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Hydrodynamic and hydrochemical levels of groundwater in perennial crops of the Vinces canton, Los Ríos, Ecuador

Niveles hidrodinámicos e hidroquímicos de aguas subterráneas en cultivos perennes del cantón Vinces, Los Ríos, Ecuador

Níveis hidrodinâmicos e hidroquímicos das águas subterrâneas de culturas perenes no cantão de Vinces, Los Ríos, Equador

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Crop production

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Abstract

The static and dynamic levels, as well as the quality of groundwater sources used for agricultural production, represent an important factor in understanding the characteristics of the use of wells for this activity and the influence on the decline in static levels during the dry season. The objective of this research was to determine the behavior of the hydrodynamic and hydrochemical levels of groundwater used in plantain, banana, and cocoa production to improve water resource utilization in the Clariza parish of the Vinces canton, Ecuador. Data were collected from 10 production units in the area. For the dynamic levels, a constant-rate pumping test was performed. For water quality characteristics, *in-situ* tests for pH, electrical conductivity (EC), and total dissolved solids (TDS) were performed, and no values were recorded that would restrict their use for agricultural activities. The declines in dynamic levels were constant and progressive during the dry season due to the irrational use of water through pumping systems. Dynamic levels measured using the pumping test determined maximum drawdowns between 6 and 8 m in depth; however, well recovery showed constant rising levels, indicating aquifer recharge.

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Resumen

Los niveles estáticos, dinámicos y calidad de agua de fuentes subterráneas empleados para la producción agrícola representan un factor importante para conocer las características de uso de los pozos para esta actividad y la influencia sobre el descenso de los niveles estáticos durante los meses de época seca. El objetivo de esta investigación fue determinar el comportamiento de los niveles hidrodinámicos e hidro químicos de aguas subterráneas usadas en la producción de cultivos de plátano, banano y cacao, para mejorar el aprovechamiento del recurso agua en la parroquia Clariza del cantón Vinces, Ecuador. Se realizó un levantamiento de información en 10 unidades productivas de la zona. Para los niveles dinámicos se realizó una prueba de bombeo a caudal constante. Para las características de calidad de agua se hicieron pruebas *in situ* de pH, conductividad eléctrica (CE) y sólidos totales disueltos (STD) no registrándose valores que restrinjan su uso para actividades agrícolas. Los descensos de niveles estáticos fueron constantes y progresivos en la época seca por el uso irracional del agua mediante los sistemas de bombeo. Los niveles dinámicos mediante la prueba de bombeo determinaron niveles máximos de descensos entre 6 y 8 m de profundidad, sin embargo, la recuperación de pozos tuvo ascensos constantes, identificando recarga del acuífero.

Palabras clave: niveles estáticos y dinámicos, recuperación, calidad de agua.

Resumo

Os níveis estáticos e dinâmicos e a qualidade das fontes de água subterrânea utilizadas para a produção agrícola representam um fator importante para a compreensão das características do uso de poços para esta atividade e a influência no declínio dos níveis estáticos durante a estação seca. O objetivo desta pesquisa foi determinar o comportamento dos níveis hidrodinâmicos e hidroquímicos das águas subterrâneas utilizadas na produção de banana-da-terra, banana-da-terra e cacau, a fim de melhorar a utilização dos recursos hídricos na paróquia de Clariza, no cantão de Vinces, Equador. Os dados foram coletados em 10 unidades de produção da área. Para os níveis dinâmicos, foi realizado um teste de bombeamento de fluxo constante até que um nível de rebaixamento contínuo. Para as características de qualidade da água, foram realizados testes in situ de pH, condutividade elétrica (CE) e sólidos dissolvidos totais (SDT), e não foram registrados valores que restrinjam seu uso para atividades agrícolas. As quedas dos níveis estáticos foram constantes e progressivas durante a estação seca, devido ao uso irracional de água por meio de sistemas de bombeamento. Os níveis dinâmicos medidos por meio do teste de bombeamento determinaram quedas máximas entre 6 e 8 m de profundidade; no entanto, a recuperação dos poços apresentou aumentos constantes, indicando recarga do aquífero.

Palavras-chave: níveis estáticos e dinâmicos, recuperação, qualidade da água.

Introduction

The importance of water resources is recognized worldwide, and they are increasingly scarce. Water, as a natural resource, is essential for the agricultural and livestock development of countries (Salazar & Alma, 2018). In developing countries such as Ecuador, water resources are used in a greater proportion for agricultural irrigation and play an essential role in crop production and food security (Hoogesteger & Wester, 2018).

In Ecuador, the agricultural sector uses more than two-thirds of the water extracted from rivers, lakes, and aquifers. Agriculture is not only the sector that consumes the most water in terms of volume; it also consumes more than other uses. The irrational use of water has accelerated, leading to a drastic reduction in aquifer levels at the regional and global levels (Noori *et al*., 2023 springs, and qanats, from 2002 to 2017, here we show a significant decline of around −3.8 mm.year^{-1} in the nationwide groundwater recharge. This decline is primarily attributed to unsustainable water and environmental resources management, exacerbated by decadal changes in climatic conditions. However, it is important to note that the former's contribution outweighs the latter. Our results show the average annual amount of nationwide groundwater recharge (i.e., ~40 mm.year^{-1}; Jasechko *et al*., 2024). As a result, aquifers for use in intensive agriculture could be overused; their extraction rate could have exceeded the recharge rate due to the increase in crop areas without proper management and the adoption of good practices to save water resources (Ríos *et al.*, 2020; Noori *et al*., 2023 springs, and qanats, from 2002 to 2017, here we show a significant decline of around −3.8 mm.year^{-1} in the nationwide groundwater recharge.

This decline is primarily attributed to unsustainable water and environmental resources management, exacerbated by decadal changes in climatic conditions. However, it is important to note that the former's contribution outweighs the latter. Our results show the average annual amount of nationwide groundwater recharge (i.e., ~40 mm.year^{-1}). On the other hand, studies of the declines of levels have been evidenced at a global level, in America, and in Colombia by Armenta and Gallardo (2016); Mexico, by Santos *et al*. (2019) and Hernández (2020), and globally in countries (USA, Mexico, Chile, South Africa, Afghanistan, Asia, Thailand, China, Iran, Saudi Arabia, and Spain) reported by Jasechko *et al*. (2024).

The static level of deep wells is the vertical distance from the ground to the level at which the water is located. In general, producers do not have the knowledge of what the hydrodynamic characteristics of their wells are for agricultural use (Dipardo *et al*., 2021). Likewise, they are unaware of the hydrochemical characteristics that can limit production (Dipardo *et al*., 2021; Mancilla *et al*., 2021).

In this sense, the General Directorate of Water (2017) is responsible for diagnosing the quality of groundwater, indicating sources of contamination, and establishing restriction zones to ensure the sustainable management of water resources.

In the Province of Los Ríos, Ecuador, the scarcity of data on piezometric studies and volume of water extracted generates uncertainty at the local level that can accurately demonstrate the reduction of static levels of groundwater resources caused by the indiscriminate use of water and the increase in areas of perennial cycle crops such as banana from 61,937 ha in 2016 to 62,540 ha in 2022 and cocoa from 96,200 ha in 2016 to 120,187 ha in 2022, as detailed by the Ministry of Agriculture and Livestock (MAG, Ecuador, 2023). In this context, the objective of this research was to determine the behavior of the hydrodynamic and hydrochemical levels of groundwater used in the production of plantain, banana, and cocoa crops in the Clariza parish of the Vinces canton, Ecuador.

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Materials and methods

Study area

The research work was carried out in the Clariza parish, in the Vinces canton, Los Ríos province, located between coordinates 1°33’ 00’’ S and 79° 44’ 00’’ W, at 39 m.a.s.l., with an average temperature of 25 ºC and average annual rainfall of 1453 mm (National Institute of Meteorology and Hydrology [INAMHI], 2023). The area presented clay-loam soils, and the planting of perennial crops such as plantain, banana, and cocoa.

In reference to the rainfall data of the National Institute of Meteorology and Hydrology (INAMHI), an average rainfall of 1,453 mm was recorded in the area of the Vinces canton from 2005 to 2015, however, 91 % of the rainfall was concentrated in the rainy season (January to May) and the remaining 9 % in the dry season (June to December).

Research method

The research method was based on a descriptive design, where producers of the plantain, banana or cocoa items were selected, in production and with irrigation, leaving a total of 10 producers, presenting the productive units the following areas: four with 3 ha; two with 3.5 ha; one with 6.5 ha, one with 30 ha; one with 70 ha and the last with 100 ha. Baseline information was collected, such as cultivated species, crop area, type of irrigation, type of well construction, georeferencing, diameter, depth, and coverage of the well, pumping system, and pump characteristics (capacity, type of pump, motor rpm). In addition, the hydrodynamic (static level, dynamic level) and hydrochemical variables (pH, electrical conductivity EC, total dissolved solids TDS) of groundwater used in the production of agricultural crops in the dry season (June to December) were evaluated; however, this drought period was extended until mid-January due to the absence of rainfall in the evaluation area.

Data collection for hydrodynamic monitoring

In the selected wells, the declines in the level of water were recorded. The static level reading was made by introducing a TLC meter (Temperature, Level, and Conductivity), Solinst brand, model 107, United States of America, into the well (located next to the pumping head) until the acoustic signal indicating the water level was obtained. This procedure was performed monthly while the pumping group was not in operation. For the dynamic level, the pumping test was started and the pump was energized at constant flow or pressure, followed by the reading of times (min), 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20, 25, 30, 40, 50, 60, 80, 100, 120, 160 and 200.

Pumping. Time (min): Time elapsed since the start of the pumping test.

Drawdown (m): Difference between the dynamic level and static level.

Water level (m): Position occupied by groundwater and/or the time that elapses to recover the well.

After pumping, the motor (pumping head) was immediately turned off, and the measurement and time of the recovery levels of the well were taken. Hydrochemical evaluation was performed *in situ,* obtaining the water sample after one hour of pumping; three subsamples of 1 L of water were collected. The Tester brand equipment, HANNA HI 98130 model, Colombia, was used, taking the readings on a monthly basis, creating a record of the variables of pH, EC, and TDS *in situ*.

On the other hand, the volume of discharge was estimated in m^3 per ha; the measurements were made by taking the pressure at the beginning and at the end of the irrigation module (first and last Griven sprinkler, LM995B model, Venezuela, respectively), the discharge level was determined by applying formulas to calculate the rainfall intensity based on its flow and spacing, this variable was determined at the beginning and last month of the evaluation of static levels.

Volume of irrigated area = Volume * number of modules in operation.

Volume of irrigated area $m^3.day^{-1}$ = Volume * number of working hours of the pumping equipment.

Results and discussion

Seven producers presented crop areas with a range of 3 to 6.5 ha of plantain, banana, and cocoa production, with deep wells drilled in an artisanal way with a depth of 30 to 60 m and diameters ranging from 3 to 6 inches, they had sprinkler irrigation systems and pumping systems at flow and/or pressure from 6 to 13 HP with 3600 rpm. On the other hand, three producers had a larger area (30 to 100 ha of banana). These producers also had deep wells with industrial construction, approximately 70 to 100 m deep and 12 inches in diameter, with sprinkler irrigation systems, in addition to pressure pumping systems with a range of 60 to 100 HP with 1,800 to 2,000 rpm, clay loam to silty clay loam soils, with pH between 6.6 and 7.3; EC less than 1 $dS.m^{-1;}$ and soils with a range of 3 to 3.6 % in organic matter.

The groundwater wells used by farmers in the Clariza sector of the Vinces canton are mainly destined for the agricultural use of perennial crops in the dry season months (late May to December). However, in the evaluation period, the dry season was extended until mid-January. In this context, producers with less than 6.6 ha have wells with a range of 30 to 60 m in depth and diameters of 4 to 6 inches, with a production area of less than 7 ha. These deep wells are drilled using rotary drilling, pressure-flow pumping systems, and sprinkler irrigation system infrastructure.

The other producers had 30 or more ha, with wells of 60 to 100 m deep; 12 inch diameter with deep wells drilled with rotary drilling, with pressure discharge systems and sprinkler irrigation systems to meet the water needs of each crop.

The use of water for agricultural activities is maintained in the dry season with the use of water from deep wells of artisanal construction. In this regard, Machado (2023) indicated that a better understanding of how aquifer systems work should be promoted among those involved in groundwater. Loor *et al*. (2019) reported that cultivation practices have an influence on groundwater, since in areas of high agricultural activity, contamination can be generated with a deterioration of aquifers.

Hydrodynamic variables of groundwater

Figure 1 shows the static level (m) data of the productive units of the Clariza sector from June 2022 to January 2023, showing an initial measurement of 1.29 m in June and reaching a 5.98 m decline by the final evaluation in January. Large producers had similar constant and progressive declines in water levels in a range from 1.55 m to 5.98 m for agricultural irrigation use.

On the other hand, Figure 2 shows the map of isobaths in the evaluation area, showing constant declines in water tables in the research period, with values of less than 6 m for small and large producers.

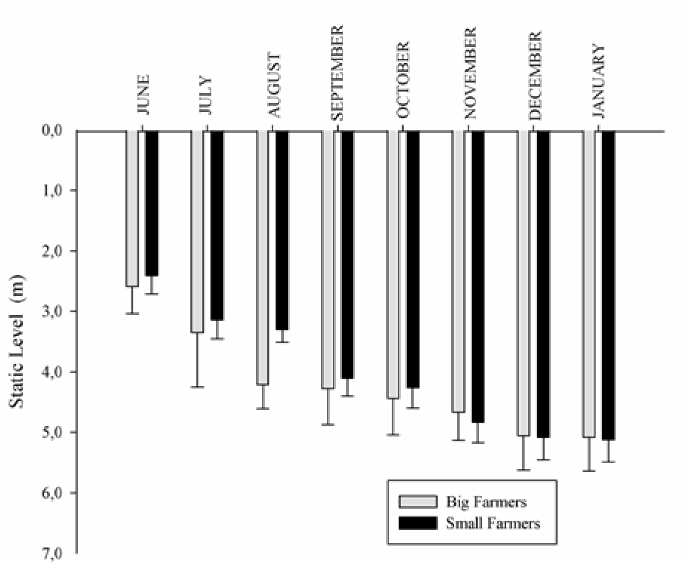

Figure 1. Static groundwater levels (m) of the Vinces canton.

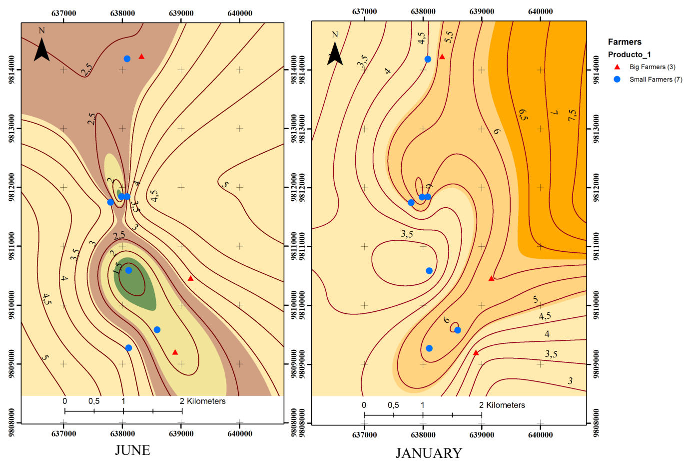

Figure 2. Map of isobaths (m) of the groundwater level in the Vinces canton.

The evaluation of the static levels of wells used for agricultural production showed levels of decline in the dry season up to 5.98 m in depth for small and large producers. The results of this evaluation agree with Santos *et al.* (2019) who indicate that the decline in static levels occurs due to various factors such as the extraction of water through pressure and flow pumping systems for agricultural irrigation, declines in soil moisture, or absorption by the root area of the crop; however, it differs from the findings of Armenta and Gallardo (2016) who report declines in static levels in ranges of 17 to 21 m in depth, and Hernández *et al*. (2020) with more than 50 m in depth, descending due to the different agricultural activities during the months that the dry season lasts.

On the other hand, Figure 3 details the drawdown in dynamic levels recorded during the pumping tests of three producers in the Clariza area carried out on August 25, 27, and 30 at constant flow; the graph details the behavior of the wells. For production unit 4, pumping began at a constant discharge flow (6 $L.s^{-1}$), observing that, at minute 0, the level was at 3.69 m, at the time of starting the pumping test, the level dropped to 5.3 m at min 1, leading to constant drawdowns until minute 40, where a significant level of 6.03 m was recorded, showing a recovery at minute 50, reaching 5.6 m. On the

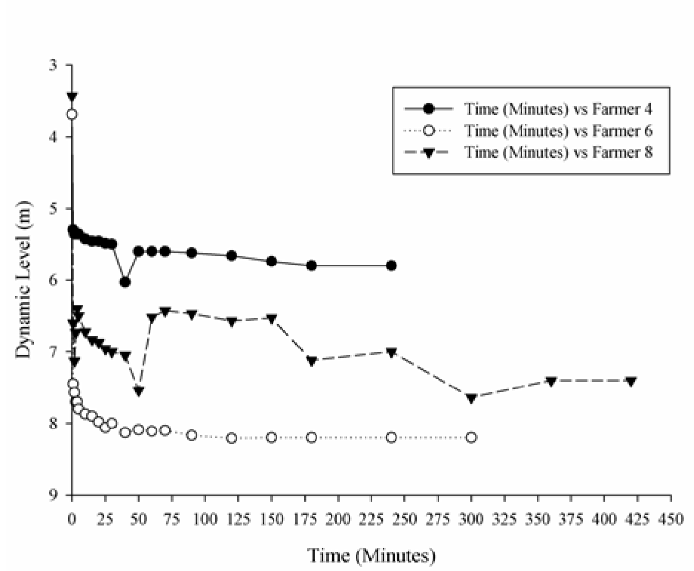

Figure 3. Dynamic levels of groundwater wells in the Vinces canton.

other hand, it was followed by similar drawdown patterns, showing a stabilization in the curve from minute 150 to minute 240 with a constant dynamic level of 5.8 m in depth, stabilizing the curve and culminating the pumping test.

In the case of production unit 6, pumping began at a constant discharge flow (8 $L.s^{-1}$). It was observed that, at min 0, the level was at 3.69 m, at the time of starting the test, the level declined to 7.45 m at min 1, leading to drawdowns until min 120, which registers its maximum drawdown of 8.21 m, showing a recovery of the well in the measurement of min 150, reaching 8.20 m, following drawdowns of similar shape and showing a stabilization in the curve from min 150 to min 300 with a constant dynamic level of 8.20 m in depth, stabilizing the curve and culminating the pumping test.

In production unit 8, pumping began at a constant discharge flow (10 $L.s^{-1}$) and it was observed that, at min 0 the level was at 3.43 m, at the time of starting the test, the level fell to 6.6 m at min 1, leading to constant drawdowns until min 50 when it registered the maximum drawdown of 7.54 m, showing a recovery of the aquifer at minute 60, reaching 6.52 m and drawdowns to 7.64 m; reflecting a stabilization in the curve from min 360 to min 420, with a constant dynamic level of 7.4 m in depth, stabilizing the curve, ending the pumping test.

Figure 4 shows the behavior of drawdown vs. time, showing in the graph that production unit 4 had drawdowns with respect to the static level of 2.34 m in depth at 40 min, and it was stabilized at 180 min with 2.11 m. Production unit 6 showed consecutive drawdowns of 4.52 m at 120 min and was stabilized at 150 min. Productive unit 8 presented consecutive drawdowns until minute 50 with 4.11 m; however, the drawdown was reduced as a result of aquifer recharge. In addition to the extraction of water from the well at constant flow, the drawdowns increased to 300 min with 4.21 m and stabilized at 360 min of the pumping test.

In Figure 5, the recovery of the wells is observed, being one of the main hydraulic characteristics to identify if the well is receiving recharge from the aquifer; therefore, it is evident that the wells for agricultural use had a progressive and constant recovery with a recharge duration of 60 to 90 min in the wells of the evaluated producers.

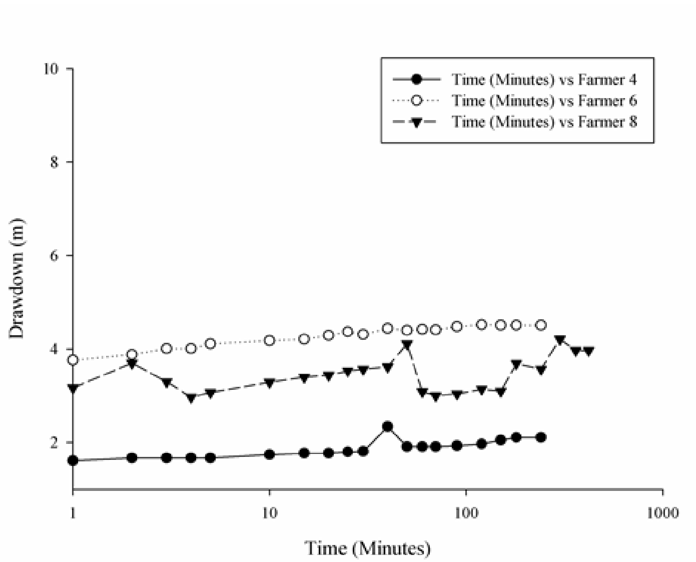

Figure 4. Drawdown of groundwater wells in the Vinces canton.

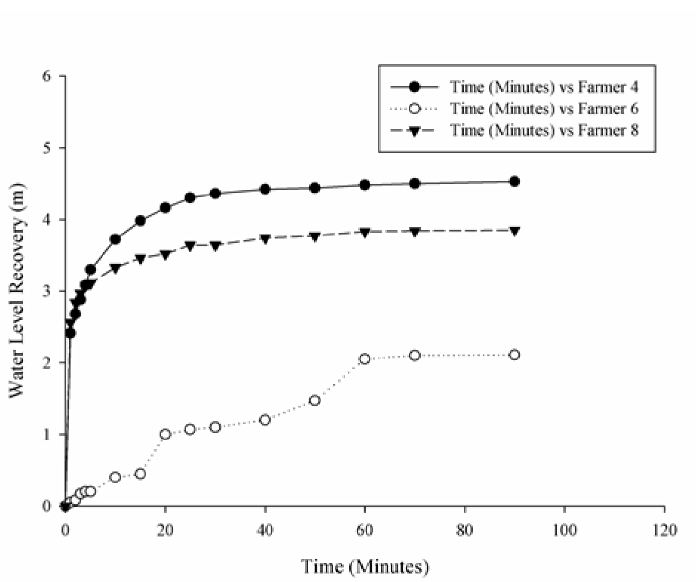

Figure 5. Recovery of groundwater wells in the Vinces canton.

The evaluation of dynamic levels, drawdown and recovery by pumping test using the TLC meter, was carried out in 2 wells of small producers and 1 well of a large producer, the initial dynamic level of the small producers was 3.69 m, the declines were constant and progressive, reaching a constant dynamic level at 5.80 m and 8.20 m in depth, stopping the pumping test at 240 min and 300 min respectively and with a drawdown level of 2.11 m and 4.51 m respectively.

In production unit 10, the initial level was 3.43 m, the dynamic level reached up to 7.40 m at 420 min and a level of drawdown of 3.97 m, and the recovery of the three wells for agricultural production had constant and progressive rising levels, as a characteristic that the wells are receiving aquifer recharge between 60 and 90 min after the pumping test is completed. Therefore, it differs from the report by Gómez (2020), where the declines reached depths of 70 m and 140 m, a drawdown of 40 m; however, the recovery ranged between 60 and 360 min with flows of 30 to 60 $L.s^{-1}$. On the other hand, Aguirre *et al.* (2022) report drawdowns in dynamic levels, ranging from 5 m to 98 m during pumping tests in the Ñuble River aquifer in the central valley of Chile.

Hydrochemical variables of groundwater

Figure 6 shows the water pH data of small and large producers in the Clariza sector from June 2022 to January 2023, which details that the productive units with 3 to 6.5 ha presented a water pH that varies between 6.91 ± 0.13 pH. However, large producers had a similar range of 6.93 ± 0.23 pH in the months evaluated. Therefore, they do not have any degree of restriction for agricultural use, being the appropriate range for irrigation water, whose ranges are specified between 6 to 9 pH, according to the General Directorate of Water (2017).

The values of electrical conductivity of the water in the months evaluated are detailed in Figure 7. Producers with 3 to 6.5 ha had an electrical conductivity ($mmhos.cm^{-1}$) of water that ranged from 0.78 ± 0.22 $mmhos.cm^{-1}$. However, large producers had a higher range of 1.74 ± 0.68 $mmhos.cm^{-1}$ in the months evaluated. These values do not have any degree of restriction on agricultural use, according to the data presented by the General Directorate of Water (2017), detailing that the chemical parameters of water for agricultural irrigation (EC) are in optimal ranges from 0.7 to 3.0 $mmhos.cm^{-1}$.

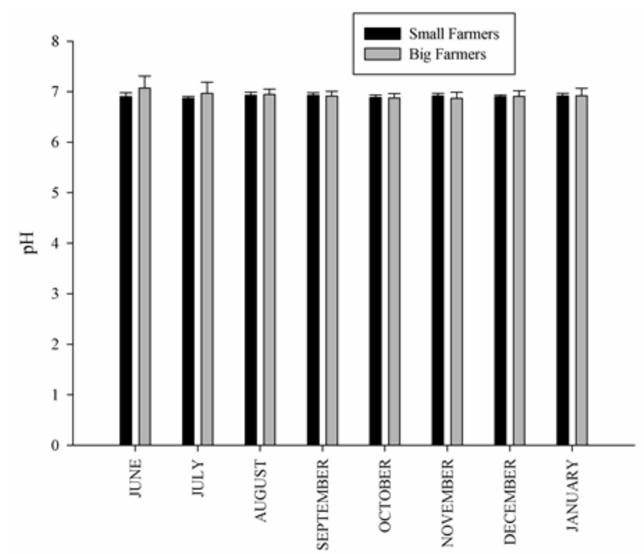

Figure 6. pH of irrigation water, Vinces canton.

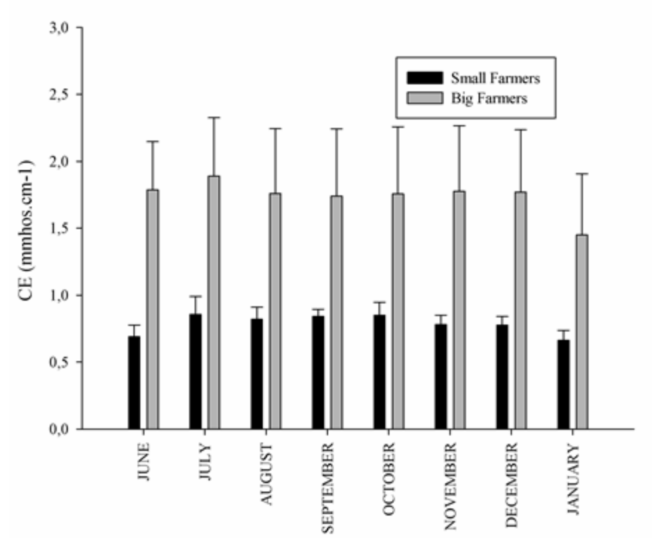

Figure 7. Electrical conductivity of irrigation water, Vinces canton.

Figure 8 shows the TDS values in the water; productive units of less than 7 ha reflected values in a range of 0.45 ± 0.13 ppt TDS. However, for productive units with 30 or more ha, the value was higher with 0.86 ± 0.30 ppt of TDS in the months evaluated, so they do not have any degree of restriction for agricultural use. The General Directorate of Water (2017) reports TDS values ranging from 0.10 ppt to 2 ppt.

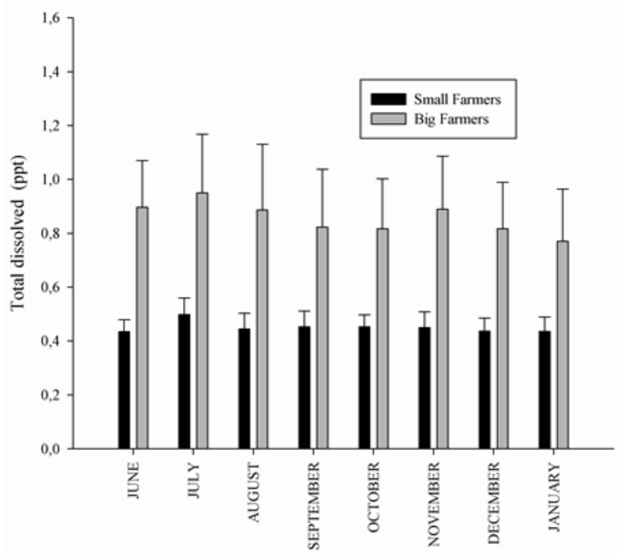

Figure 8. Total Dissolved Solids (TDS) in the irrigation water of the Vinces canton.

Water quality values recorded in the wells for the variables pH, EC, and TDS in small producers ranged from 6.63 to 7.16 for pH, 0.43 to 1.42 mmhos.cm^{-1} for EC, and 0.20 to 0.71 ppt for TDS. However, large producers showed a slight increase in the evaluated variables, with pH values from 6.55 to 7.40, EC from 0.80 to 2.59 mmhos.cm^{-1}, and TDS from 0.40 to 0.71 ppt. These values present no restrictions for agricultural use according to the General Directorate of Water (2017).

Table 1 details the estimation of the volume of water for irrigation of small producers, where they have a range of 394 m^3 to 2,940 m^3 of irrigation per day; however, for large producers, the volume of water discharge for agricultural irrigation was 17,500 to 73,040 m^3 of water per day. On the other hand, in the dry season, the application volumes ranged from 9,846 m^3 to 115,050 m^3 in small producers, and in large producers, 2,625,000 m^3 to 11,102,080 m^3 to meet the water needs of the aforementioned crops.

Table 1. Estimation of the volume of irrigated water in the dry season, Vinces canton.

Producer	Irrigated area (ha)	Volume of irrigated water (m^3) per day	Total volume of irrigated water (m^3) in the dry season
Producer 1	3	2,940	73,500
Producer 2	3	4,602	115,050
Producer 3	3	543	13,575
Producer 4	3	959	23,975
Producer 5	3.5	-	-
Producer 6	3.5	394	9,846
Producer 7	6.5	27,200	680,000
Producer 8	30	17,500	2,625,000
Producer 9	70	73,040	11,102,080
Producer 10	100	36,680	5,758,760

Prepared by the authors.

Conclusions

The declines in static levels were constant and progressive in the dry season due to the irrational use of water through pumping systems for agricultural use. The dynamic levels through the pumping test determined maximum drawdowns between 6 to 8 m in depth; however, the recovery of wells had constant rising levels, identifying aquifer recharge.

Recommendations

Producers, knowing the behavior of the hydrodynamic and hydrochemical levels of groundwater used in the production of perennial crops, should improve the use of water resources in the Vinces canton, Ecuador. Access to adequate groundwater and sustainable management of water resources are essential to ensure food security and agricultural development.

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