem service provision	
6	SC	Carrasco-Badajoz, C. et al. [67]	Aquatic macroinvertebrate trophic guilds, functional feeding groups, and water quality of an Andean urban river	2022	Urban river based on trophic guilds and functional feeding group yields a similar or better diagnosis than quality indices based on taxonomic approach at the family level, besides providing information on its trophic functioning.	Environmental variables and biotic indices increased significantly in the most impacted stations, where the abundance of most taxa decreased. The components of trophic guilds and functional groups varied, and those feeding on fine particles increased in sites with a higher urban impact. The metrics based on trophic characteristics were highly correlated with the BMWP/Col and ABI indices. Therefore, these indices can be used to estimate river water quality and provide information on its functioning	
7	SC	Choque-Quispe, D. et al. [68]	Proposal of a Water-Quality Index for High Andean Basins: Application to the Chumbao River, Andahuaylas, Peru	2022	Formulate a water-quality index for a high Andean River through the Delphi method, taking it as an application case the river of the Chumbao micro-basin, Andahuaylas, Apurímac, Peru, covering the seasons 2018 to 2021.	The application of WQIHA in the water from the high Andean basin of the Chumbao river showed that the areas surrounding the head of the basin present good quality, and they are not threatened, showing levels close to the natural state, and that it is rarely seen. However, urbanized areas are frequently threatened and degraded, due to anthropic practices; and that degradation has been increasing over time.	
8	SC	Custodio, M. et al. [69]	Water quality dynamics of the Cunas River in rural and urban areas in the central region of Peru	2021	The objective of the present study was to evaluate the water quality dynamics of the Cunas River in rural and urban areas in the central region of Peru, during 2017–2019.custo	The results obtained reveal that the physicochemical parameters did not exceed the environmental quality standards for water, except BOD5 and Fe. Water quality according to the WQI in the rural sectors was qualified as good quality water and in 67	

(*continued on next page*)

Table 3 (*continued*)

#	DATABASE	AUTHORS	TITLE	YEAR	AIM	CUALITATIVE RESULT	LIMITATIONS
						% of the urban sectors, as poor-quality water	
9	SC	Meneses-Campo, Y. et al. [70]	Comparison of Water Quality Between Two Andean Rivers by Using the BMWP/COL. and ABI. Indices	2019	To evaluate the results of two biological quality indexes, as well as their relationship with some physicochemical parameters in two high mountain rivers with different levels of anthropic intervention, as a mechanism to provide information for their protection and conservation through knowledge of the physicochemical and biological quality of their waters.	The results obtained show that the ABI index, which is an index created for Andean Mountain systems, is more sensitive to impacts than the BMWP/Col index.	The is not enough information
10	SC	Carrasco, C. et al. [71]	Aquatic macroinvertebrates in streams associated with high Andean wetlands of Ayacucho	2020	To compare the diversity, composition and abundance of macroinvertebrates and the physicochemical characteristics of stream water in two high Andean wetlands in Peru.	The richness, composition and density of macroinvertebrates were different in streams depending on the bofedal with which it is associated. The contribution of the springs to the streams generates drastic changes in the quality of the water and the macroinvertebrates, determining the formation of assemblages with different richness and structure.	Uses high Andean wetlands
11	WoS	Pimentel, HF; Oyague, E and Sanchez, E [72]	Environmental quality assessment in central Andean Rivers: Using the ecological thresholds concept, environmental quality standards, and biotic indexes	2022	To assessed and analyzed the applicability of three environmental tools: Water Quality Standards, Biotic Indexes, and Stable States Concept, that were applied through five Peruvian Andean rivers monitoring during ten years, from 2009 to 2018. Our objectives were: (i) compare the results obtained applying WQS, community structure, and Biotic Indexes to identify the Environmental Condition of the studied rivers, (ii) identify and analyze which stable states had the rivers' ecosystems and (iii) identify the key variables that explain the Stable States observed during the whole period.	A simple tool cannot be used to evaluate the quality of water resources. Quality standards analyze variable by variable and do not consider the interactions between them; the quality results also are restricted to good or bad conditions.	There are not similar studies

In short, the methodology was based on the following flowchart (Fig. 1).

3. Discussion and results

The results obtained on the subject of the study are presented below and will be analyzed from different perspectives to extend the panorama of documents available.

After the procedure of inclusion and exclusion analyze, a total of 11 articles has been taken, which are reflected in Table 3, consequently different criteria analysis is realized.

General description of the selected studies:

By employing the keywords in the navigation bars, a total of 446 documents were accessed in different scientific bases: Scopus (318), Web of Science (19), Science Direct (62), Springer (42), Scielo (0) and Taylor & Francis (5), as shown in Fig. 2.

However, the following records were selected by peers according to the subject of study based on filters according to inclusion and exclusion criteria, as well as on a data table according to the PRISMA-ScR methodology, from the total of results obtained by primary search, 11 scientific research articles were taken at the end (Fig. 3).

As shown in the previous figure, the Scopus database is the one that has the most significant number of articles that our study will analyze (7), followed by Science Direct, which has three articles used, and Web of Science, which contributes with one, taking into consideration that the other databases such as Scielo, Springer and Taylor & Francis did not obtain articles for analysis because they do not focus on the topic of study according to the guidelines previously determined. They were repeated studies with other databases.

On the other hand, the number of analyzed articles (Fig. 3) counterbalanced by the search for articles using keywords "water quality" AND "Andean river" (Fig. 2), with the most significant number in Scopus with a total of 318 articles, of which only seven are used for analysis, Similarly, in Science Direct, of the 62 obtained from a simple search, only three were chosen for analysis; likewise, Web of Science obtained 19 studies in its navigation, of which only one was used; however, the Springer, Scielo and Taylor & Francis repositories obtained values of 42, 0 and 5 documents, respectively, but no article was considered from these repositories (Fig. 3).

Equally important, taking into consideration that the Andes Mountains range crosses the countries of Argentina, Bolivia, Chile, Colombia, Ecuador, Peru, and part of Venezuela, we have evaluated the number of studies to be analyzed in each country, thus inferring the analyses carried out concerning water quality in high Andean rivers (Fig. 4).

As can be seen, there is a significant difference between countries such as Venezuela, Bolivia, Argentina, and Chile, where most of the countries that conform to the Andean Mountain range do not have articles that are included in this study, focused on determining the quality of water in high Andean rivers. Relatively the most significant number of studies analyzed is in Peru (6), followed by Ecuador (3) and Colombia (2).

After a brief analysis of the selected studies, they were grouped methodologically according to the techniques used to determine water quality in different bodies of water in South America and by the use of different indexes that was based on determining the rate of quality; being these groups by Biotic Index (BI) and physical-chemical analysis (FQ), however, methods can be used in combination to have greater veracity of results, in this case, Biotic Index with physical-chemical analysis (FQ + BI); On the other hand, more methodologies could be used for the evaluation of water quality, such as the use of satellite images or mathematical models; unfortunately, among the 11 final articles chosen, they did not fit the latter mentioned. Thus, Fig. 5 shows the distribution of the FQ, BI, and FQ + BI methods of the scientific articles.

The method that is used in greater quantity is that of bioindicators, to which seven articles are attributed; on the other hand, the physical-chemical analyses are also recurrent in the study of water quality, having a total of 3 articles which are taken into consideration in this review; however, the use of both methodologies described above is found in only one article in this study. In brief, it is possible to recognize which methodology is the most widely used, and the reasons for its use should be analyzed, whether for effortless, time, costs, or sensibility.

Furthermore, an analysis by year of publication of the selected articles (11) is shown in Fig. 6, highlighting the growth of articles on the analysis of high Andean water quality over the years.

As seen in the previous graph, there is an excellent skew in the publication of articles focused on the water quality of high Andean rivers from 2004 to 2015, with no production focused on these topics. However, a great demand has been perceived in the last six years

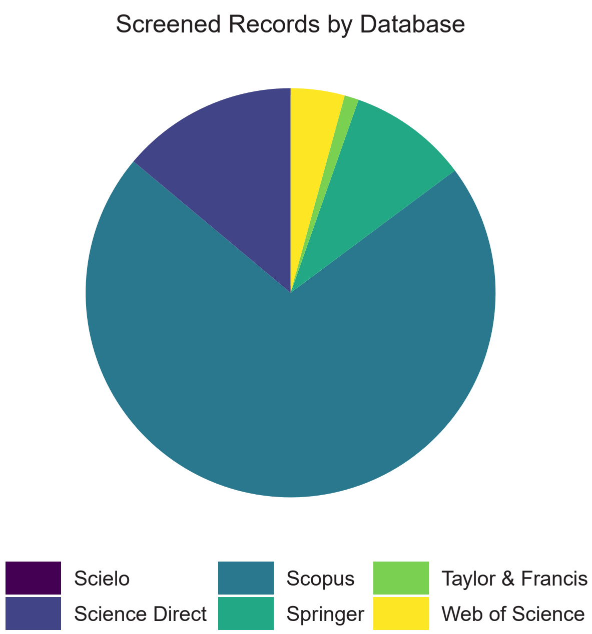

Fig. 2. Number of publications on water quality by the first screen using keywords grouped by the database.

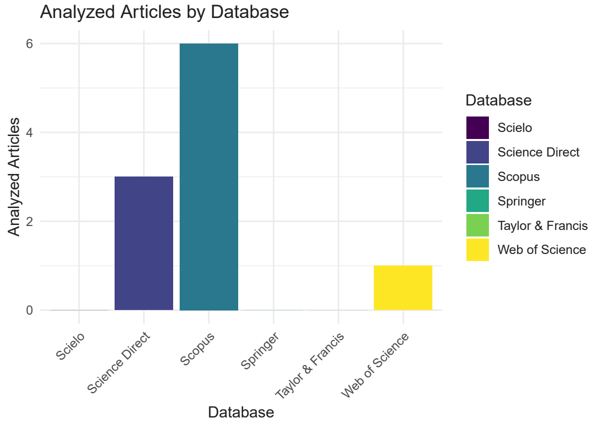

Fig. 3. Number of publications selected for water quality PRISMA-ScR research.

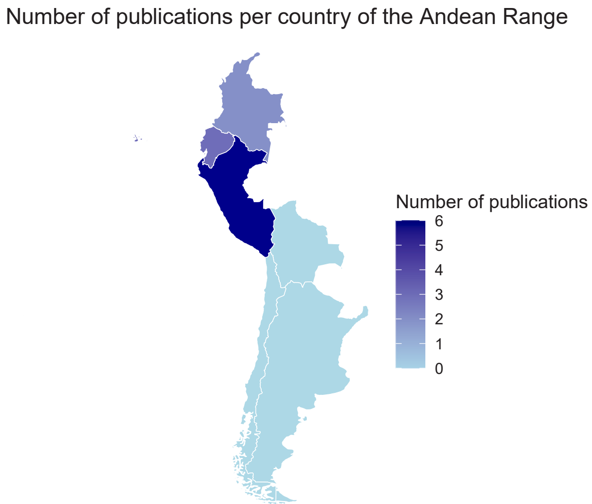

Fig. 4. Number of publications selected for water quality PRISMA-ScR research by countries conformed Andean range.

with a continuous number of studies, where 2022 has a maximum of 4 studies published, in addition to the fact that this year (2023), there is already a publication until May of the same year in which the search for articles in the different digital repositories was carried out.

3.1. Authors concessions

Physicochemical parameters play a pivotal role in water testing for diverse purposes with their selection contingent upon the intended use of the water, emphasizing the need for quality and purity. Water encompasses various impurities, including floating, dissolved, suspended, and microbiological contaminants. In their study, Rey et al. (2022) [66] delve into contaminants originating from agriculture and their subsequent impact on water for subsequent uses. The parameters under investigation include nutrients, organic matter, sediments and pathogens. Notably, toxic compounds derived from pesticides and fertilizers are not considered. This omission stems from the assumption that the majority of water quality indices do not incorporate these particular contaminants within their parameters. The study aims to assess the influence of agriculture on water quality.

Conversely, other scrutinized studies focus on analyzing water quality concerning human urbanization in various sectors where rivers are subject to the influence of anthropogenic activities in general, which doesn't define an activity in specific, while Rey et al. (2022) [66] only focuses in the agriculture activity as a root of water pollution.

According to Schuch et al. [73], more than traditional techniques based on physical, chemical, and bacteriological characteristics are required to efficiently evaluate freshwater bodies due to the versatility of the uses they may have. Therefore, integrated quality analyses that consider the biological aspects of the system may be methodologies of greater assertiveness compared to traditional ones. Therefore, of the eleven articles subject to analysis, most use biological techniques to determine water quality alone (6) or

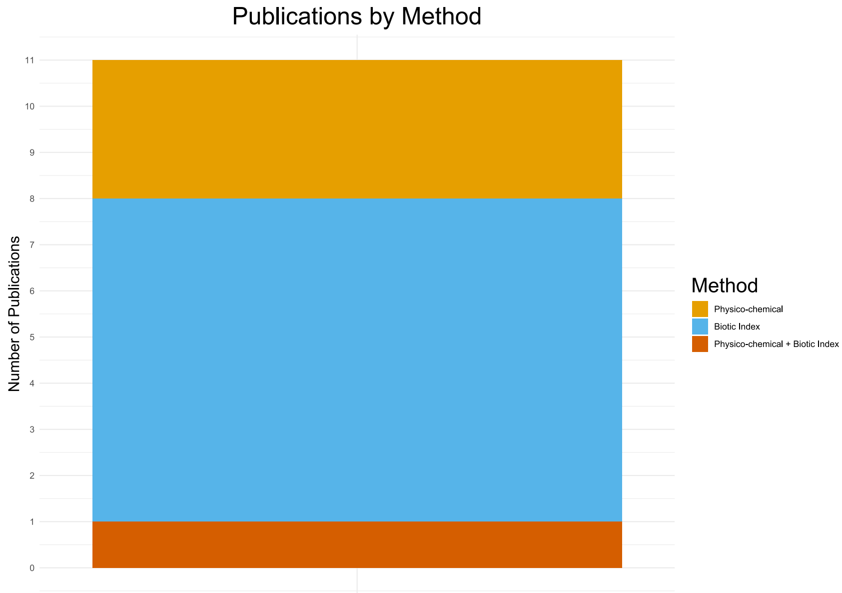

Fig. 5. Number of publications selected for water quality PRISMA-ScR research by the methodology employed.

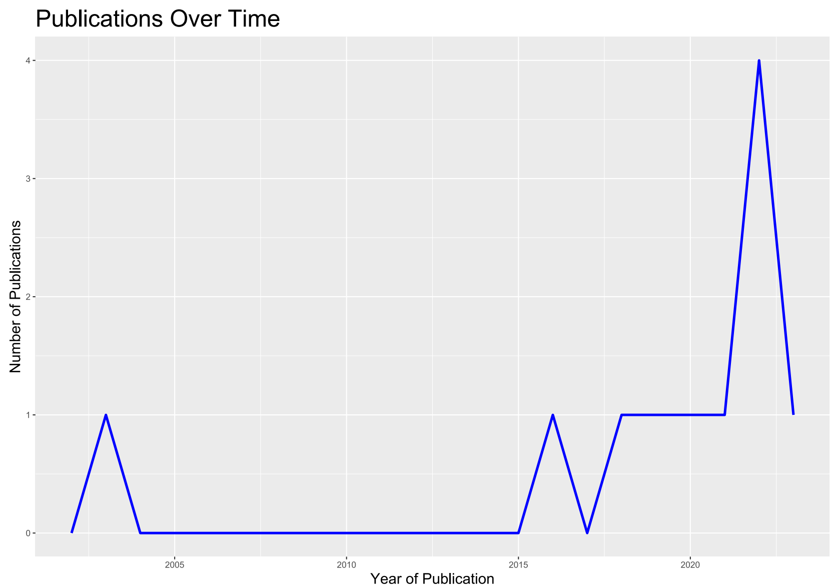

Fig. 6. Number of publications selected for water quality PRISMA-ScR research by years of publications.

accompanied by physicochemical indices (1) to validate results and correlate the variables obtained.

What can be seen in the study of Castillejo, P. et al. [62] using diatoms and their changes in species composition along a river, concluding that despite the existence of studies on diatoms, there is still a gap in information to accurately determine an accurate result of water quality, proposing to develop a trophic index of diatoms in the Andean region of Ecuador. Meanwhile, Damanik-Ambarita, M. et al. [63], despite recognizing the application of biotic indices and their adaptations such as the BMWP-Col, suggest the study of more variables in these indices to analyze more precisely the areas that are affected by various activities such as agriculture, as in the case of their study.

However, in this context, some indexes based on bioindicators proposed by different developed countries but adapted to different South American countries, an evident lack can be reflected among them, as pointed out in the study by Carrasco-Badajoz, C. [67], where there are differences between the BMWP-Col, ABI, and EPT indices, where he finds errors between them in their water quality results, which in the same way is mentioned by Meneses-Campo, Y et al. [70], where he concludes that despite using the adapted indices such as BMWP-Col and ABI, he finds the latter more sensitive for the analysis of water quality of two Colombian rivers, reflecting more accurate results. On the other hand, Pimentel, HF et al. [72] attribute better water quality assessment characteristics using the ABI index than the EPT index.

However, despite the adaptations and the fact that some indexes are better suited than others, Choque-Quispe, D. et al. [74] proposes their water quality index using already established parameters, giving them individual weights and performing multivariate analysis, having actual values adjusted to their study area in high mountain rivers of Peru.

Therefore, despite having multiple methods to determine water quality in rivers, the methodologies suffer adaptations that still do not establish in which countries one works better than another because the area is unique as the high Andean rivers, so their results do not tend to be accurate, therefore for different study areas, so the same method does not represent the most efficient; Likewise, the proposal of new methodologies such as diatoms can be helpful, but the lack of information and scientific literature on diatoms and other species to be used as bioindicators represents a significant gap in these water quality evaluation studies.

3.2. The potential of the study in supporting SDG

The Sustainable Development Goals (SDGs) are a call to action, emphasizing the need for joint efforts among nations [75], these goals are characterized as integrated and indivisible, where a greater understanding of the relationship can influence the goals and improve cross-sectoral coordination [76]. In this context, the sixth goal [75], Clean Water and Sanitation, aims to balance the water cycle for sustainable life on Earth [77], achieving this goal by focusing on two key factors: water quantity and water quality, both essential for water security and development [78,79].

The results obtained from PRISMA-ScR of water quality in Andean highland rivers provide substantial information on monitoring data within ecosystems as major water source providers for the countries comprising the Andes Mountains; these data serve as a primary resource to identify areas requiring water assessments, sanitation improvements, and in need of water resource conservation and protection initiatives in the future; this approach aligns with SDG 6. The goal is to achieve equitable access to resources with equal opportunities for all with adequate sanitation, less pollution, avoiding harmful discharges and minimizing chemical emissions, integrating source water protection and ecosystem restoration. For example, the study conducted by Hasan et al. (2023) [80], mentions that there are emerging trends in sustainable water management for agriculture, including water-efficient technologies such as alternating wetting and drying, crop irrigation, mulching, etc., whose application can prevent environmental concerns, avoid water pollution, minimize yield reduction and ensure long-term sustainability [80].

For its part, SDG 15, dedicated to life on land, aims to protect, restore and promote the sustainable use of terrestrial ecosystems, combat desertification and reverse land degradation, and halt biodiversity loss. Agricultural expansion is a direct driver of deforestation, and highlights the need to conserve, restore and properly use terrestrial ecosystems, including forests, wetlands, mountains and drylands (SDG 15, target 15.1) in conjunction with the sources that can be found in these places, such as freshwater that can affect different ecological services for humans and the biodiversity found in their surroundings.

In this context, our study provides insight into the critical importance of water sources, ensuring their quality through the protection of ecosystems and, consequently, the unique biodiversity residing in the areas. The study can provide the intention for planning in the management of ecological services, which can contribute to the prevention of land conversion, such as agriculture near water resources, given the effects this produces, mentioned in the study by Rey et al. (2022) [66]. Urbanization is a clear pollutant, that poses risks to biodiversity, territorial integration and water quality. Therefore, this paper analyzes studies that address the problems generated by anthropic activities and suggests integrated management that involves the populations, making them aware of the problem, and governmental entities to have regulations on the subject.

The analysis reveals the need to intensify research in this area, not only to achieve the SDG 6 in terms of access to clean water and sanitation but also to address SDG 15 in the preservation of terrestrial ecosystems. The connection between both SDGs underscores the importance of adopting integrated approaches that consider human needs and the conservation of ecosystems to achieve sustainable development in the high Andean rivers.

3.3. Limitations

The bibliometric analysis performed within the PRISMA-ScR is based on five of six databases analyzed, since in the first search with the keywords according to the research topic, one of them did not reflect results; in addition, biases are observed within the data extraction, since the filters between one repository and another vary in the exclusion criteria, some being more specific and of wide selection or filters of greater depth for the more strenuous and forceful selection of the articles for the final selection.

On the other hand, the ambiguity of the topic of water quality may include more perspectives than those on which the present study is based, given that topics such as ecological quality were found, which is a part in which water quality intervenes, but not in its totality, in the same way, the Andes mountain range has many climatic floors, and some studies were not focused on the analysis of high mountains as was the main objective of this document, having studies that do not adapt to the area of study. Further investigation of the articles will provide additional information, such as methodologies and study techniques within each water quality determination method.

4. Conclusions

Water is one of the most important resources for the world since it allows the development of life and different socioeconomic activities that are fundamental for the development of populations, especially in those located in the mountains, where water is a nearby and abundant resource. The objective of this review is to know the scientific literature on water quality studies of high Andean rivers in recent years, using PRISMA-ScR, which was designed to obtain water quality studies in high Andean rivers, which can also be extrapolated to water quality situations of different water sources or ecosystems.

Therefore, after the application of the scope systematization methodology, 446 articles were identified using only Boolean operators in 6 high impact databases, of those obtained by simple search, eleven scientific publications were selected in the last 21 years using inclusion and exclusion criteria with the help of the different filters of the platforms, based on the research question, in addition, tables were used to focus the study topic with precise and concise information.

The aforementioned articles were subjected to a bibliometric analysis, where the repositories of origin, countries of study, methods to determine water quality and years of publication were analyzed, highlighting in the latter the low number of articles obtained in two decades in five of the six digital repositories, in addition to the non-existence of publications in some countries that make up the Andean mountain range, Peru, Colombia and Ecuador are the places where there are the most significant number of water quality records, with 6, 2 and 3 respectively, in addition to the methods for the analysis of water quality, the methodology of biotic indexes is found in greater abundance (7), followed by physicochemical parameters (3) and the union of the two mentioned (1); On the other hand, it is remarkable the lack of consensus within the same study and within studies of the same country, due to the absence of methodologies easily adaptable to the different study zones within the Andean mountain range, being used different WQI in different countries, such as ABI that has different versions according to the study locality and different WQI models that are available according to the analysis with the parameters that are available.

However, high-altitude rivers are particularly relevant, because the water resources of these areas represent the main source of water for populations, ensuring that they are available in quality and quantity; Therefore, a detailed evaluation of the existing literature reveals the critical importance of these resources, which is why it is linked to the sixth and fifteenth Sustainable Development Goals (SDGs), which reveal the importance of preserving water quality in these ecosystems, to satisfy human needs such as drinkable water, but safeguard the biodiversity and health of these sectors. Achieving it through investment, conservation and quality training focused on water and sanitation, through innovation and action testing, with a holistic and comprehensive approach to water management. The methodology proposed is novel, since there are no previous studies that appear to have been carried out, and allows for the replicability of the study using changes in the environment, variables, river environments and altitudes according to the extent of the research and the objectives of each researcher.

Finally, this study opens the possibility for the develop of complete and detailed water quality studies in high Andean rivers, because it explores various approaches, study areas and methodologies considering different types of parameters (physicochemical, biotic or mathematical models) and potentially developing new models or improving existing WQI models specifically designed for these ecosystems, allowing an analysis of the Water Quality Index (WQI) in high-altitude rivers in the Andes. By recognizing that some existing models may not align perfectly, which could generate values that do not accurately reflect the reality of these ecosystems, this study contributes knowledge to these shortcomings and discrepancies that could affect the effectiveness of the protocols and strengthen the regulations established by the governments of different countries, which underlines the need for personalized attention to guarantee the accurate representation of water quality in high Andean rivers.

Ethic declaration

The authors declare that they present an original investigation being the first Scoping PRISMA review in this domain, based on other authors' studies that are appropriately cited or quoted. All the authors have participated in multiple activities to complete the present document.

Data availability

Yes, data is available in the repository https://github.com/CarlosMatovelle1200/WaterQualityScoping.

CRediT authorship contribution statement

Carlos Matovelle: Validation, Supervision, Project administration. **María Quinteros:** Visualization, Supervision, Project administration, Investigation. **Karen Sofía Quinteros:** Writing – review & editing, Writing – original draft, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Karla Jaramillo:** Software, Resources, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research is funded by the Research Department, of Catholic of Cuenca University associated by the RIVSEC Project with ID number PICSN22 in SURNORTE call.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e30552.

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