ORIGINAL ARTICLE

Diagnosis and evaluation of pressurized irrigation systems in Portoviejo City, Manabí, Ecuador

Diagnóstico y evaluación de sistemas de riego presurizados del cantón Portoviejo en Manabí, Ecuador

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ABSTRACT: During 2022, an investigation was conducted on 16 farms to evaluate management of pressurized irrigation systems in Portoviejo City. Factors that affected management were identified, such as; A) Presence of leaks or breaks in the irrigation system deployed on the field, B) Modifications done to the initial project constructions, C) Lack of knowledge regarding managing, operating and maintaining (AOM) irrigation system, D) Absence of a filtering system, E) Absence of a hydraulic design of the system or implementation of a hydraulic project, F) Absence of water collectors. Factor D) was the most frequent troubling issue, identified in 14 out of 16 evaluations. Quality of the system was tested based on hydraulic evaluation and calculations to determine the uniformity of the output following the established hydraulic system norms. As a result, Localized irrigation systems displayed the highest rating, with a maximum efficiency of 93.90%. Sprinkler systems had a wider range, from 29.90% to 73.10%, with an average of 52.33%, which was considered unacceptable. Factor A showed little variation in uniformity evaluations, while factor D, C and E showed greater disparity in uniformity values.

Keywords: hydraulic evaluation, factor, sprinkler irrigation, localized irrigation.

RESUMEN: Durante 2022, se realizó una investigación en los sistemas de riego presurizados de 16 fincas del cantón Portoviejo para evaluar su gestión desde la etapa de proyección hasta la operación de los Sistemas. Los Factores limitantes más relevantes que afectaron la gestión fueron: A) Presencia de fugas o roturas en campo presentes en el sistema, B) Modificaciones constructivas al proyecto inicial, C) Desconocimiento de procedimiento de Administración, Operación y Mantenimiento (AOM) del sistema de riego, D) Ausencia de sistema de filtrado, E) Ausencia de proyecto o diseño hidráulico del sistema, F) Ausencia de obras de captación. El factor D) fue el problema más frecuente, identificado en 14 de 16 evaluaciones. La Calidad del Riego se evaluó a partir de evaluaciones hidráulicas y cálculo de los Coeficientes de Uniformidad establecidos en las Normas para estos sistemas. Se evidenció una mayor Uniformidad en los sistemas de riego localizado con un máximo del 93.90%. La Uniformidad en los sistemas de aspersión tuvo un rango amplio, de 29.90% a 73.10%, con una media de 52.33%, lo cual categoriza como inaceptable. El factor A mostró poca influencia en la Uniformidad, mientras que los factores limitantes D, C y E fueron los que mayor incidencia tuvieron en la calidad del Riego.

Palabras clave: evaluación hidráulica, factor, riego por aspersión, riego localizado.

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INTRODUCTION

Efficient irrigation management represents a crucial challenge in optimizing water use in crop production, being one of the most fundamental objectives in sustainable agriculture. This approach is particularly relevant given that irrigated agricultural practice constitutes the main source of freshwater consumption (Escribano, 2007; Herath *et al.*, 2014; FAO, 2022).

For irrigation in semi-arid areas, there is an increasing probability of water scarcity scenarios (Fontanet *et al.*, 2022). In Ecuador, approximately 81% of freshwater goes to irrigation systems used in agricultural sectors (World Bank, 2020). In the country, inadequate irrigation management is observed in all irrigation systems, from collection to application on the land, including water flow, storage, distribution, and plot irrigation methods. In most irrigation plots, the process is carried out in an improvised manner and without planning (Nieto *et al.*, 2018).

A crucial factor in the evaluation of irrigation systems is the uniformity in the distribution of water on the surface of the irrigated area, which directly influences management, quality, crops, the efficiency of water use, the cost of irrigation, and therefore, production (Salassier *et al.*, 2008). The lack of uniformity in water distribution can cause irregular crop development and in some cases, the accumulation of salts in the soil, which can lead to soil degradation (Cunha *et al.*, 2008). Christiansen (1942), proposed the first coefficient of uniformity, which used deviation methods as a measure of dispersion (CU). On the other hand, Merriam & Keller (1978) considered the Distribution Uniformity Coefficient (UD) as the relationship between the average 25% of the lowest values of the irrigation areas and the average collected area.

Hydraulic Designs are the foundation that guarantees optimal functioning in an Irrigation system based on Agronomic Design. However, there are additional factors that can impact the quality of irrigation such as planning and management. One of these aspects is the difference between laboratory results and field measurements focused on defining the maximum and minimum limits in water usage by plants (Evett *et al.*, 2019). Reyes *et al.* (2022) also recognized drawbacks in hydraulic systems used for water distribution and the possible obstruction caused by particles present in irrigated water, like Rocha (2019), who identified the absence of technical advice to achieve correct technological 'adoption'. by farmers." The efficient use of water in irrigation is affected by other factors, such as the lack of technology, inadequate design, problems in emitters such as leaks and breaks, a lack of uniformity, and absence of filtration systems installed before the main pump Li *et al.* (2022) and required systematic maintenance (Pérez, 2022). In addition, excessive slopes, poor selection of the emitter, and lack of systematic maintenance. Masseroni *et al.* (2024) point out that to promote water conservation in agriculture, a paradigm shift should be explored toward strategies aimed at increasing the flexibility in scheduling and improving the design and management found on field layout during irrigation practices.

According to Bohórquez *et al.* (2015), UD refers to the equality in the delivery of water to various areas during irrigation. This uniformity may be influenced by discrepancies in pressures, variations in the manufacture of drippers, possible clogging, uneven distribution of water, and the release of water by drippers after each irrigation cycle. Sokol *et al.* (2022) state that the use of drippers with built-in pressure compensators to maintain stable flow rates during pressure variations that may occur in the network guarantees greater irrigation uniformity; however, this advantage is not yet known by all farmers in Manabí.

It is important to remember that proper maintenance and efficient management of irrigation systems are essential to achieving good water quality. To reduce water consumption in irrigation, it is essential to optimize irrigation programs through accurate calculations of crops and the amount of water needed. These improvements are complementary and fundamental to any irrigation optimization process, which must consider the capacity of the distribution network to apply water effectively in the field (Bohórquez *et al.*, 2015).

Christiansen uniformity (CU) and distribution uniformity (DU) are the most widely used irrigation quality evaluation indicators, focusing on overall uniformity and local water deficit, respectively (Xue *et al.*, 2023). According to Sánchez (2023), in the majority of hydraulic evaluations carried out on pressurized irrigation systems in Portoviejo city, unacceptable ratings were obtained based on the CU and UD. These results were caused by a lack of adequate design, a lack of control elements to improve operation, obstructions, and breakages (Sánchez, 2023),

Vanella *et al.* (2021) demonstrated the usefulness of using Electrical Resistivity Imaging (ERI) to identify soil wetting and drying patterns as well as the geometric characteristics of wet bulbs, which are the most influential variables for optimal designs and management in localized irrigation systems.

Santiesteban and Santisteban & Díaz (2022) and Lavalle (2020) demonstrate fundamental values in Uniformity Coefficients from Hydraulic Design applied to localized Irrigation Systems. Although these estimated values must be within acceptance ranges, adopting very high values could generate designs that are too far from an attainable output once systems are built and in operation. This would reduce guarantees for efficiently irrigating crops.

In some countries with greater technological availability, the benefits of remote detection are analyzed (Corbari and Corbari & Mancini (2023); Erazo *et al.* (2023) to achieve more precise and efficient water distribution methods during irrigation.

Based on the background presented, the objective of the study was to diagnose and evaluate the operation of pressurized irrigation systems in Portoviejo City.

MATERIALS AND METHODS

Study location

The study was carried out in the Portoviejo area, which is located 30 km from the coast of Ecuador, in the central-northern part of the province of Manabí. Said area has two plains, Portoviejo River Valley and Riochico Valley, which have irregular terrain and are suitable for agriculture and other human activities. The slope does not exceed 5%; both are located between 37 and 60 m above sea level, in a subtropical and tropical zone, with an average temperature of 24 ºC, which can reach a maximum of 36 ºC.The average annual precipitation from 2000 to 2009 is 596.20 mm, with 2000 and 2008 as the wettest years and 2001, 2003, and 2009 as the driest (GAD Portoviejo, 2015). The study was carried out on 16 farms located in the parishes of Abdón Calderón, Alajuela, Portoviejo, and Riochico, as shown in Figure 1, which represents their spatial distribution in Portoviejo City.

Methodology

Under a descriptive research approach, the procedure consisted of identifying possible anomalies or irregularities that could affect the operation of said systems. During an inspection, special attention was paid to aspects such as leaks, structural damage, obstructions in emitters and sprinklers, and any indication that may compromise the uniformity of the evaluated systems. All observations and findings were meticulously recorded, thus facilitating a detailed analysis of the conditions present in irrigation systems inside the City.

This visual inspection stage provided a solid basis for subsequent evaluation of hydraulic conditions and distribution uniformity in the region's pressurized irrigation systems. Once all the anomalies and irregularities were identified, as in visual inspections, six limiting factors were detected that affected the management of the irrigation systems, which are detailed in Table 1, which is presented below:

For hydraulic evaluations, the irrigation uniformity evaluation sheet in the sprinkler and localized irrigation systems was used, which was based on international standards UNE-EN 15097 (2007) e ISO 15886-3 (2021), respectively, to evaluate irrigation uniformity. With this, information related to the hydraulic aspect of the systems was collected, which made it possible to determine uniformity in each of them.

Christiansen uniformity coefficient (CU): The concept of uniformity coefficient was created by Christiansen (1942) and is used as a statistical measure of uniformity in irrigation systems (equation [1]) and is defined as:

$$CU(\%) = \left[1 - \frac{\sum_{i=1}^{n} |x_i - \bar{x}|}{n * \bar{x}}\right] * 100 \quad [1]$$

Where:

x_i= volume of water accumulated in each rain gauge, in mm.

$\bar{x}$= average volume of water collected in all rain gauges, in mm.

n= number of rain gauges involved in the evaluation.

Distribution Uniformity (UD): The concept proposed by Merriam & Keller (1978), was adopted, where it indicates that; The uniformity of distribution of the irrigation system is expressed as a percentage, and it is the division by the average of the volume collected in the lower quarter of the drippers that apply less water ($V_{25\%}$) and VM refers to the average of the volume collected in all the sprinklers and emitters evaluated, multiplied by one hundred (equation [2]). The calculation of this index is based on information collected during field evaluation and is used to determine the severity of problems in the water application process.

$$UD(\%) = \frac{V_{25\%}}{V_m} * 100 \quad [2]$$

The study considered the calculation of the Flow Distribution Uniformity (UDq) (equation [3]) y Pressure distribution uniformity (UDp) (equation [4]) which are expressed through the following equations:

Flow distribution uniformity (UDq)

$$UD_q(\%) = \frac{\overline{q25\%}}{\bar{q}} * 100 \quad [3]$$

Where:

UD_q= Uniformity of flow distribution, expressed as a percentage.

$\overline{q_{25\%}}$= It is the lowest average of the 25% found in drippers flow rates 25%, in l/h.

$\bar{q}$= It is the average flow rate found on sprinklers and emitters used on tested irrigation blocks, in l/h.

Pressure distribution uniformity (UDp)

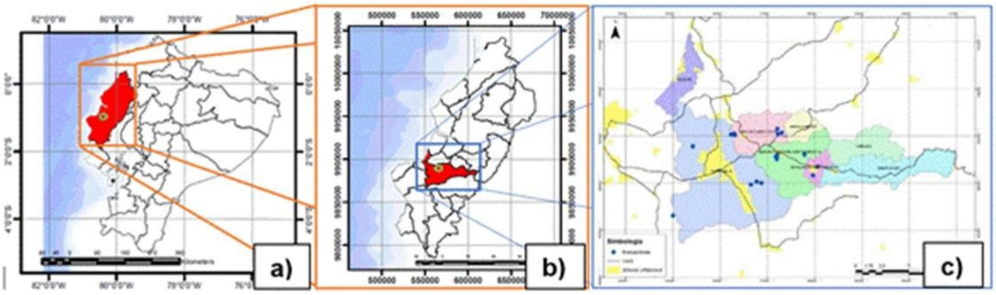
$$UD_P(\%) = \frac{\overline{p25\%}}{\bar{p}} * 100 \quad [4]$$

Where:

UD_p= Uniformity of pressure distribution, expressed as a percentage.

$\overline{p_{25\%}}$= It is the lowest average pressure readings of the 25% found in drippers, in bars.

$\bar{p}$= It is the average pressure found on drippers used on tested irrigation blocks, in bars.



Note: Location of Portoviejo City: Ecuador (a), Manabí province (b), Location of evaluated farms (c).

FIGURE 1. Spatial distribution of evaluated properties under study.

TABLE 1. Affectation factor detected in evaluations carried out in the Portoviejo canton

Factor Identification	Troublesome factor detected
A	The presence of leaks or field breaks in the system
B	Constructive modifications to the initial project
C	Lack of knowledge of the administration, operation, and maintenance (AOM) procedures of the irrigation system
D	Absence of a filtering system
E	Absence of a project or hydraulic design of the system
F	Absence of a water collector

Irrigation uniformity Quality: Christiansen (1942), classification was used to describe and evaluate pressurized irrigation systems, taking into account their uniformity and distribution coefficients. This evaluation is presented in Table 2.

TABLE 2. Rating of Uniformity Coefficient and Distribution Uniformity of evaluated irrigation systems

CU, UD (%)	Quality
> 95	Excellent
85 - 95	Good
80 - 85	Acceptable
70 - 80	Poor
< 70	Unacceptable

Note: CU uniformity coefficient and UD Uniformity of distribution, expressed as a percentage, according to Christiansen (1942).

After collecting the necessary information, a correlation analysis between variables was carried out to identify cause-effect relationships between identified problems, which made it possible to identify the most influential limiting factors in uniformity and management of irrigation in pressurized irrigation systems in the City. These assessments were carried out with the aim of better understanding hydraulic conditions, UDq, and UDp in this region, which will provide valuable information for the management and improvement of irrigation systems in the future.

RESULTS AND DISCUSSION

Visual inspection results

During visual inspection, it was possible to identify limiting factors that represent crucial elements that influence the operation and efficiency of these systems. Table 3 lists each of the limiting factors identified during evaluations carried out in irrigation systems in the city.

As can be seen in Table 3, the factor that appeared most frequently was factor D) Absence of a filtering system, detected on a total of 14 occasions out of 16 evaluations carried out. The lack of filtration systems is a cause for concern in irrigation, being even more accentuated in localized irrigation systems; implementation of filtration systems is essential to prevent blockages in emitters. According to Sánchez *et al.* (2009), blockages in emitters harm crop uniformity and production, which underlines the urgent need to use effective filtration technologies to improve both the physical and biological quality of water.

Similarly, it can be seen in Table 3 that the second most occurred factor was C, with a total of 12 appearances in 14 evaluations. According to MAATE-Ecuador (2021), the lack of continuous technical, economic, social, and environmental training leads to an increased weakness in crop providers, both at public and communal levels. The latter manifests itself in poor management in the administration, operation, and maintenance of irrigation systems, which is why it is advisable to constantly train operators to correctly handle and maintain irrigation equipment before handling it. (Santisteban & Díaz, 2022 and Claudio Benites, 2021).This recommendation also agrees with the assessments of Zubelzu *et al.* (2023) when verifying the tendency of farmers not to abandon traditional practices despite new programming tools that are made available to them.

TABLE 3. Limiting factors identified in each evaluation

Evaluation No.	Irrigation Method	Affected area coding						Total, factors detected
		A)	B)	C)	D)	E)	F)	
1	1		✓		✓	✓		3
2	1				✓	✓		2
3	1			✓	✓	✓		3
4	1		✓	✓	✓	✓		4
5	1	✓	✓	✓	✓	✓	✓	6
6	1		✓		✓		✓	3
7	2		✓	✓	✓	✓		4
8	2				✓	✓		2
9	2		✓	✓			✓	3
10	2	✓	✓	✓	✓	✓		5
11	2			✓		✓		2
12	2	✓	✓	✓	✓			4
13	2		✓	✓	✓			3
14	2		✓	✓	✓	✓		4
15	2		✓	✓	✓	✓	✓	5
16	2			✓	✓	✓		3
The total frequency of each factor		3	11	12	14	12	4	

Note: Irrigation method; 1 Sprinkling, 2 Localized. Affected area coding; A) Presence of leaks or breaks present in the system, B) Modifications to the initial project, C) Lack of knowledge of AOM procedure of the irrigation system, D) Absence of a filtration system, E) Absence of hydraulic project or design of the system, F) Absence of water collectors.

As a previous factor, factor E is identified with 12 mentions in evaluations, as can be seen in Table 3. An adequate irrigation system design is essential to ensure efficiency in water use in the agricultural sector. It is essential to promote the effective use of water resources in agriculture and livestock, which implies improving techniques and tools used for managing the distribution and application of water irrigation. In addition, it is vital to focus on the design, review, and evaluation of irrigation systems (Espinosa *et al.*, 2016).

Next, factor B, with a total of 11 appearances within 16 evaluations, is found in Table 3. The modifications made in irrigation systems should have been evaluated before the implementation of a new system to establish the parameters the previous system had and tailor the new design to specifications. That is to say, know the current situation of the system to be able to design any modification in the most optimal way to avoid increased pressure to improve or traditional irrigation methods (Martí *et al.*, 2023).

Factor F is identified, which is presented in 4 out of 16 evaluations carried out, as can be seen in Table 3. In this context, water collectors refer to a set of hydraulic structures designed to divert or capture water from a channel. These structures include elements such as a slope and an intake, which can be placed both lateral or at the bottom. In addition to their main functions, these also can retain sediments transported by the river from elevated areas during floods (Rodríguez *et al.*, 2014).

And last but not least, factor A was identified on 3 occasions out of 16 evaluations carried out. The presence of leaks and breaks in irrigation systems results in a loss of water volume that is not used by the crop (MAGAP-Ecuador, 2015).

In Figure 2, you can see a frequency histogram obtained from 16 evaluations carried out on irrigation systems in Portoviejo City.

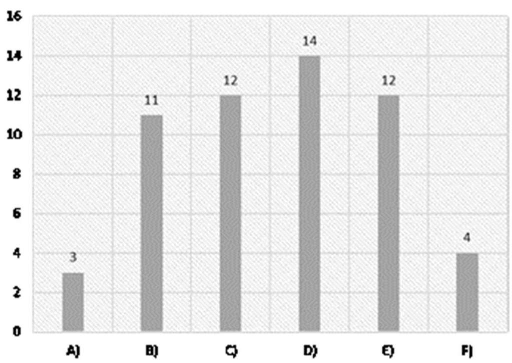


FIGURE 2. Limiting factors were identified in each of the evaluations.

As can be seen in Table 3 and Figure 2, the factor that appeared most frequently was factor D, detected on a total of 14 occasions out of 16 evaluations carried out. Depending on the quality of water used in the system, obstructions will occur, which may be due to suspended mineral particles (clay, silt, sand), organic matter, and precipitates (mainly carbonates). By adopting a filtering system, blockages of sprinklers and emitters are prevented, which are considered one of the most serious problems in pressurized irrigation systems (Monge, 2018).

Results of uniformity in irrigation systems

Once hydraulic evaluations were carried out, results of the sprinkler irrigation systems were obtained and are presented in Table 4.

Table 4 presents the results of 6 evaluations carried out in pressurized sprinkler irrigation systems. Notably, CU shows a range of values from a minimum of 29.90% to a maximum of 73.10%, with an average of 52.33%. In terms of CU rating, it stands out that 83.33% of sprinkler irrigation systems evaluated are considered unacceptable, while 16.67% are classified as poor. It is relevant to note that evaluation number 5 shows the lowest CU value and matches with evaluations in which the greatest number of limiting factors affecting uniformity in the irrigation system were identified.

Similarly, in Table 4, you can see results from 6 evaluations, where UD exhibits a range of values from a minimum of 29.60% to a maximum of 65.90%, with an average of 46.93%. Regarding UD rating, all sprinkler irrigation systems evaluated are considered unacceptable. It is important to indicate that, as with CU, evaluation number 5 yields the lowest value of UD and is associated with a greater number of limiting factors that influence uniformity in the irrigation system.

Regarding localized irrigation systems, only flow UD (UDq) and pressure UD (UDp) were evaluated. Table 5 below presents results from hydraulic evaluations in localized irrigation systems.

Table 5 presents results from 10 evaluations carried out in localized pressurized irrigation systems. Notably, UDq shows a range of values from a minimum of 44.00% to a maximum of 93.10%, with an average of 72.75%. Regarding the UDq rating, it is observed that 40% of systems are considered unacceptable, 20% are classified as poor, 10% as acceptable, and 30% are considered good. It is relevant to note that evaluation number 15 shows the lowest value of UDq and coincides with one of the evaluations in which the greatest number of limiting factors that influence uniformity in the irrigation system were identified.

Similarly, in Table 5, you can see results from 10 evaluations, where UDp presents a range of values from a minimum of 25.64% to a maximum of 96.85%, with an average of 70.33%. Regarding the UDp rating, it is highlighted that 50% of the systems are considered unacceptable, 20% are acceptable, 10% are classified as good and 20% are considered excellent. It is important to mention that evaluation number 13 yields the lowest value of UDp and coincides with one of the evaluations in which the greatest number of limiting factors affecting uniformity in the irrigation system were identified.

The variability of UD was examined in each evaluation in relation to the limiting factors detected in the study. In Figure 3, you can see which limiting factors show the greatest and lowest recorded data variability.

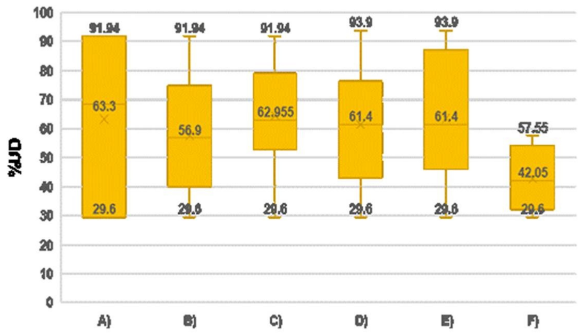
TABLE 4. Results of CU and UD, of the sprinkler irrigation systems evaluated

System ID	Irrigation Method	C.U.	Quality	UD	Quality	Affected area coding					
						A)	B)	C)	D)	E)	F)
1	1	59.20	< 70 Unacceptable	36.50	< 70 Unacceptable		✓		✓	✓	
2	1	73.10	70 - 80 Poor	65.90	< 70 Unacceptable				✓	✓	
3	1	55.40	< 70 Unacceptable	52.60	< 70 Unacceptable			✓	✓	✓	
4	1	52.70	< 70 Unacceptable	56.90	< 70 Unacceptable		✓	✓	✓	✓	
5	1	29.90	< 70 Unacceptable	29.60	< 70 Unacceptable	✓	✓	✓	✓	✓	✓
6	1	43.70	< 70 Unacceptable	40.10	< 70 Unacceptable		✓		✓		✓

TABLE 5. Results from UDq and UDp, in evaluated localized irrigation systems

System ID	Irrigation Method	UDq	Quality	UDp	Quality	Affect identification					
						A)	B)	C)	D)	E)	F)
7	2	54.06	< 70 Unacceptable	67.84	< 70 Unacceptable		✓	✓	✓	✓	
8	2	93.90	85 - 95 Good	95.65	> 95 Excellent				✓	✓	
9	2	57.55	< 70 Unacceptable	37.44	< 70 Unacceptable		✓	✓			✓
10	2	91.94	85 - 95 Good	78.57	80 - 85 Acceptable	✓	✓	✓	✓	✓	
11	2	91.07	85 - 95 Good	80.00	80 - 85 Acceptable			✓		✓	
12	2	68.36	< 70 Unacceptable	57.66	< 70 Unacceptable	✓	✓	✓	✓		
13	2	80.49	80 - 85 Acceptable	25.64	< 70 Unacceptable		✓	✓	✓		
14	2	74.83	70 - 80 Poor	96.85	> 95 Excellent		✓	✓	✓	✓	
15	2	44.00	< 70 Unacceptable	93.70	85 - 95 Good		✓	✓	✓	✓	✓
16	2	71.28	70 - 80 Poor	69.94	< 70 Unacceptable			✓	✓	✓	

When observing Figure 3, it is evident that factor C shows the least variation in UD values in evaluations in which this factor was present. In contrast, it can be noted that factor A in the field within the system is the one that presented the greatest variability in UD values in Figure 3.



Note: The diagram represents dispersion and symmetry in UD measurement in each evaluation related to the limiting factors detected. The X represents the average UD for each limiting factor. The top and bottom bars represent the top and bottom of each chart, respectively. The upper and lower yellow lines represent the maximum and minimum values, respectively, identified in each factor.

FIGURE 3. UD variability in limiting factors identified in each evaluation.

The previous results match with studies done by Bohórquez *et al.* (2015), where deficiencies that impact UD in irrigation were identified, which include inappropriate regulation of pressures in irrigation subunits and a lack or deterioration of pressure gauges. at critical points in the network, partially clogged emitters due to the presence of chemicals in systems with poor control of pH values found in water or fertilizer solution, especially at the end of the irrigation season, and water leaks in the network.

During the development of this research paper, Rocha (2019) statement could be verified when he stated that 'Irrigation intervention processes should not be focused on hydraulic infrastructure as an end to a mean, the construction of pressurized irrigation infrastructure does not imply technological change by itself. In this sense, intervention processes that provide technological innovation in irrigation must pay special attention to the technological adoption done by farmers, providing the required technical support promptly."

CONCLUSIONS

- The result of this study reflects the "Absence of filtering system" (identified in 14 out of 16 evaluations carried out) as the most influential factor in the quality of irrigation, which has an impact on its efficient management. It implies allocating more irrigation time to compensate for the poor uniformity that this factor causes in the water distribution of the irrigation dose.
- The average value of the Uniformity Coefficient obtained for sprinkler irrigation was 52.3%, which is categorized as UNACCEPTABLE. This category is also applicable to the average value of Distribution Uniformity that was obtained for these systems (46.9%).
- The behavior of Pressure Distribution Uniformity in Localized Irrigation Systems reached higher values than those found in sprinkler systems, with an average of 70.3%. This value was very close to the average value found in Flow Distribution Uniformity that was obtained in those systems (72.7%), which demonstrates a greater guarantee in the quality of irrigation with this technique compared to sprinkling. However, 40% of the systems evaluated are also categorized as UNACCEPTABLE.
- Factors that most influenced the quality of localized irrigation were “Ignorance in managing, operating and maintaining quality procedures in irrigation systems” and “Absence of a filtering system”.

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