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DESIGN OF A MONITORING PROGRAM WITH THE APPLICATION OF BOLIVIAN STANDARD NB/ISO 5667-4: A CASE STUDY OF MILLUNI, BOLIVIA

Alvizuri Tintaya, Paola Andrea [(1)]; Villena Martínez, Esteban Manuel [(1)]; Torregrosa López, Juan Ignacio [(1)]; Lo Iacono Ferreira, Vanesa Gladys [(1)]; Lora García, Jaime [(1)]
[(1)] Universitat Politècnica de València.

Bolivia is located at position 20 among the countries with the highest water availability in the world. However, its surface and underground water potential have not been completely determined. Nor have thorough studies of water quality in the sources of supply been conducted, which creates uncertainty about the type of water that is accessed. It is, therefore, essential to monitor the freshwater sources that supply large cities in the country. The surface waters of Milluni are the main contribution to the department of La Paz. These waters are very close to abandoned and illegal mining areas in operation, which makes them highly vulnerable to imminent heavy metal contamination. This study proposes a monitoring program for the upper part of the Milluni micro-basin considering its particular characteristics. The proposal takes into account both Bolivian Regulations NB / ISO 5667-4 and international standards.

Keywords: monitoring; surface water; mining; heavy metals

DISEÑO DE UN PROGRAMA DE MONITOREO CON LA APLICACIÓN DE LA NORMA BOLIVIANA NB/ISO 5667-4 - CASO MILLUNI, BOLIVIA

Bolivia está situada en la posición 20 entre los países con mayor disponibilidad de agua en el mundo. Sin embargo, su potencial hídrico tanto superficial como subterráneo no ha sido completamente determinado. Tampoco se han realizado estudios minuciosos de calidad del agua en las fuentes de abastecimiento, lo cual genera una incertidumbre sobre el tipo de agua al que se tiene acceso. Es, por tanto, imprescindible realizar monitoreos a las fuentes de agua dulce que abastecen grandes ciudades del país.
Las aguas superficiales de Milluni son la principal contribución para el departamento de La Paz. Estas aguas se encuentran muy cerca de áreas mineras abandonadas e ilegales en funcionamiento, lo cual las vuelve altamente vulnerables a una contaminación inminente por metales pesados. Este trabajo propone un programa de monitoreo para la parte alta de la microcuenca de Milluni, considerando sus particulares características. La propuesta toma en cuenta tanto la Normativa Boliviana NB/ISO 5667-4 como normas internacionales.

Palabras clave: monitoreo; agua superficial; minería; metales pesados

Correspondencia: Paola Alvizuri Tintaya paoaltin@upvnet.upv.es

1. Introduction

Water quality is an issue that concerns governments, private sectors, universities, and communities worldwide. Considerable amounts of time, effort, and money have been spent to control, protect, manage, and restore surface water resources recognizing the importance of water for the quality of the environment, economic development, and social welfare of a country (Rivas & Maldonado, 2011).

According to the Scientific and Technological Consultative Forum (2012), in Latin America, Bolivia has the largest supply of freshwater per capita. However, its surface and underground water potential have not been completely determined. In addition, thorough studies on water quality sources have not been conducted, which creates uncertainty about the type of water that is accessed.

The best system to guarantee the safety of drinking water is integrated and preventive management in which all relevant agencies collaborate (WHO, 2006). Among the most important points within this management system is the methodology that allows measurements and systematic observations to be made of water quality, which is referred to as a monitoring program. These programs aim to define a standardized procedure, minimize errors, and ensure the generation of consistent data and information on water bodies (Autoridad Nacional del Agua, 2011).

The upper part of the Milluni micro-basin was taken as the study area because its surface waters provide the largest amount of water to two cities with a high population density in Bolivia. The lagoons of Milluni are very close to illegal, functioning, and abandoned mines, which compromises their water quality. This study proposes a monitoring program that considers the particularities of the Milluni area and also takes into account both Bolivian regulations (NB/ISO 5667-4) and international standards for its design.

1.1. Milluni micro-basin

The Milluni Valley is located approximately 4600 m.a.s.l. in the Bolivian tin belt, which consists of large sulfide deposits in the eastern Andes. This 40 km^2 area is part of the basin system of the Altiplano Plateau, which presents extreme climatic conditions that are typical of the area (Ahlfeld, Schneider-Scherbina & Bolivia, 1964).

The strongest mining exploitation in Milluni occurred between 1940 and 1990. Although widespread mining activities stopped approximately 20 years ago, the impact of mining waste on water quality remains a serious national environmental problem. Another problem that affects water quality in this area is the small-scale and often illegal mining activities for which no accurate information is available (Salvarredy-Aranguren et al., 2008).

1.1.1. Surface water bodies in Milluni

There are four lagoons in the upper Milluni basin, namely the Pata Khota lagoon, Jankho Khota lagoon, Milluni Chico lagoon, and Milluni Grande lagoon (Iltis, 1988). Figure 1 shows the location of the lagoons.

Figure 1: Water bodies in the Milluni area

Source: Google Earth, 2019.

- The first two are natural lagoons that receive waters from the snowmelt of Huayna Potosí Mountain. Here, water pollution is very low or completely absent.
- The third lagoon, namely Milluni Chico, is an artificial lagoon with an irregular shape. It captures mine drainage waters to prevent them from entering and contaminating the fourth lagoon, which does not work very well.
- The fourth lagoon, namely Milluni Grande, is the reservoir of all the waters in the area, and it contains a dam. It has a capacity of 10 000 000 m^3 and an area of 2 450 000 m^2 (Raffailac, 2002).

The water stored in the Milluni Grande dam is used to meet the demand for drinking water in the cities of La Paz and El Alto. Milluni waters undergo pretreatment and are distributed to two treatment plants of the Public Social Company of Water and Sanitation before entering the distribution network. Despite this, there is a high susceptibility to the presence of heavy metals in these waters. Figure 2 shows the connection between Milluni Chico and Milluni Grande where the storage dam is located.

Figure 2: Connection between Milluni Chico and Milluni Grande where the storage dam is located

Source: Alvizuri, 2019.

1.1.2. Monitoring experiences in Milluni

The Management Unit of the Katari Basin, which belongs to the Ministry of Environment and Water of Bolivia, is the body in charge of monitoring the Katari basin from 2006 to the present. This macro-basin, which is defined as strategic by the National Watershed Plan, houses the Milluni area.

It should be noted that a specific monitoring program for the upper part of Milluni has not been designed. The monitoring program for the Katari macro-basin was developed with many limitations in terms of human, economic, and time resources. An analysis of the historical data belonging to the Milluni area determined some inconsistencies in the development of the program. The most important are a non-uniform monitoring frequency, variation in the location of the monitoring points, and variation in the parameters to be analyzed (Alvizuri, 2019).

The upper part of the Milluni micro-basin is relevant because it includes a water storage dam for the public water supply, which has a high probability of heavy metal contamination. This area should have a monitoring program designed to consider its particularities in order to reduce the risk to public health.

2. Goal

The aim of this study is to design a monitoring program that considers the particularities of the upper part of the Milluni micro-basin, seeking that it can be incorporated into the integrated water resources management system of the macro-basin to which it belongs.

3. Methodology

To address the goal of this study, a depth analysis of the protocols and regulations of international organizations such as the United Nations Environment Program and the World Health Organization (UNEP / WHO) and the International Organization Standardization (ISO) was carried out. Detected the differences and similarities of both international standards, the fundamental and necessary components were defined in terms of monitoring programs for the quality of surface water. These fundamental components were the basis for the design of the monitoring program for the study area. In addition, the particularities of the area were

considered and the specifications of the water resources management system in the Katari macro basin were taken into account, so that the proposed program can be aligned and be part of it. Both the analysis of the standards and the proposed monitoring program for the Milluni area are described in the results section.

4. Results

On a first stage, a review of the regulations and protocols for the design of surface water monitoring programs is carried out. Once the key components that should be part of the design of a monitoring program are clearly mentioned, a proposal is build according to the special characteristics of the case study described in the introduction.

4.1 Analysis of international standards

There can be as many types of monitoring programs as there are objectives, water bodies, pollutants, and water uses (Chapma & WHO, 1996). A functional monitoring program generates valid information for the exact identification of the contaminant, which makes it possible to choose the type of treatment required for its elimination (Alvizuri, 2019).

An analysis and comparison between the “Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programs” protocol and the “ISO 5667-1: 2006 Water quality - Sampling - Part 1: Guidance on the design of sampling programs and sampling techniques” were conducted in order to identify the components that a monitoring program should have.

Monitoring is defined by the ISO as “the programmed process of sampling, measurement and subsequent recording or signaling, or both, of various water characteristics, often with the aim of assessing conformity to specified objectives.” According to the UNEP/WHO, the type of monitoring program to be implemented must be defined, and this is linked to its purpose or objective. The main components for the design of a water quality monitoring program are stipulated in the international standards, which are set out in Table 1.

Table 1: Components for the design of a water quality monitoring program

Component order	UNEP/WHO, 1996	Component order	ISO, 2006
1	Clearly define the objectives and purpose of the program	1	Define the purpose of the monitoring program taking into account previous experiences in the area
2	Define the expectations and intended uses of the information generated by the program	2	Define the objectives of the program
3	Preliminary survey	3	Determination of sampling points
4	Delimitation of the area covered by the monitoring program	4	Define the frequency and duration of sampling
5	Determination of sampling sites and sampling stations	5	Define the analytical requirements for the variables to be studied

6	Define the water quality variables to be measured	6	Define what sampling protocols will be used (sampling, transport, and storage to avoid contamination of the samples)
7	Define the proposed frequency and timing of sampling	7	Determine the resources needed for program implementation
8	Estimation of resources for program implementation	8	-
9	Establish a plan for the control and monitoring of program quality	9	-

Source: Own elaboration, 2020.

The revised international standards are from different decades, but they expose many similarities with respect to the components that a water quality monitoring program must contain. Both documents emphasize that the objectives and purpose of the program are the initial and most important parts that define the other components.

Both standards present a strategy to optimize the design of the program. On one hand, ISO 5667-1: 2006 indicates that it is important to take into account previous experiences in the area to obtain feedback that can contribute to the program that is being designed. On the other hand, the monitoring program design guide proposes the implementation of a 1 y pilot at the beginning of the program that supports the optimization of the program to be implemented.

Some of the most significant similar components between both international standards include the delimitation of the area to be studied, determination of the sampling points, the definition of the frequency and duration of the sampling, determination of the variables to be measured, and estimation and determination of the resources (time and money) that must be allocated to the program to be successful in its implementation.

Regarding these differences, it was observed that the document “Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programs” has a final component for the constant optimization of the program, which ISO 5667-1: 2006 does not consider.

The established components, guidelines, and recommendations proposed by the international standards will be taken into account for the design of the water quality monitoring program for Milluni.

4.2 Monitoring program for the upper part of the Milluni micro basin

In many countries, water quality monitoring programs are found in protocols, guides, and/or regulations. In the specific case of surface water bodies, such as lakes and lagoons, there are rarely specific sections. Bolivia adopts ISO 5667-4: 2016. This study proposes its application to determine basic and specific foundations for the design of a monitoring program of natural and artificial lagoons for the upper part of the Milluni micro-basin.

Table 2: Components for the water quality monitoring program: Milluni case study

No.	Component	Summary of the result by component
1	Define the objectives and purpose of the program	Initially, the study area will be characterized with the objective of determining the water quality of the Milluni area. After 1 year, the program will become a water quality control program in the upper part of the Milluni micro-basin with the objective of joining the water management of the area and generating data.
2	Preliminary survey	This part will have a duration of 1 y, where considering previous experiences of monitoring in the area, guidelines will be obtained to optimize the monitoring program for the other years if required.
3	Delimitation of the area covered by the monitoring program	The area covered by the monitoring program is important because the water after the Milluni Grande dam is used for human consumption. The upper part of Milluni includes the following four lagoons: ● Pata Khota: A natural lagoon with an irregular shape that receives water from the snowmelt from Huayna Potosí. It is located 4665 m.a.s.l. ● Jankho Khota: A natural lagoon with an irregular shape that receives water from the Pata Khota lagoon. It is located 4560 m.a.s.l. ● Milluni Chico: An artificial lagoon at an altitude of 4550 m.a.s.l. with an irregular shape that receives water from natural springs and mines. The artificial lagoon aims to capture drainage from the mines to prevent it from entering the Milluni Grande lagoon ● Milluni Grande: Located at 4530 m.a.s.l., the Milluni Grande lagoon receives effluent from natural springs, the Milluni Chico lagoon, and drainage from mines. It also receives water from the Jankho Khota lagoon through a bypass system, which consists of a pump that draws water from the Jankho Khota lagoon, through an open cement channel, and to the Milluni Grande dam.
4	Determination of sampling points	The sampling points were identified according to the “Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programs” protocol. The four points are as follows: ● Point 1: This point aims to identify the reference conditions in the watercourse system. It is located at the head of the Pata Khota lagoon.

No.	Component	Summary of the result by component
		● Point 2: This point is located after the effluent of the Milluni Chico lagoon, and aims to identify any signs of deterioration in water quality. ● Point 3: This point seeks to identify if the water body in the watercourse system meets the desired water quality standards. It is located in the storage dam at the exit of the Milluni Grande lagoon. ● Point 4: This point is located after the pretreatment where lime is applied to the water, and it has the objective of evaluating the effectiveness of water quality management intervention.
5	Define the frequency and duration of sampling	To identify the monitoring frequency for the pilot year, an analysis of previous monitoring in the area was used (Alvizuri, 2019), as recommended by ISO 5667-1. It was possible to identify that being an area with important seasonal variations, it is necessary to contemplate two important seasons of the year, namely the rainy season and dry season. Sampling will be conducted three times in the dry season and three times in the rainy season with intervals of 1 mo between samples with the aim of identifying if there is variation in the pollutants during the months of these seasons. After finishing the characterization or pilot year, the frequency must be defined according to the objectives of the water quality control program while taking into account time and money limitations of the entity that is in charge of general monitoring of the area.
6	Define the water quality variables to be measured	The following basic parameters of water quality will be determined in situ by international standards: ● pH ● DO ● Conductivity ● Turbidity ● Temperature Considering that the predominant activity in the area is mining, metal ion control will be conducted and metal ions will be analyzed in certified service laboratories.
7	Define sampling protocols, including sampling, transport, and storage, to avoid contamination of the samples	The protocols established in “ISO 5667-4: 2016 Water quality - Sampling - Part 4: Guidance on sampling from lakes, natural and man-made” will be followed.

No.	Component	Summary of the result by component
8	Determine the resources needed for program implementation	This is a very important component. It should be considered that both economic resources and trained personnel are limited because the Milluni area belongs to the management system of the Katari macro-basin, which has limited resources.
9	Establish a plan for the control and monitoring of program quality	Initially, the plan focuses on evaluating the results of the pilot, namely the first year of the program, in order to redefine the following important components: ● Sampling points ● Sampling rate ● Variables

Source: Own elaboration, 2020.

Bolivia Standard ISO 5667-4: 2016 has many similar components and references to ISO 5667-1: 2006. For this reason, its application is linked to the application of ISO 5667-1: 2006. Most of the components of these regulations are the same, with the exception that ISO 5667-4: 2016 proposes specific recommendations for the monitoring protocol for natural and artificial lakes, which was adopted entirely within the previously proposed monitoring program. Figure 3 shows the monitoring points located in Milluni.

Figure 3: Monitoring points in the Milluni area

Source: Alvizuri, 2019.

5. Discussion and conclusion

The upper part of the Milluni micro-basin is an important area because its surface water bodies supply water for two important cities in Bolivia. Although Milluni waters pass through treatment plants, there are no specific treatments for heavy metals. This issue is not minor because Milluni's waters have been affected by mining. The Milluni sector must be rigorously monitored to control its water quality and prevent risks to public health.

Analyzing international standards, it was determined that the objective and purpose of a monitoring program is fundamental for the other components to be determined. The monitoring program for the Milluni area will characterize the upper part of this micro-basin. It will then be redefined to fit the water quality management of the Katari micro-basin.

The other components were defined as indicated in the revised standards, and the Bolivian standard ISO 5667-4: 2016 was mostly applied. The area for the program will comprise the four surface water bodies of Milluni and a pretreatment area located after the lagoons. The four sampling points meet the objectives specified in the “Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programs.” Point 1 aims to identify the reference conditions in the watercourse system. Point 2 aims to identify any signs of deterioration in water quality. Point 3 seeks to identify if the water body in the watercourse system meets the desired water quality standards. Point 4 has the objective of evaluating the effectiveness of water quality management intervention.

The frequency of monitoring was defined by analyzing previous experiences in the area and their results. Sampling in the pilot year will be conducted three times in the rainy season and three times in the dry season, with intervals of 1 mo between samples. The objective is to observe the change in pollutant concentrations and analyze whether the number of samples should be modified later. The frequency of sampling is limited by economic resources and people qualified to perform the sampling. For this reason, only two marked times of the year are prioritized in order to observe the behavior of pollutants when phenomena of maximum concentration and dilution of pollutants occur, which correspond to periods of drought and rainfall in the area.

The variables for sampling were defined. Basic parameters of water quality, namely pH, DO conductivity, temperature, and turbidity, will be measured in situ. Heavy metals will be analyzed in the laboratory because these are the most likely contaminants in the area for which there are no specific treatments in the treatment plants. The type of sampling to be applied will follow the protocols established in “ISO 5667-4: 2016 Water quality - Sampling - Part 4: Guidance on sampling from lakes, natural and man-made.”

In defining the resources necessary for the implementation of the monitoring program in its initial stage, everything must be adjusted according to the Integrated Water Resources Management of the Katari macro-basin. This is an important limitation in terms of more frequent intervention in the area. In this sense, the key to the proper implementation of the program is to determine a representative sampling frequency of the area as well as to discriminate the variables to be measured to avoid extra analytical costs.

All monitoring programs must be evaluated for proper operation and optimization. Thus, after the first year of characterization of the area, an evaluation of the program is proposed to redefine certain components such as the sampling points, sampling frequency, and variables in order for the program to function optimally and to align with the water management of the area.

Further research on the design of water quality monitoring programs should be conducted taking into account the limitations within the management systems of the areas that comprise them with the objective of proposing workable programs that can be conducted and simultaneously generate information that responds to the objective set for the program.

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