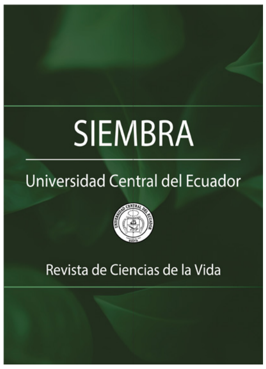
Public policies and technical plot irrigation in Ecuador. A case study of the Píllaro Irrigation System - north branch



Políticas Públicas y riego parcelario tecnificado en el Ecuador. Estudio de caso Sistema de Riego Píllaro - Ramal Norte

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Abstract

The framework of public policies for management of water resources, proposes arguments for the efficient use of water, where technical plot irrigation projects are born, as is the case of the Píllaro-north branch irrigation system, considered one of the most representative experiences of massive and collective pressurized irrigation in the country in the last 20 years. This system currently has more than 5,000 beneficiaries, distributed in 115 irrigation modules, across 3,359 hectares, and 7,700 smallholding lots, with an assigned flow of 1,265 l s^{-1}, and an allocation of 0.39 l s^{-1} ha^{-1}per hectare. This experience of collective modernization is the result of co-management between users, the state and development agencies. This technification process, which has been carried out for 20 years, has brought with it transformations in the territory, making it a precise scenario for evaluating and analyzing the reasons for its success. This technification experience considered key concepts such as the social construction of technology, where four aspects are closely related: infrastructure and civil work, normative, social and institutional components, at national, provincial and local scales. It is also evidenced that the technification of irrigation is seen in an integral and comprehensive perspective, where a "reproduction of technology" is carried out as an endogenous process, allowing a strong interdependence and unity between infrastructure, regulations and the reagents organization.

Keywords: irrigation, modernization, land plots, public policies.

Resumen

El marco de las políticas públicas para la gestión de los recursos hídricos propone argumentos para el uso eficiente del agua, en donde nacen proyectos de riego parcelario tecnificado, como es el caso del sistema de riego Píllaro-ramal norte, considerado una de las experiencias más representativas de riego presurizado masivo y colectivo en el país, en los últimos 20 años. Actualmente este sistema posee más de 5.000 usuarios beneficiados, distribuidos en 115 módulos de riego, bajo una superficie de 3.359 ha, y 7.700 lotes de minifundio, con un caudal asignado de 1.265 l s^{-1}, y una dotación por hectárea de 0,39 l s^{-1} ha^{-1}, siendo esta experiencia de tecnificación colectiva resultado de una cogestión entre los

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usuarios, el Estado y organismos de desarrollo. Este proceso de tecnificación se ha llevado a cabo durante 20 años, lo que ha traído consigo transformaciones en el territorio, por lo que, este es un escenario preciso para evaluar y analizar el porqué de su funcionalidad. Esta experiencia de tecnificación considera conceptos claves como la construcción social de la tecnología, en donde están íntimamente relacionados cuatro aspectos: infraestructura y obra civil, lo normativo, lo social y lo institucional, tanto nacional como provincial y local. Se evidencia además, que la tecnificación del riego es vista de manera integral, en donde se realiza una "reproducción de la tecnología" como un proceso endógeno, permitiendo una fuerte interdependencia y unidad entre la infraestructura, lo normativo y la organización de regantes.

Palabras clave: riego, tecnificación, parcelario, políticas públicas.

1. Introduction

Water is a essential resource for agriculture, and its efficient use is fundamental for sustainable development. According to data from the Banco Central del Ecuador (2021), agriculture is a vital sector of the economy, accounting for approximately 8.2% of GDP, and providing employment to more than 20% of the total population. Despite this contribution to the country's economic figures, agriculture faces significant challenges, among which is the management of water resources for agricultural activities.

In Ecuador, as elsewhere in the world, pressure on water resources is strong and intensifying over time. According to the data proceeding from the Authorizations' bank of the National Water Secretariat (SENAGUA, 2017); now Ministry of Environment, Water, and Ecological Transition [MAATE], in 2007 the authorized flow reached 479 m3 s^{-1}, corresponding to 31,519 authorizations, while in 2017 the authorized flow was 520 m3 s^{-1} and there were 41,945 water use authorizations. This means that, in 10 years, the authorized water flow increased by 9%, while the authorizations for its use by increased by 33%. Exports, according to Gaybor Secaira (2008), presently represent another indicator of this pressure on water. Unlike in the past, when production was mainly rain-fed, nowadays all, or almost all, of the area in export crops is under irrigation.

In addition to this increase in demand for water and the decrease in flow rates, other aggravating factors such as the gradual decline in water quality, and the growing distance to access water sources cause even greater pressure on the use of this resource, as well as an increase in social conflicts between the different actors involved, competing for water management.

In the context of climate change, in order to address the problem of reduced natural flows and increased demand for water, technical proposals, such as pressurized irrigation, have been developed for water use optimization With this aim, in 2012, the Ministry of Agriculture, Livestock, Aquaculture, and Fisheries [MAGAP][1] developed the National Irrigation and Drainage Plan [PNRD] (MAGAP, 2012) as a public policy planning tool, which strongly promotes the technification of parcel irrigation. This document was updated in 2019 by SENAGUA and in 2021 by MAATE.

Similarly, starting 2015, the central government, through the Undersecretariat of Irrigation and Drainage, (today Undersecretariat of Technified Parcel Irrigation of the MAG), considered parcel irrigation to be an essential means to optimize peasant production under the umbrella of the Technified Irrigation Project for small and medium-sized producers [PIT, from now on]. This being part of the Project running from 2015 to 2020 to Promote Agricultural Production through the Implementation of Water Resource Use and Utilization Systems for Rural Development and Food Sovereignty.

The PIT project involved an unintervined part of the Píllaro North branch [PRN] irrigation system, the first massive and collective pressurized irrigation system in the country (of the last 20 years), according to the MAG. However, the pressurization experience integrates several intervention processes. It began in 2003, and has involved the support for socio-organizational and technical-productive processes at the Ecuadorian Agricultural Services Center (CESA) since 2000, in addition to the support from the Provincial Government of Tungurahua, and the German Development Bank Kreditanstalt für Wiederaufbau [Kfw], which became involved in 2006. Years later, in 2015 the MAG joined in, providing support through the PIT project. Despite this, there are neither academic studies on the articulation of public policies on technified parcel irrigation, nor

[1] The Ministry of Agriculture, Livestock, Aquaculture, and Fisheries [MAGAP] changed its name to the Ministry of Agriculture and Livestock [MAG] on May 24, 2017, through Executive Decree N°6. This was due to the transfer of aquaculture and fishing activities to a different government department.

on the conceptualization of this terminology.

For the analysis of public policies on the technification of parcel irrigation, this study used a water governance and hydrosocial territories theoretical approach. These understand water governance as "the set of political, social, economic, and administrative systems established to develop and manage water resources, as well as the provision of water services, at different levels of society" (Rogers & Hall, 2003).

According to Vargas and Soares (2008), water governance is an environmental management process that links economic, social, and cultural activities, which are seemingly unrelated, yet closely connected in terms of their impact on physical-biotic systems and the environment. Therefore, the term water governance refers to a broader concept than water management, implying a much deeper process of intertwinement between society and the state through public policies.

As a consequence, understanding water governance provides a useful perspective for analyzing the increasing complexity and interdependence of different levels of government and the governmental, private and social actors who participate with divergent interests in the decision-making process, and interact in the exercise of public water policies. Or, as Vegas Meléndez (2017) puts it, governance is a process of validating public policies through the direct participation of both citizens and influential actors within a common local social context, allowing the technical analysis of sustainability projects.

However, political ecology has given rise to debates that address the interaction between the environment and society in terms of the distribution of, and access to ecological resources; their control, discourses, political systems, and the authority to legitimize them, as well as in terms of the conflicts they generate. Within this context, key concepts have been established to understand the social dynamics associated with water, such as those of hydrosocial territory (Damonte Valencia, 2015).

For Boelens et al. (2016), the hydrosocial territory is the contested imaginary and socio-environmental materialization of a spatial and multi-scalar network in which human beings, water flows, ecological relationships, hydraulic infrastructure, financial means, administrative and legal provisions, and cultural practices and institutions are interactively defined. Additionally, these networks are aligned and mobilized through epistemological belief systems, political hierarchies, and discursive regimes of representation.

Thus, water territories are historically constructed and contested through interactions between society, technology, and nature. This clearly shows, for instance, in the management of both watersheds, and/or irrigation systems, and hydrological cycles, which are mediated by governance structures and human interventions intertwining the biophysical, technological, social, and the political (Boelens et al., 2016).

Despite the importance of plot irrigation technification reflected in the public policies of the irrigation subsector, there exists limited analysis on this topic within Ecuador. Therefore, this research aims to contribute to the development of knowledge about public policy, as well as to propose a model of technification of plot irrigation with a comprehensive, sustainable, and equitable approach, in line with the reality of a territory and the local population in charge of its management.

This research has the following objectives: to analyze the public policy on technified plot iirrigation and its institutional framework in Ecuador; to characterize the technified parcel irrigation model implemented in Píllaro North branch: its design, assembly, and management; in order to determine the existence of crop intensification in the production systems of the technified parcel irrigation model implemented in Píllaro North branch; to establish the cost and sources of financing for the technified parcel irrigation model implemented in Píllaro North branch; as well as to identify and characterize the capacities and values of the irrigators' organization that enabled progress in technification. The central hypothesis is to investigate the elements that have generated public policies for technified parcel irrigation in Ecuador and the consistency of their application at the national and local levels. To this end, the case study will be the Píllaro North branch irrigation system.

Finally, this study characterized the technified parcel irrigation model implemented in the Píllaro north branch irrigation system, which aims to improve the efficiency of irrigation application in the parcels through the use of sprinkler or drip technologies, and thus ensuring sufficient irrigation to meet the demands and needs of the crops identified in the area. Irrigation system where problems of infrastructure for collection, conveyance, and distribution, water rights and allocation, water supply to the system, and organization of users for the Administration, Operation, and Maintenance [AOM] of the system, while highlighting the alliances that system users have managed to establish with different local and national actors to either influence, or to be taken into consideration within State investment projects complying with public policies on the modernization of parcel irrigation.

2. Materials and Methods

2.1. Description of the study area

The Píllaro irrigation system is one of 76 public systems in the country. It has an authorized flow rate of 3,180 l s^{-1}, an irrigable area of 7,500 ha (design area), and 11,075 users, making it representative of the Sierra region in terms of flow volume and number of users.

The construction of the Píllaro Irrigation System dates back to the late 1970s, when the Pucará Hydroelectric Power Plant was completed. With the aim of taking advantage of the turbined water from this plant, the Ecuadorian Institute of Hydraulic Resources [INERHI] built the Píllaro Irrigation Canal along its pipeline (3 tunnels) to the main distribution tank in the Santa Rita sector, which distributes the flow to two branches: El Cahupi ("North Branch") and El Rosario ("South Branch"), benefiting 7,500 families (Recalt, 2010). This irrigation system is located in the province of Tungurahua, Píllaro canton, covering the parishes of San Andrés, Presidente Urbina, and La Matriz (Figure 1).

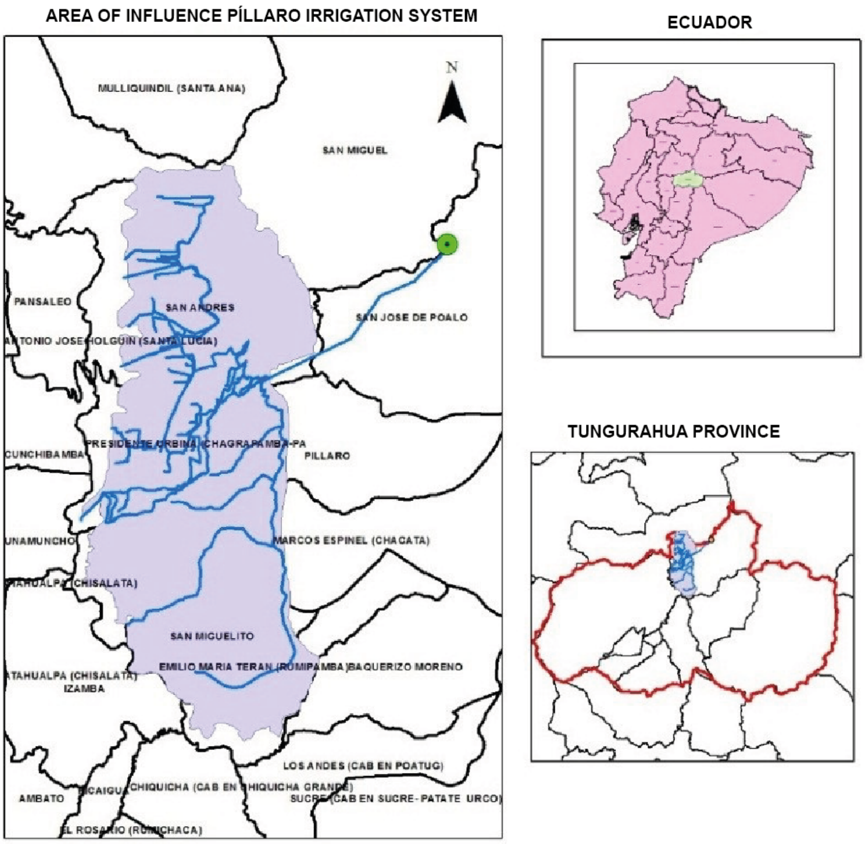

Figure 1. Location of the Píllaro irrigation system - North branch.

2.2. Method

For this research the case study method was chosen for the following reasons:

a) To study in depth the particular characteristics of the Píllaro north branch irrigation system, based on experience and observation of the facts.
b) It would not be possible to study the entire universe of works on this subject due to limited time, and high costs involved in the research; therefore, only this particular case is being studied.
c) Multiple variables can be analyzed based on this particular case.
d) The issue of parcel irrigation technification as a public policy proposal is a relatively new topic.

According to Yin, 1989, as cited in Jiménez Chaves (2012), a case study conceptually consists of a detailed description and analysis of unique social units, It is the study of the particularity and complexity of a singular case, in order to understand its specific activities and circumstances. Within the case study method, data can be obtained from a variety of sources, both qualitative and quantitative, such as documents, archive records, interviews, and direct observation.

This study combined qualitative and quantitative methodologies. Thus, for specific objective one—to analyze the public policy of technified parcel irrigation and its institutional framework in Ecuador— authors conducted a literature review of secondary and basic information obtained from the regulatory, legal, institutional, planning, and public investment framework implemented in relation to technified parcel irrigation policies.

Subsequently, for specific objective two, to characterize the technified parcel irrigation model implemented in Píllaro North branch, its design, assembly, and management, primary information was generated through the application and processing of surveys, and integrated with a literature review to provide historical context for the PRN irrigation system, as well as to describe its design, implementation, and management stages.

Next, for specific objective three, which is to determine the existence of crop intensification in the production systems of the parcel irrigation model implemented in Píllaro North branch, a characterization of peasant production systems was carried out through the application of a structured format to a reasoned, non-probabilistic sample of irrigation system users living in the territory. The instrument was applied to a total of 54 users, and compared with the secondary information available.

In order to characterize the production system, the counterfactual method was used, (which is) a quasi-experimental design used in impact assessments. This allowed for the comparison of two different scenarios, in this case, producers without irrigation (counterfactual or control group), and with irrigation (treatment). The counterfactual scenario was created through a control group made up of peasant farmers without irrigation, with similar characteristics in terms of land area to peasant farmers with irrigation, so that they could be compared. The aim was to answer the following question: - What would be the current situation of irrigated producers if they did not have irrigation? This was done by comparing the results obtained from economic and social indicators of irrigated producers with those of the control group, to calculate the effect or impact attributable to irrigation.

In the Cardo Santo area (sector irrigation board), located in the parish of San Andrés de Pillaro, according to the hydraulic modulation of the irrigation system, the modules known as M1, M2, and M3 are at the tail end of the system, and it is the only area where there are still very few users with no irrigation. Thus, in this area, the tool was applied to 54 cases, divided into three subgroups according to the stratification by land tenure ranges.

Based on this methodology, and according to the economic rationality and agrotechnical logic of the management of its productive units, in the Cardo Santo area, a type of producer A1 was identified with no access to irrigation and an average area of 0.26 ha, whose productive axis was cereals (corn, barley, and wheat); and, three types of producers with access to irrigation (A2, B, and C), whose main production was grass, yet differing in terms of surface area and certain crops that they add to their production system, such as potatoes, corn, beans, and onions. Of these (types), only the first (A) is comparable, both for those with no access to irrigation, and those with access to irrigation. This made it possible to identify the changes that have taken place in the production systems of the study area based on the economic indicators of productivity.

Moreover, specific objective four, which is to establish the cost and sources of financing for the technified parcel irrigation model implemented in Píllaro North branch, was achieved through a literature review of the project, as well as an analysis matrix of existing costs.

Finally, for specific objective five, which is to identify and characterize the capacities and values of the irrigation organization enabling progress in technification, by conducting a qualified opinion survey of a sample of 54 users of the system, information on the perception of these capacities and values was collected.

3. Results and Discussion

3.1. Analysis of public policy on technified irrigation and its institutional framework in Ecuador

The national legal framework for irrigation management in Ecuador is currently defined by: the Constitution of the Republic of Ecuador, the Code of Territorial Organization, Autonomy, and Decentralization [COOTAD]; the Organic Code of Planning and Public Finance [COPFP], the Organic Law on Water Resources, Use and

Exploitation [LORHUyA[2]], and its regulations, the Organic Law on Rural Lands and Ancestral Territories [LOTRTA], Resolutions of the National Competence Council (N° 0008-CNC-2011, 0012-CNC-2011, and 010-CNC-2012), Presidential Decrees (such as No. 206-2017; No. 989-2020), Ministerial Agreements and Resolutions of MAG and MAATE (such as MAGAP-2012-0342, MAATE-2022-096), and Ordinances of Decentralized Autonomous Parish and Cantonal Governments.

Regulatory documents addressing macro issues: irrigation to guarantee food sovereignty, including planning, competencies, budgets, and the sole water authority; with a particular focus on technified parcel irrigation, which is addressed through the planning of programs and projects with budgets, targets, and indicators.

The irrigation and drainage subsector in Ecuador is the result of socio-organizational, economic, institutional, political, and regulatory implications and changes - PNRD Update (MAATE, 2021). The institutions related to irrigation in Ecuador are summarized in Table 1.

Table 1. Institutional transitions related to irrigation and its technification in Ecuador.

N°	Institution	Period	Affiliated with/Unit
1	National Irrigation Fund	1944 – 1966	Ministry of Public Works
2	Water Resources Directorate	1944 – 1966	Ministry of Development (later Ministry of Agriculture)
3	Ecuadorian National Institute of Water Resources [INERHI]	1966 – 1994	National Water Resources Council
4	National Water Resources Council [CNRH]	1994 – 2007	Ministry of Agriculture, Livestock, and Fisheries
5	National Irrigation Institute [INAR]	2007 – 2010	Ministry of Agriculture, Livestock, and Fisheries
6	Provincial Decentralized Autonomous Governments [GAD]	2011 - present	
7	Ministry of Agriculture, Livestock, Aquaculture, and Fisheries	2011 – 2015	Undersecretariat of Irrigation and Drainage
	National Water Secretariat [SENAGUA]	2015 – 2020	Undersecretariat of Irrigation and Drainage
8	Ministry of Agriculture and Livestock [MAG]	2015 - present	Undersecretariat of Technified Parcel Irrigation
9	Ministry of Environment, Water, and Ecological Transition [MAATE]	2020 a la present	Undersecretary of Drinking Water, Sanitation, Irrigation, and Drainage

Source: PNRD 2021-2026 (MAATE, 2021).

Indicating that currently (2025), the institution responsible for promoting parcel irrigation is the MAG's Undersecretariat of Technified Parcel Irrigation. According to its functional organic statute, the entity's mission is to "coordinate, promote, control, and monitor the management of agricultural use and exploitation of water resources and the technification of plot irrigation at the national level.

Whereas, the mission of the Undersecretariat of Drinking Water, Sanitation, Irrigation, and Drainage of the Ministry of Environment and Water Management (MAATE), is: "To coordinate the management of the drinking water, sanitation, irrigation, and drainage sectors through the development and application of both technical and regulatory instruments, with the aim of contributing to the efficiency of public and community providers in terms of continuity, quality, sustainability, and equity under the approaches of comprehensive and integrated water resource management."

[2] The National Assembly of Ecuador passed this law on June 24, 2014. However, in 2015, the Confederation of Indigenous Nationalities of Ecuador [CONAIE], the Confederation of Kichua Peoples of Ecuador [ECUARUNARI], and other social organizations filed a constitutional challenge. The basis for this challenge was the claim that there was insufficient citizen participation and pre-legislative consultation. In 2022, the Constitutional Court of Ecuador declared the law and its regulations unconstitutional and ordered the President of the Republic to draft and submit a new bill to the National Assembly for consideration within 12 months. Consequently, the prevailing legal framework and its associated regulations will remain in effect. As of 2024, three bills have been submitted but not yet reviewed by the National Assembly (Consorcio de Capacitación para el Manejo de los Recursos Naturales Renovables [CAMAREN]. 2024).

Additionally, analyzing the statute of the Decentralized Autonomous Government of Tungurahua, one finds the Directorate of Water Resources and Environmental Conservation, and within it, the Irrigation and Drainage Management Oversight Unit. Among its powers and responsibilities: to conduct studies concerning both traditional and technified irrigation, according to the Provincial Irrigation Plan.

3.2. Characterization of the technified parcel irrigation model implemented in Píllaro North branch: its design, assembly, and management

Currently, the Píllaro North branch irrigation system has a permanent water use allowance for irrigation of 1,270 L s^{-1}, which, distributed over 3,217 ha, amounts to 0.39 L s^{-1} ha^{-1}, giving an evapotranspiration replacement value of 3.36 mm day^{-1}. Whereas, for the Píllaro area, the average evapotranspiration is 3.50 m day^{-1}, which is close to optimal. With the application of pressurized irrigation, this situation further improves application efficiency and coverage within the plot.

The process of modernizing plot irrigation in the Píllaro North branch was carried out in two phases:

i) ***the suitability of the technology package (until 2003)*** which integrated support for people based on the perceived need to modernize irrigation at the plot level, focusing on the development of designs, which translates into cadastral surveying, hydrological studies with micro-basin characterization, analysis of agroclimatic parameters, soil-water-plant analysis, and a production proposal to obtain the agronomic design that integrates the technical analysis of the irrigation methods to be implemented, reaching the hydraulic design with the designed flow, sectors, and shifts; and, hrough the hydraulic scheme with the works to be implemented.

ii) ***ii) the adoption of new technology (by 2015)***, This involved several tests of the installation and commissioning of the system, with local promoters in each irrigation module checking the condition of the water supply infrastructure, such as pressure-reducing tanks or open boxes located at the top of the module, to ensure that they were clean and that the filters were free of debris, thus preventing clogging of the pipes. In addition, they had solid knowledge of how to operate the valves, first opening the drain valves before operating the sprinklers to prevent dirt and/or stones from entering and clogging the pipes. They also knew the layout of the pipes so that all the control and air valves were in perfect condition without leaks, and could be adjusted correctly. In other words, they had detailed knowledge of how irrigation worked on their plots.

At the same time, the leaders of the irrigation system provided support to strengthen their management tools, such as statutes, internal regulations, and user registers, and put them into practice. Users also received training in production in order to strengthen their economic production system at both the plot and local levels.

Table 2 herebelow presents a summary attempting to identify the particularities of each component of the Píllaro North branch irrigation system that make it work and serve as a national benchmark, ultimately allowing us to understand the social construction and local reproduction of technology in the case object of this study.

Table 2. Particularities of the components of the Píllaro system – North branch.

Components of the irrigation system	Particularities
Irrigation infrastructure and network	• Hydraulic design with the greatest possible detail in the cadastral survey (definition of the boundaries of houses, sectors, etc.). • Management of the module-sector (25–30 ha), which makes it more manageable, respecting the rationality of the territory, i.e., it remains in the same neighborhood. • Design of distribution at the module level rather than the plot level. • Implementation managed by local developers who have undergone extensive training. • Users' understanding of the need to optimize water use.
Rights and distribution	• Shifts are resolved (shift conversion) within this system, with water arriving every 8 days for 12 hours at a flow rate of 0.39 L s^{-1} ha^{-1}. • To ensure the proper implementation of each module, there is a local promoter and an operator or water carrier. In addition, there is an Administration, Operation, and Maintenance [AOM] manual for the maintenance of parcel irrigation, which establishes the agreements for the proper management of this irrigation model. • Fee of USD 8 ha^{-1} $year^{-1}$ plus USD 0.50 to the water carrier per month.

Components of the irrigation system	Particularities
Irrigators' organizations	• High level of organization. The General Users' Association [JGU] guarantees water from the source to the module or sector, and the local promoter guarantees it at the plot level to each user. • Management and enforcement of management instruments (statutes, internal regulations, user registry, fines, and relatively low delinquent accounts). • Strong counterpart in unskilled labor. • Permanent participation of users in the design, construction, maintenance, and operation of the system.
Production systems	• Previously: corn, lupine, zambo, barley • Currently: corn, potatoes, oats-vetch, beans, broccoli, Paiteña onions, grasses, vegetables, fruit trees • The management of production systems was addressed using a systemic approach, analyzing the set of agricultural, livestock, and non-agricultural activities interrelated with the agroecological environment
Strategic alliances	• Leaders with institutional relationship skills who managed to articulate their interests with the Tungurahua GAD, the MAG, and NGOs • A direct relationship between the JGU and public entities

3.3. Determination of the existence of crop intensification in the production systems of the technified parcel irrigation model implemented in Píllaro North branch

The counterfactual method, which is a quasi-experimental design used in impact assessments, was used to characterize the agricultural and production systems. This method allows for the comparison of two different scenarios, in this case, producers without irrigation (counterfactual or control group), and with irrigation (treatment).

The counterfactual scenario was created using a control group of farmers without irrigation, with similar characteristics to farmers with irrigation in terms of land area; so, that they could be compared. The aim was to answer the question: What would the current situation of producers with irrigation be, if they did not have irrigation? This was done by comparing the results obtained from economic and social indicators of irrigated producers with those of the control group, in order to calculate the effect or impact attributable to irrigation.

Within the Píllaro North branch irrigation system is the Cardo Santo area (sectoral irrigation board), located in the parish of San Andrés de Píllaro. According to the hydraulic modulation of the irrigation system, the modules designated M1, M2, and M3 are at the tail end of the system. In these three modules, based on the users' registry, there are 248 plots under 111 users. In these modules, there is an unirrigated area for comparison purposes.

In the Cardo Santo area, based on economic rationality and the agrotechnical logic of managing production units, a type of producer A1 without access to irrigation was identified, with an average area of 0.26 ha, whose main production is cereals (corn, barley, and wheat), and three types of producers with access to irrigation (A2, B, and C) whose main production is grass, but differing in terms of surface area, and (certain) crops integrated to their production system, such as potatoes, corn, beans, and onions.

Of these types, only the first (A) is comparable, both for those without access to irrigation, and those with access to irrigation. This allows to identify the changes that have taken place in the production systems in the study area.

With regard to the economic productivity indicators for these types of producers, the net agricultural income [NAI], which is the amount of money that the producer actually has to live on once the wealth generated [VAN] has been distributed in the payment of land rent, water rent, hired labor, credit, etc., was analyzed.

The NAI generated in Cardo Santo for farmers who do not yet have irrigation was USD 579 ha^{-1}, with a yield of 13 q ha^{-1} of corn, sold at a price of USD 20.00; 10 q of barley sold at USD 25.00 and 10 gg of wheat sold at USD 22.00. It should be noted that this type of farming produces one cycle of corn, barley, and wheat per year, yielding a gross product per hectare of USD 730. It is worth mentioning that this type of farmer is rare in the study area, as most agricultural producers already have access to irrigation.

Meanwhile, type A2 with access to irrigation generates a total NAI of USD 1,179 ha^{-1}, from its productive system composed of grass and potatoes (50% grass and 50% potatoes), with two potato harvests per year and a dairy cattle breeding system (two cows in production, average yield of 8 L cow^{-1} day^{-1}), pigs, and guinea pigs.

Considering the NAI generated by type A1 without irrigation, which corresponds to USD 579 ha^{-1}, and comparing it with the NAI generated by type A2 with irrigation, which reaches USD 1,179 ha^{-1}, we see that the irrigated type exceeds the non-irrigated type by 204%, which shows that technical irrigation has an impact on this economic indicator, which represents the amount of wealth obtained by a farmer as a result of their agricultural activity in their production system or farm. It should also be considered that irrigation allowed for two potato cycles per year.

3.4. Establishment of the cost and sources of financing presented by the technified parcel irrigation model implemented in Píllaro North branch

The cost of one hectare of the parcel irrigation model implemented in the Píllaro North branch system amounts to USD 2,600, which includes preliminary works, earthworks, PVC pipes in general, PVC accessories in general, valves in general (gate valve kits and air valve kits), complementary works (hydrant kits, parcel irrigation application kits, pressure relief tank equipment accessory kits). Added to the value indicated in Table 2 are the studies prior to parcel irrigation, which amount to USD 200.00.

With regard to the financing of the technified parcel irrigation system, this is presented in a historical summary in Table 3:

Table 3. Financing of pressurized land irrigation in the Píllaro North branch Irrigation System. 2000-2020.

N°	Concept	Funder	Period	Total Funding
1	Insertion phase	Intermón[3]	2000-2001	29,196.93
2	Irrigation and Local Development Píllaro North branch Phase I		2001-2002	1,712,991.18
3	Irrigation and Local Development Píllaro North branch Phase II	Agro Acción Alemana AAA	2006-2011	626,555.51
4	Irrigation and Local Development Píllaro North branch Phase III	Agro Acción Alemana AAA	2008-2012	397,225.47
5	Project for the widespread adoption of plot irrigation technology Phase I	German Federal Ministry for Economic Cooperation and Development (BMZ)	2013-2014	1,597,450.00
6	Project for the widespread adoption of plot irrigation technology Phase II	Ministry of Agriculture and Provincial Government of Tungurahua	2015-2016	3,347,800.00
7	PIT Plot Irrigation Project	Ministry of Agriculture and Provincial Government of Tungurahua	2018 -2020	1,649,185.00
	Total			**9,360,404.09**

The users interviewed mentioned that the cost they assumed is that corresponding to the cost of the sprinklers, which is USD 12.00 each, to which they added the contribution of five mingas per plot. One hectare requires eight sprinklers and 28 mingas. If the mingas are valued at a daily wage of USD 15.00, each irrigator would contribute around USD 516.00, or 17% of the total cost of one hectare.

State investments for improvements to the main and secondary canals are not considered, as this study focuses on the modernization of irrigation at the plot level. However, according to the records of CESA (2014), this intervention in the main and secondary canals amounts to around USD 13.0 million, including works on the southern branch of the Píllaro irrigation system.

3.5. Identification and characterization of the capabilities and values of the irrigation organization that enabled progress in technification

Management capacity is necessary within irrigation organizations, as they must demand active and effective participation in the identification, design, preparation, implementation, and supervision of technological improvement projects, since this enables collective empowerment and learning processes. Organizations must be capable of self-management, and of organizing fee collection, as well as of resolving internal conflicts and participating in technical training processes in: AOM, organizational management, sustainable agriculture, and watershed management.

[3] Intermón was a German non-governmental organization that initially financed the irrigation modernization project in Tungurahua.

Users' perception of management capacity is high, according to 71% of those interviewed, while the remaining 29% rated it as average. Users with a high perception indicated that, if public, community, and private co-financing mechanisms existed, the development of co-management of this system would be successful and would allow for the sustainability of these processes.

Internal conflicts arise due to the methods or limits of water distribution, control over shifts, and demand for access to water. Users' perception of internal conflict management is 57% high, 34% medium, and the remaining 9% low. One mechanism for problem solving is set out in the internal regulations for administration, operation, and maintenance, which establish the rights and obligations of users.

As to users' perceptions of equity values, 63% of the interviewed responded that it is high, while the remaining 37% rated it as medium in their responses. Users whose perception is high indicated that there is equity within the system, mentioning that they have equitable access to water in terms of flow and time. They also mentioned that they feel they are treated equally in mingas, in participation in general assemblies, and in fines if they commit any offense, as stipulated in the general regulations.

Regarding the perception of transparency, 54% rated it as high, 31% as medium, and the remaining 14% as low. The leaders mention that every six months they present a management report at the general assembly. It should be noted that this system uses accounting software to record all income and expenses. The irrigation system has been using this software since 2014. It is relatively easy to use and issues a register of members by module and surface area ("user register"), as well as a user billing system that automatically grants a 10% discount to those who pay in the first three months of the year, Also, it issues accounts receivable, up-to-date payment reports, and billing history for reporting to the Internal Revenue Service.

4. Conclusions

Although Ecuador has a comprehensive legal and regulatory framework that addresses both drinking water and irrigation water from the macro and the micro level, such as the 2008 Constitution, the Code of Territorial Organization, Autonomy, and Decentralization [COOTAD], the Organic Law on Water Resources, Use and Exploitation of Water [LORHUyA], as well as Presidential Decrees and GAD Ordinances, among others; the issue of the technification of plot irrigation is not addressed with great focus, with few sections considering it. Since Ecuador does not have a specific approach to technified irrigation of individual plots in its legal and regulatory instruments, it ends up being very confusing, and each institution interprets it according to its own competence and powers.

From an institutional standpoint, Ecuador has undergone a confusing institutional restructuring in recent years. This made it difficult to understand the competences and powers of the institutions related to irrigation and the technification of individual plots.

Public policies on irrigation and, more specifically, technified irrigation of individual plots, although planned for the long term (15 years), change with the authority in power and what it expresses through its Development Plan. This is reflected in the programs aimed at the technification of irrigation of individual plots contemplated in the PNRD and its updates, which vary from the name to the planned budget.

There is limited consistency between the prioritization of interventions—official planning—and their implementation at the national and local levels. In other words, planned projects are not being implemented, either due to a lack of timely resource transfers or institutional capacities for budget execution.

This model of irrigation technification highlights some key principles, including that irrigation technification is viewed holistically and considered a social construct in which "technology reproduction" takes place in an endogenous process, allowing for strong interdependence and unity between infrastructure, regulations, and the organization of irrigators. Physical-technical, economic-productive, socio-organizational, political, and ecological aspects were incorporated into this process.

In other words, the technified parcel irrigation model implemented in the Píllaro North branch irrigation system is characterized by its focus on improving the efficiency of irrigation application in the parcels through the use of sprinkler or drip technologies, thus ensuring sufficient irrigation to meet the demands and needs of the crop identified in the area. Issues related to infrastructure for collection, conveyance, and distribution, water rights and allocation, water supply to the system, and user organization for the AOM of the system.

It must be acknowledged that irrigation is a fundamental means of increasing productivity and food supply, as well as of generating more employment and increasing farmers' income levels. This is reflected in the NAI generated by non-irrigated producers, which corresponds to USD 579 ha-1, compared to the NAI generated by irrigated producers, which reaches USD 1,179 ha-1, exceeding that of non-irrigated producers by 204%, which shows that irrigation has an impact on the economic indicator that represents the amount of wealth obtained by a farmer as a result of their agricultural activity in their production system or farm. It should also be considered that irrigation allowed for two potato cycles per year.

Public investment in the modernization of parcel irrigation in areas where small family farming predominates is a very concrete mechanism for redistributing the country's wealth. In the Píllaro North branch irrigation system, the reference cost of implementing one hectare of gravity-fed pressurized parcel irrigation ranges from USD 3,000 to USD 5,000. However, if we look at the total public investment and the national and international cooperation entities that have intervened in this territory for irrigation, this item amounts to around nine billion dollars from 2000 to 2020, showing that there has been significant investment over a long period of time.

The General Assembly of Users of the system has carried out a series of actions involving articulated processes of coordination, participation, negotiation, and consensus-building with public and private entities, such as, for example, the cadastral survey of the project's area of influence; the preparation and ongoing updating of user registers; the definition of an equitable distribution of water, determining irrigation shifts and times according to the area to be irrigated; the design and implementation of a tariff system for water use; the acquisition of computer software to manage the resources collected; achieving a high level of recognition, representativeness, identity, and credibility both within the area and outside it.

Contributor roles

- Ana Gabriela Velastegui Páez: conceptualization, data curation, investigation, methodology, resources, project administration.
- Soledad Montserrat Valdivieso Armijos: investigation, validation, writing – original draft.

Ethical implications

The authors declare that the ethical principles of autonomy, dignity, non-discrimination, justice, representativeness, voluntariness, confidentiality, and anonymity were applied in the collection of information through surveys. Additionally, all information about the purpose and methodology of the research was shared. Informed consent was obtained from all participants.

Conflict of interest

The authors declare that they have no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

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