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DEVELOPMENT OF A LOW-COST KIT FOR THE ANALYSIS OF IRRIGATION WATER QUALITY IN RURAL BOLIVIAN COMMUNITIES

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In the community of La Maica, the last agricultural area in the municipality of Cochabamba, Bolivia, it has been shown that the irrigation water used is not of adequate quality. This situation can have a direct effect on crops and on the quality of agricultural soil, affect surface and groundwater bodies, and affect the health of farmers and consumers. Thus, the deficiency of crop productivity has generated in recent years an increase in the vulnerability of the population in the area. Therefore, in order to better manage irrigation water, the objective of the project was to develop with the community an affordable kit to perform analysis of the main physicochemical characteristics of wáter with natural pigments and locally available materials. After pigment selection, the designed tests were subjected to an analytical validation and a calibration phase of the kit by farmers. The accuracy, sensitivity, relative specificity, reproducibility and repeatability of the kit were determined. Thus, the kit designed allows the analysis of five chemical parameters of water with natural pigments and one biological parameter.

Keywords: test kit; water quality; irrigation; natural pigments

DESARROLLO DE UN KIT DE BAJO COSTO PARA EL ANÁLISIS DE CALIDAD DE AGUA DE RIEGO EN COMUNIDADES RURALES BOLIVIANAS

En la comunidad de La Maica, última zona agrícola del municipio de Cochabamba, Bolivia, se ha evidenciado que el agua de riego utilizada no presenta una calidad adecuada. Esta situación puede generar un efecto directo en los cultivos y en la calidad del suelo agrícola, afectar a los cuerpos de agua superficiales y subterráneos, e incidir en la salud del agricultor y consumidor. Así la deficiencia de productividad de los cultivos ha generado en los últimos años un aumento de la vulnerabilidad de la población de la zona. Por lo tanto, para poder gestionar de mejor forma el agua de riego, el objetivo del proyecto fue de desarrollar con la comunidad un kit accesible económicamente para realizar análisis de las características fisicoquímicas principales del agua a partir de pigmentos naturales y materiales disponibles localmente. Después de la selección de los pigmentos, las pruebas diseñadas fueron sometidas a una validación analítica y a una fase de calibración del kit por agricultores. Se determinaron la exactitud, la sensibilidad, la especificidad relativa, la reproducibilidad y la repetibilidad del kit. De esta manera el kit diseñado permite analizar cinco parámetros químicos del agua con pigmentos naturales, y un parámetro biológico.

Palabras clave: kit de análisis; calidad de agua; riego; pigmentos naturales

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1. Introduction

The quality of irrigation water is of great importance. This is due to its potential to influence crop quality and production, in addition to human health and ecosystems (Graczyk, Z, Graczyk, T., and Naprawska, 2011). Indeed, the success and sustainability of agriculture depend largely on the quality of water used for irrigation (Arshad and Shakoor, 2017). Therein lies the importance of analyzing its quality. However, due to anthropogenic activities, water quality can be negatively impacted by pollution from organic matter, excess nutrients, suspended solids, metallic elements, pesticides, and industrial chemicals (Haydar, Arshad, and Aziz, 2009).

In this context, irrigation water quality analysis can be performed by mobile laboratories, better known as kits, or by conventional laboratories, where the analysis methodology is chosen by the agency responsible for monitoring (Bartram and Ballance, 1996). In Bolivia, most irrigation water quality studies are conducted by universities and Non-Governmental Organizations (NGOs), such as CENDA (2018). An example was the Rocha River water quality analysis conducted in May 2018 in the Ucuchi and Chiñata districts in the municipality of Sacaba by CENDA (2018) using commercial kits. It is worth mentioning that the kits present effectiveness and feasibility due to their rapid measurement for this type of water resource.

The use of water sources contaminated with wastewater for agricultural purposes is a common practice in Bolivia due to the high-water demand and the precipitation deficit in the months of March to November. Through the study of Cisneros, Pacheco, and Feyen (2007), it is known that 5,000 hectares of crop cultures are irrigated with this type of water. 86% of this superficy are located in the departments of La Paz and Cochabamba. Despite the importance of determining the quality of water from such sources, there are no irrigation water classification regulations in Bolivia. Therefore, there is little inspection of irrigation water quality by the Autonomous Municipal Governments. However, universities such as the Universidad Católica Boliviana and the Universidad Mayor de "San Simón" conducted studies to determine the impact of the use of this type of water on agricultural activities (Catacora, 2019; Ampuero, 2001; Medrano, 2001).

An example of these studies is the one conducted by Catacora (2019), in which a sample of water from the Rocha River (which is one of the sources of irrigation water used) was used to determine the impacts of irrigation on the soil in the Maica Central Area, Cochabamba. The result shows that the water source is not suitable for irrigation due to its high values of Electrical Conductivity (EC), Sodium Adsorption Ratio (SAR), Potential Salinity (SP), Effective Salinity (SE) and bicarbonates which induce soil salinity. Moreover, the presence of toxic levels of chlorides (193 mg/L) and boron (0.71 mg/L) for crops, in addition to a high presence of parasites were highlighted. It should be added that Ampuero (2001) determined that these soils already have a high salt content, which affects agricultural production. High salinity in an irrigation water source not only reduces plant growth, but also reduces plant evapotranspiration, thus presenting a greater impact (Oster, 1994).

Irrigation water quality monitoring is not followed-up in Bolivia within the water management due to the lack of interest from farmers and the difficult accessibility to reliable water analysis mechanisms and tools (Catacora, 2019). The options for purchasing an irrigation water test kit present certain complications in Bolivia, such as the importation of the kit. In addition, the cost varies depending on the number of parameters that the kit analyzes, for example, according to the official website of the Hach brand, the Soil and Irrigation Water Test Kit, Model SIW-1 has a cost of 40 USD. Another example is the kit catalog of the Infoagro website, which mentions that the HANNA INSTRUMENTS-Water Quality-Combined Test Kit HI 3817, costs 328 euros, this kit performs the analysis of six parameters and each parameter has 100 tests. Therefore, these options are not accessible to the low-income communities of Bolivia.

2. Goal

Develop a low-cost kit for irrigation water quality analysis for the community of La Maica.

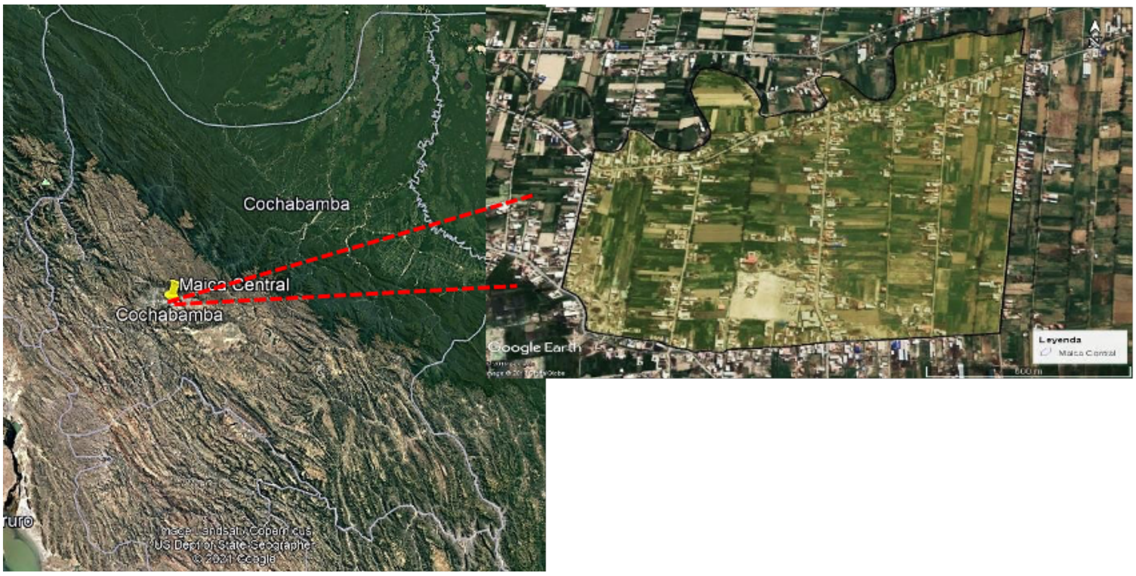
3. Material and Methods

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

3.1. Study area.

La Maica Central covers an area of 140 ha (Figure 1). It is located in the Itocta canton, in the Cercado province of the Department of Cochabamba, 6.5 km south of the city center. This area is also classified as district nine of the municipality of Cochabamba.

Figure 1. Maica Central area, Cochabamba



Source: own elaboration, 2023.

The climate of the study area is semiarid, with annual temperatures between 17º and 18º C. Due to rainfall patterns, there is a humidity deficit during eight to nine months of the year, which mainly affects agricultural production (Ampuero, 2001). The geology of the area consists mainly of Quaternary sediments. Likewise, the texture in the area is silty and clayey. The pH is high in the area (Moscosso and Coronado, 2002).

According to Ampuero (2001), the structure of La Maica's soils is affected by the high salt content. For this reason, it is common to find crusted and compacted soils, which reduce their usability for irrigation purposes. In addition, due to the soil textures present in the La Maica area, the soils are imperfectly drained internally and moderately drained externally.

Regarding crops and economics, the crops grown in the study area are alfalfa (*Medicago sativa),* corn (*Zea mays*) and common grass (*Lolium sp.*). These crops are used as feed for cattle (Garcia and Corzo, 2008). This is because the main activity in the area is milk production, which is also their main source of income. The milk production is sold almost entirely to PIL enterprise (Moscosso and Coronado, 2002).

Rodriguez Requiz (2020) mentions that the area has two irrigation sources. Nevertheless, the authorized Angostura irrigation canal does not supply enough water because the water is only sent twice a year. The second water source is the Rocha River, which is highly contaminated, and its water quality is not ranked as irrigation water.

Both milk production and fodder crops use contaminated water. The survey conducted by Rodriguez Requiz (2020) determined that the community of Maica Central presents an abnormal rate of diseases such as enteritis, cholera, typhoid fever, and acute diarrheal episodes, and that it suffered from cholera years ago. Contact with contaminated water in crops can be the cause of contracting water-related pathogenic diseases.

3.2. Methodology

In this section are presented the different experimental steps needed to validate the low-cost kit for irrigation water quality analysis.

3.2.1. Selection of natural pigments

28 natural pigments were selected according to the literature and their ease of availability (Table 1). These pigments were tested for bicarbonates, electrical conductivity, cations, and anions measurements. Two methods were used to extract the pigments. The first was boiling the material in water (Hu, Tanaka, A. and Tanaka, R., 2013) and the second one was mixing the material with commercial ethanol (70%) (Ngamwonglumlert, Devahastin, and Chiewchan, 2017).

Table 1. Options for obtaining pigments.

Options for natural pigments			
Rose laurel (anthocyanins)	Onion peel (anthocyanins)	Red bean (anthocyanins)	Horseradish peel (anthocyanins)
Lysander (anthocyanins)	Strawberry (anthocyanins)	Rose "Ingrid Bergman" (anthocyanins)	Beet greens (anthocyanins)
Purple cabbage (anthocyanins)	Purple grape skin (anthocyanins)	Hibiscus flowers (anthocyanins)	Chrysanthemum flowers (anthocyanins)
Blackberry (anthocyanins)	Purple potato (anthocyanins)	Black tea (other flavonoids)	Green tea (other flavonoids)
Coffee (other flavonoids)	Turmeric (other flavonoids)	Purple corn (anthocyanins)	Peach infusion (anthocyanins)
Red apple peel (anthocyanins)	Apple infusion (anthocyanins)	Eggplant peel (anthocyanins)	Bougainvillea fuchsia color (anthocyanins)
Bougainvillea red color (anthocyanins)	Bougainvillea sour cherry color (anthocyanins)	Bougainvillea lilac color (anthocyanins)	Salvia splendens (anthocyanins)

Source: own elaboration, 2023.

pH, electrical conductivity, bicarbonate, cation, and anion contents were tested. The concentrations prepared were in accordance with Peruvian regulations (Supreme Decree No. 002 of the Peruvian Ministry of Environment, 2008). However, Law N° 1333 of Bolivia was also considered. Different concentrations were made, one that was below the chosen standard, one at the limit of the standard and the others above it. In addition, high solutions of the substances (10, 100 and 1,000 ppm) were carried out. The purpose of this was to test whether the chosen pigments change color at high concentrations of the substances, where concentrations equal to or greater than 10 ppm of metals can be found in dry season in water sources used in the area such as the Rocha River (d'Abzac et al, 2020). The prepared solutions are presented in the table 2.

Table 2. Tested experimental conditions.

Chemical parameter	Concentrations
1. pH	2 to 12
2. Bicarbonates	100, 200*, 300, 400, 500, 1,000 (mg/L)
3. Chromium (VI)	0.1*, 0.3, 0.5, 1, 10, 100, 1,000 (mg/L)
4. Iron (II)	0.5, 1*, 3, 5, 10, 100, 1,000 (mg/L)
5. Iron (III)	0.5, 1*, 3, 5, 10, 100, 1,000 (mg/L)
6. Calcium	100, 200*, 300, 400, 1,000 (mg/L)
7. Magnesium	100, 150*, 250, 350, 1,000 (mg/L)
8. Copper	0.1, 0.2*, 0.5, 1, 10, 100, 1,000 (mg/L)
9. Boron	0.3, 0.5*, 6*, 7, 10, 100, 1,000 (mg/L)
10. Sulfates	200, 300*, 400, 500, 1,000 (mg/L)
11. Nitrates	5, 10*, 20, 30, 100, 1,000 (mg/L)
12. Sulfides	0.05*, 0.1, 0.5, 1, 100, 1,000 (mg/L)
13. Sodium	100, 200, 300, 500, 1,000 (mg/L)
14. Carbonates	3, 5*, 7, 9, 10, 100, 1,000 (mg/L)
15. Chlorides	50, 100*, 500*, 700*, 800, 1,000 (mg/L)
16. Zinc	1, 2*, 10, 100, 1,000 (mg/L)
17. Electrical conductivity	864, 1,128, 1,544, 2,000*, 2,400, 2,900 (µS/cm)

Note: *Permissible limit in accordance with Peruvian regulations.

Source: own elaboration, 2023.

Regarding the fecal coliform test, the culture medium chosen was liquid. It was verified that the test first changed color by repeating the proposed methodology five times. This was performed from an undiluted sample. Subsequently, two dilutions of the contaminated sample were performed. That is, the control, the 50% dilution, and the 1% dilution were used. Each of them was repeated four times.

Finally, for the statistical analysis carried out with the multiparametric equipment (Hanna HI98194), ten repetitions of the pH and electrical conductivity measurements made by the multiparametric equipment were carried out for the preparation of the solutions. This was done in order to determine the confidence interval, using the t-Student (Sánchez Turcios, 2015), and the average concentration. In the case of determining the probability of color change, three daily repetitions were performed for seventeen days with the pigments in which a color change was observed in each test, in such a way that the duration of the natural pigments was simultaneously determined by observation in the tests during the time mentioned. This is because, the longer the time, the color change with the substances will not be the same. In this way, it was determined at what time the pigment no longer effectively detects the concentrations of the parameters by color change.

Also, for the analysis of the matrix effect, the effect of several substances in the same solution on the pigment was observed. The reason is that it was desired to verify the influence of different factors (several groups) on the color change of the tests. In addition, the selection of the factors will be random. This time, the pigment color change with the presence of more than one cation and anion was analyzed for each chosen test. The matrix effect was analyzed by observation and repetition.

3.2.2. Validation of the pigments

For the validation step of the alternative methods, intra and interlaboratory phases were performed (Hund, Massart, and Smeyers-Verbeke, 2000). First, in the intralaboratory phase of validation, water quality analysis was performed on ten complex water samples (Table 3) with standard laboratory methods (Vogel, 1991; Baird, Eaton and Rice, 2017) (Table 4). The results were compared with the results of the analyses performed by the selected natural pigments which were repeated ten times.

Table 3. Information on the ten water samples for intralaboratory analysis.

Sample	Coordinates	Type of water source	Estimated degree of contamination
1	17°23'13.97"S 66° 7'52.47"W	River (Rocha)	Very high
2	17°23'11.82"S 66° 9'51.61"W	River (Rocha)	Very high
3	17°25'1.13"S 66°11'7.25"W	River (Rocha)	Very high
4	17°24'42.47"S 66°11'2.01"W	River (Tamborada)	Very high
5	17°24'42.47"S 66°11'55.76"W	Canal	Medium
6	17°23'48.53"S 66°11'40.05"W	Tap water	Very low
7	17°23'20.20"S	Lagoon	Medium

	66°12'21.28"W		
8	17°26'17.18"S 66° 9'43.58"W	Flood (irrigation)	Very high
9	17°22'1.20"S 66°10'5.79"O	Canal	Medium
10	17°22'14.94"S 66° 8'50.44"O	Well	Very low

Source: own elaboration, 2023.

Table 4. Description of the methods used for qualitative and quantitative analysis with the standard method.

Parameter	Method
pH	Hanna Edge – Hanna Instruments HI11310
Bicarbonates	Quantitative analysis (Baird, Eaton and Rice, 2017) Chapter 2320. Alkalinity
Electrical Conductivity	Hanna Edge – Hanna Instruments HI763100
Sulfides	Qualitative analysis (Vogel, 1991) Chapter 4.6: Reaction with silver nitrate Quantitative analysis (Baird, Eaton and Rice, 2017) Chapter 4500. Sulfide. F. Iodometric method
Sulfates	Quantitative analysis (Baird, Eaton and Rice, 2017) Chapter 4500. Sulfate. E. Turbidimetric method
Iron	Qualitative analysis (Vogel, 1991) Chapter 3.21: Reaction with Ammonium Sulfate Quantitative analysis (Baird, Eaton and Rice, 2017) Chapter 3111. Metals by Flame Atomic Absorption. Chapter 3-20. Direct Air-Acetylene Flame Method PerkinElmer AAnalyst 200
Fecal Coliforms	Quantitative analysis (Baird, Eaton and Rice, 2017) 9221.C. Standard total coliform fermentation technique

Source: own elaboration, 2023.

For the interlaboratory phase of validation, the use of the alternative method by six different people was evaluated. For the elaboration of the tests, the corresponding ingredients and materials were provided. Subsequently, two water samples were analyzed, one from the tap and the other from the Tamborada River, which was previously analyzed in the intralaboratory stage. The analysis of each sample had three repetitions. Of the six people who participated in this phase, one was a farmer from the Maica area. The second was a farmer from the area of Tiquipaya and finally, the last four were people related to agriculture in the province of Capinota.

In this validation phase, the results obtained were analyzed to determine the relative accuracy, the relative sensitivity, and the relative specificity based on Ortega González, Rodríguez Martínez, and Zhurbenko (2013).

4. Results and discussions

The results obtained and their discussion are presented below.

4.1. Home tests

The colorimetric tests were developed for anions, cations, and pH. It was experimentally determined that for each colorimetric test, sixteen drops of each concentration and three drops of the pigment would be placed in an ice recipient. If the pigment obtained was concentrated, only one drop was used. On the other hand, if the pigment obtained was neither so concentrated nor so soft, three drops were used. It was expected that the molecules related to the pigment (anthocyanins, flavonoids, or curcumin) would change their color due to chemical changes in the medium (Selvaraj et al., 2014; Bhat et al., 2016; Smellie et al., 2020)), for this reason if the number of drops of pigment was greater than the number of drops of the concentrations of the prepared solutions it was not expected to observe an appreciable change in color. Likewise, it was considered that with sixteen drops of the medium with three drops of the pigment the concentration of the medium does not change appreciably. A higher number of sample volume is not recommended because the color fades and the color change at each concentration is not clearly visible.

For the electrical conductivity, two connector cables were used, positive and negative, with "alligator clamps". A 3.5 V rechargeable battery was used. The connectors were introduced into the solution for ten seconds. It was determined a ten second time because if for longer time a dark color appears in the solution which does not allow to observe a color differentiation. Finally, if repetitions are performed, it was observed that the alligator clips should be cleaned every minute so that the color they are releasing does not affect the color change in the medium.

In the case of fecal coliforms, the first step was to prepare a culture medium from powdered milk, 100 mL of the water sample, and gentian violet. To eliminate the other bacteria, present in the water, such as gram-positive bacteria, gentian violet was used because of its efficiency in disinfecting these types of bacteria (Dragan and Michalak, 2019). In addition, the culture medium was heated to a moderate temperature to kill the remaining bacteria once it was disinfected with gentian violet, and because fecal coliforms grow at a temperature of 44.5 °C (Sladek et al., 1975). The methodology was as follows:

1. The glass containers, their lid, and the metal spoons are sterilized in a pot with a lid (30 min of boiling).
2. The containers are taken out and while they are still hot, 130 mL of water to analyze and four drops of gentian violet pigment are added.
3. Then the filled container is taken back to the pot for only one minute to increase the water temperature
4. 1,5 teaspoons of powdered milk are added with the sterilized spoon.
5. Cover the culture medium and wait between 48 to 96 hours maximum at room temperature.
6. If milk coagulates, the presence of fecal coliforms can be considered.

4.2. Obtaining pigments for colorimetric tests

Of the 28 pigments initially considered, twenty pigments were chosen. The selected pigments were obtained from the following options: onion peel, Laurel rose, radish peel, strawberry, "Ingrid Bergman" rose, beet greens, purple cabbage, chrysanthemum flowers, blackberry, lysander (Iris Germanica), black tea, green tea, coffee, turmeric, purple corn (powdered), peach (infusion), apple (infusion), Jamaica flower (infusion), Bougainvillea flowers (Bougainvillea sp.) fuchsia and red.

Eight pigments were eliminated because:

- For apple peel and eggplant peel no color was obtained when boiled.
- For lilac bougainvillea the color was too soft.
- For bougainvillea cherry the color was very similar to that of red bougainvillea and so it was removed from the choices.
- For Salvia splendens a soft red color was obtained, it was also decided to remove it from the options because it is not easy to obtain.
- For the purple grape peel was removed from the options because a large quantity of them is needed and because of its difficult accessibility.
- For the purple potato that was obtained, it only presented the purple color in the peel and not in the whole potato, therefore when boiling it, the color was soft and it was mixed with the starch of the potato.

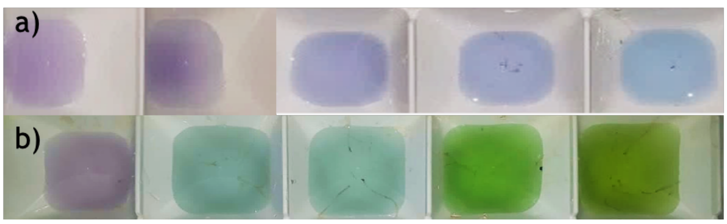
4.3. Selection of the pigments

Based on the test with simple water samples, notable color changes were observed only for pH (Lysander, purple cabbage, and purple potato), bicarbonates (Lysander and purple cabbage), electrical conductivity (all the pigments changed their color; however, the change was more noticeable in green tea, black tea and onion), sulfates (Rose Laurel, onion), sulfides (Beet greens).

In the case of metals, most of the pigments have shown little sensibility and selectivity (Fenger et al., 2021). Therefore, only black tea pigment allows identifying concentrations of the permissible limits of iron. Moreover, it has been observed a color change of the pigments for at least 2 metals. The black tea pigment was the only one with a unique color change for the iron. For all these pigments, ethanol extraction leads to better colorimetric sensibility. Indeed, extraction methods of natural pigments, like anthocyanins and flavonoids, using organic solvents achieve higher yields than methods using water (Tan et al., 2022).

The selected pigments were then used to quantify the chemical parameters in a complex matrix using natural water samples. First of all, it was noticed in all the cases a change in the color intensity with the natural water samples (Figure 2). Thus, a color calibration had to be performed for the different pigments selected in the presence of complex samples. It was decided to choose the pigments with the best robustness and the lowest color variation.

Figure 2. Color changes of the purple cabbage pigment as a function of pH (6 to 10) in a) simple sample and b) complex sample.



Source: own elaboration, 2021.

Based on the calibration step, the selection of pigments could be refined, and the following parameters were chosen with a single pigment associated (Table 4).

Table 4. Selected parameters and pigments.

Parameter	Pigment for alternative method
pH	Purple potato
Bicarbonates	Purple cabbage
Electrical Conductivity	Black tea
Sulfates	Purple onion
Sulfides	Beet greens
Iron	Black tea
Fecal coliforms	Gentian violet

Source: own elaboration, 2023.

4.4. Validation of the pigments

In the present stage, the intralaboratory validation of the tests proposed in the alternative method was carried out. The results were compared with the standard methods (Table 5).

Table 5. Intralaboratory validation results of the alternative method.

Parameter	Relative accuracy (%)	Relative sensitivity (%)	Relative specificity (%)
pH	100	100	100
Bicarbonates	100	100	100
Electrical Conductivity	100	100	100
Sulfates	100	100	100
Sulfides	33.33	26.67	8.33
Iron	86.67	57.14	75
Fecal coliforms	100	100	100

Source: own elaboration, 2023.

Results show that the parameters pH, electrical conductivity, sulfates, bicarbonates, and fecal coliforms have an accuracy, sensitivity, and relative specificity of 100%. It means that in all cases the results of the alternative method coincided with the reference method. The iron test presented a relative accuracy of 86.67%, a relative sensitivity of 57.14%, and a relative specificity of 75%. The results were not perfect but considered acceptable regarding a qualitative result. The results may be due to the capacity of black tea pigments to form complexes with various metals (Jolvis Pou, Paul, and Malakar, 2019). On the other hand, the sulfide test showed an accuracy of 33.33%, a sensitivity of 26.67%, and a specificity of 8.33%. Thus, the sulfide test was considered invalid, and it was not taken into account for the following.

The second part of the validation is the interlaboratory phase in which a comparison of the results obtained by six different persons analyzing two water samples is presented. With these results, the reproducibility and repeatability of the kit were calculated (Table 6), and the use of the manual was validated through the opinions of the people who participated in the field validation stage.

Table 6. Interlaboratory validation results of the alternative method.

Parameter	Average result tap water	Average result Tamborada river	Standard deviation of the results	Repeatability (%)
pH	1	1	0	100
Bicarbonates	1	1	0	100
Electrical Conductivity	1	1	0	100
Sulfates	1	2	0	100
Iron	1	1	0	100
Fecal coliforms	1	2	0.29	71.13

Note: For the average results, 1: Does not exceed the permissible limit, 2: Exceeds the permissible limit.

Source: own elaboration, 2023.

For the chemical tests, all six persons obtained the same results. Since in the three repetitions, the results were the same, there was no standard deviation between each analysis. It is for this reason that the repeatability calculation is 100%.

Regarding the fecal coliform analysis, for the Tamborada River sample, two people present a variation in their results. This may be due to not taking the necessary care when analyzing the sample. This method is sensitive to error because fecal coliforms can easily be found on the hands or in the environment; therefore, if due care is not taken, the result is not reliable. For this reason, it was decided to increase the sterilization time of the container and the spoon (minimum 30 minutes), as well as to increase the time in the water bath to two minutes. In addition, the sample must be sterilized in the container from which it was originally sampled, and the hands must be properly disinfected.

4.5. Manual for irrigation water quality analysis

Thanks to the previous stages, the manual of this kit was designed (Figure 3). A color palette (Figure 4) was added to allow quick reading of the tests. The different parts of the manual were evaluated by the farmers to ensure the sustainability of the kit use within the Maica community (Ajmal et al., 2020). The first chapter of the manual presents how to take water samples and the containers to be considered. The next chapter mentions the materials and procedures necessary for the preparation of the pigments. Subsequently, the interpretation of the colors to be observed in each test is presented with their respective values so that the irrigation water quality can be evaluated.

Figure 3. Irrigation water quality analysis manual cover page

Source: own elaboration, 2021.

Figure 4. Cover page of the color palette of the manual

Source: own elaboration, 2021.

Based on the observations of the community members, two additional sections have been added. Section 5 mentions the most produced crops in Bolivia with information about the maximum tolerance limit of electrical conductivity of the crop, and information on whether the crop bioaccumulates metals. In this way, once the approximate concentration levels of the respective physicochemical parameters are known, it is possible to deduce if the water quality will affect crop growth. Finally, section 6 presents three domestic treatments to reduce the concentration of some physical, chemical, and biological parameters of the water source of interest, in order to improve the quality of the irrigation water.

Finally, based on the request of the community members, the manuals were translated to Quechua language (Figure 4) to facilitate its diffusion and acceptance by the community (Siew et al., 2016).

5. Conclusions.

The objective of the project in the Maica area is to generate the tools and knowledge necessary for communities to make their own decisions in the framework of community empowerment. The irrigation water quality analysis kit is a tool that has been found relevant by the Maica community for water management. It is also worth mentioning that the advantage of this kit is that it has been analytically validated in the laboratory, it is simple to use, and low cost (around 68 Bs). The speed and validity of the results from 5 chemical analyses and a biological test will help the population to make decisions regarding their agricultural activities. Compared to other options for determining the quality of irrigation water, this kit is an opportunity, both economical and accessible, for Bolivian farming communities to be able to include it in their water and crop management habits. The translation of the manual in native language will facilitate its transfer to the farming communities.

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