

An Economic Theory Perspective for the Fight Against Poverty in the Peruvian Andes

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ABSTRACT

The fight against poverty in the Peruvian Andes is a complex task in which various professionals, such as engineers, economists, anthropologists, among others, participate. The uncertainty of the decisions taken today, no matter how appropriate they may seem, such as million-dollar investments in irrigation infrastructure, can result in over-production and, therefore, in economic recessions. For this reason, a new mathematical simulation model is proposed using system dynamics to predict recession phenomena that can occur in months or after a few years of auspicious economic growth, and that can cause sales prices to be below production costs. The author has developed the conceptualization of the production system of irrigation improvement projects in several years of multidisciplinary work in the Cusco region of Peru. The primary objective of irrigation projects is to improve the socio-economic conditions of the farmer. Techniques as the fulfillment of goals have been used to quantify qualitative dimensions such as strengthening organizations and trainings that are key to guaranteeing irrigation improvement projects' sustainability in the long term. Therefore, it has been possible to identify the variables and relationships of this type of socio-economic system. To validate the model, we verified that the simulated data are consistent with the historical data collected. Likewise, if the values of the various proposed models' variables are adequately modified, these can be applied to other types of production systems under different market conditions. The dimensions addressed, such as supply, demand, sale price, land, production volume, public budget, etc., enhance the research's importance, making the simulation model formally expressed also acquire nuances from economic theory for the fight against poverty-based on water. One of the study's conclusions is to understand the production systems, it is necessary to see them in the context of their regional economy's behavior.

1. Introduction

One of the most important policies in the fight against poverty of the Peruvian government is implementing irrigation improvement projects. In this paper, we will address issues in greater depth about the experience of Plan Meriss Inka (PEPMI) to deal with the social component. We will highlight the characteristics that make this research an economic theory of water perspective that could not be exhibited in work originally submitted in the 2019 IEEE World Engineering Education Conference (EDUNINE) [1].

The primary nature of the irrigation improvement projects implemented by PEPMI is multidisciplinary, in which professionals of different natures such as engineers, economists,

biologists, anthropologists, among others. One of the characteristics that stand out from this type of project is the high social component [2]. Since the first projects' implementation, it was observed that, despite providing rural communities with modern irrigation infrastructure. Farmers were reluctant to use it. A situation that has required social partners to decipher this peculiar impasse. Anthropologists' role in these cases has been essential to understanding the farmer's idiosyncrasy in terms of the intervention of new irrigation projects in their communities it refers.

From work carried out, it was concluded that the resistance to using the new irrigation infrastructure was because the farmer only uses the irrigation infrastructure that they have built and, therefore, they consider it as their own. So, not having participated in constructing this new irrigation infrastructure donated by the government, they did not consider it their own. To overcome this

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problem, Community participation is incorporated as part of the project's financing, which consists mainly of the farmers' workforce's valuation in the construction of the irrigation infrastructure [3]. Similarly, there are cases of projects in which it has been possible to significantly improve water resources available without the need to build new irrigation infrastructure; it was only required to improve water management and irrigation techniques to increase agricultural productivity. This experience leaves an important lesson for professionals who are not from the social area, which is that, to achieve the objectives of the projects, they should improve their communication skills and understanding of the farmer idiosyncrasies in the area [3]. The social component is just one of the many problems. It gives an idea of the complexity of understanding and managing irrigation improvement projects in the fight against poverty in the Peruvian Andes. The ability and experience to face these peculiarities have made the PEPMI to be considered as a model project in South American by the German donors German Technical Cooperation (GTZ) and the State Development Bank of the Federal Republic of Germany (KfW).

In this understanding, the primary objective to be achieved with social intervention projects is their sustainability in strengthening the organization of farmers and profitability. In other words, farmers must manage their own resources without the accompaniment of PEPMI staff and only through its own organization and self-financed by the profit that results from the sale of their products.

In the Peruvian Andes, there is the occurrence of weather phenomena such as droughts and frosts that cause the loss of crops. The main effect of having adequate irrigation infrastructure is to ensure cultivation; firstly, supplying water in case of droughts and making it possible to recover plants from frosts. So that at least one harvest per year can be ensured. This is also known as crop safety. It is possible to increase the number of agricultural seasons per year by up to two in the best cases. Then, water administration is a strategy ancestrally used since the Incas to face unpredictable climatic changes and to guarantee food for the population [4].

To overcome these problems, millions are invested in infrastructure and training. But in the projects implemented in the Chumbivilcas-Espinar provinces, it has been shown that this does not always happen. Due to the overproduction of dairy products, there was a regional recession. A phenomenon in which supply exceeds demand and produces a drop in prices. In this case, prices fell even below production costs. So, the right short-term decisions can lead to long-term problems [5].

In this research, we are concerned with developing a production model to understand the factors that participate in it. The model simulation process has allowed the model to be validated. However, to know if the production process is profitable. It is required to evaluate it in the environment of its regional economy.

Therefore, it is also necessary to conceptualize and formulate economic factors. This gives greater importance to our research as it analyzes the Andes' economy from a perspective of fighting poverty. The methodology used to achieve our objectives is mainly system dynamics, as it includes the methods of thinking of systems and servomechanisms. The same ones that are suitable for complex systems.

As a result of the research, we have obtained the formulation of the different production sub-systems such as training, investment, available water, infrastructure, and others. And we have also managed to formulate the subsystems of the regional economy such as supply, demand, sale price, competition, etc. This makes it possible to project over time the impact of the irrigation improvement projects' anti-poverty policies. It also allows us to carry out a sensitivity analysis to know if the decisions we make in implementing the project are the correct ones, mainly to avoid regional recessions or falls in products sales prices [1].

2. Related Works

2.1. System dynamics

System dynamics is a popular simulation methodology developed by J. Forrester at the Massachusetts Institute of Technology (MIT). This simulation methodology is based on the theory of servomechanisms and feedback. It is also related to areas such as general systems theory and cybernetics. It also uses methods to study complex systems that act as an interlocutor between engineering methods and the methods for social systems [6]. One of the most important applications of System Dynamics is the world model published in 1970. A simulation of the behavior of society is shown under current "unplanned" growth conditions. The results of the simulation of the model show an over-exploitation of resources and a drop in population. The more population, the more waste is generated, and the more waste, the more diseases are generated is one of the conclusions of the model [7].

In the work of Fifth Discipline, considered to impact the business world greatly, revalues Forrester's systems dynamics. The author in [5] considers important for the understanding of modern organizations the study of dynamic systems, identifying the system's environment, and feedback mechanisms with it. He does not consider essential to arrive at the formulation of mathematical models. As a conclusion to his studies, he proposes the following disciplines: systems thinking, personal mastery, mental models, the construction of a shared vision, and team learning.

For irrigation research, dynamics can also be applied to the study of water management jobs, as demonstrated in the proposal for an optimization model for irrigation management in Australia [8]. In [9], the authors also developed a simulation model for China's water transport problem. In both works, positive results have been obtained using system dynamics.

2.2. Systems thinking

Systems thinking is the fifth discipline; the importance of systems thinking lies in being the body that unites the other disciplines of intelligent organizations. This job is incisive in pointing out that one of the factors for the failure of projects is the lack of systems thinking in their implementation [5]. Systems thinking is based mainly on the method of extension or synthesis. This becomes a premise for troubleshooting, where it is recommended to first view the system as part of a bigger system [10]. In this regard, we must comment that the classical scientific method, as we know, uses the analytical or reductionist method,

which, contrary to the synthetic method, what it does is studying the system in its components. The author in [11] categorically considers as a limitation of the scientific method. However, one of the most renowned authors on epistemology comments that systems thinking is an unfounded fashion issue and cannot generate scientific knowledge [12]. The author in [10] refuted this position, who maintains that the analytical and synthetic methods do not replace each other. On the contrary, they complement each other. In the present work, we show that it is possible to generate knowledge in the scientific method's formal language, between the system and its environment (exogenous variables) and the feedback mechanisms for adjusting the endogenous variables.

2.3. Fight against poverty

Thus, water is the engine for the economy of the Andes, although its cost is relatively low given its usefulness. To highlight the importance of water, we will mention the water-diamond paradox that tries to explain the low cost of water concerning diamonds that cannot generate life. This explains that, although the marginal utility of diamonds is much greater than the marginal utility of water, water's total utility is always greater than the total utility of diamonds [13].

To eradicate poverty, the author in [14] comments that the financial system has been saved on a global scale; for example, in Mexico, the banking system has been saved. Consequently, the cost of helping the poor is much lower and, in financial terms, more profitable if they are to be part of the aggregate demand. And, despite extreme poverty, we seem to have plenty of resources. At the same time, another study concludes that almost a billion people go to sleep hungry every day. In comparison, another billion people suffer from obesity, and 30% of food production is wasted, even from its mismanagement in harvest, sales, and post-consumption [15].

3. Methodology

The experience that served as inspiration for this work was that of the irrigation improvement projects in the Chumbivilcas-Espinar provinces that, due to their height (over 3820 m.a.s.l.) and geography, these are areas where low temperatures predominate (even below zero), all this leads to the existence of extreme poverty in the area [16]. Conditions that, in the first instance, made interventions in the so-called "high" provinces impractical. However, initially, they gave unexpected positive results thanks to the experience of the PEPMI and the adaptation of strategies that consisted, mainly, in cultivating imported pastures that resisted low temperatures and that were the main engine of the livestock industry and its derivatives in the area. Which brought the economic growth of the area. Despite this, after a few years, there was overproduction that manifested itself in the drastic decrease in sales prices. Therefore, it is necessary to manage uncertainty, the consequence of the decisions we make, and that, at first, seem the correct ones in the medium and long term, can become counterproductive. The explanation for this phenomenon was that an adequate market study was not carried out. Thus, to understand the interaction of the multiple factors, it was necessary to understand the behavior of the market and the mechanisms by which the sale price was mainly obtained. In an economic theory,

appears the next components: consumers, producers, the market for goods and factors, and government intervention [13]. To formulate the simulation model of the production system, all these dimensions have been taken into account. Therefore, in this document, we will extend the original work to a perspective of economic theory whose main engine is water. In Figures 1 and 2, we can see the Sutunta lagoon and the dam built to store 4 million cubic meters to irrigate 6000 hectares.

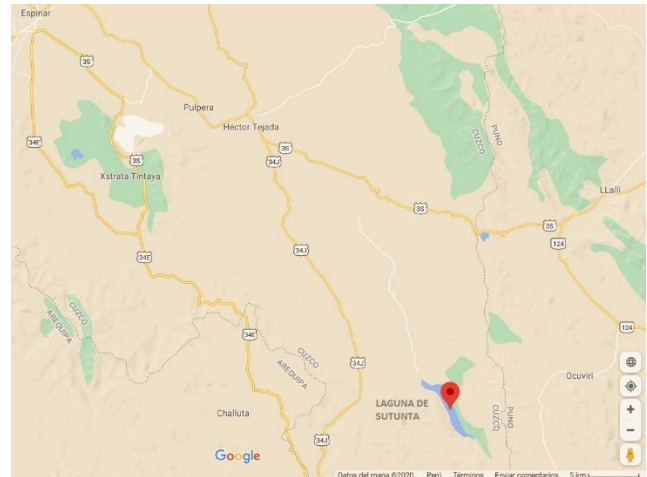


Figure 1: Location map of the Sutunta lagoon in the province of Espinar-Cusco over 4000 m.a.s.l.



Figure 2: The dam built in Sutunta lagoon

In the conceptualization and formulation of the new production model, the systems dynamics methodology was used. The same one is based on the general theory of systems proposed in [11], the author that deals mainly to provide a general framework for science. To do this, it recognizes the concept of equilibrium or homeostatic point. The same that we must reach in the interaction of supply and demand in the market model also proposed [1]. Nash's equilibrium abstracts the theory of non-cooperative games that involve sellers' participation, sets of strategies, and profits [17].

In the conceptualization phase, approximately 285 variables have been identified. The same ones have been organized in the dimensions of investment, training, organization, water for irrigation, irrigation infrastructure, production, market, environment, public budget, and water supply. As mentioned

above, the organizational dimension is primarily qualitative, and techniques have been used to allow it to be considered and provide qualitative information. This dimension has been adequate to be considered in the proposed production model. Another characteristic is that the production model allows obtaining a production volume that is considered supply and considering the existence of competition. Therefore, it is not an empirical model for educational purposes [6]; otherwise, it can provide information in a real environment. The number of variables and the peculiarities described makes it different from the authors' production models in [18], who propose a model of positive mathematical programming for models of regional production in agricultural-environmental programs and the classic spider web model [13].

The simulation of the production model has been carried out in the VENSIM program; the simulation results have served to validate the model. For validation, the Anderson-Darling normality test was used, whose results have been superior to $\alpha = 0.05$. As a result of the optimization model, non-linear programming with restrictions has been used to develop an optimization model that allows us to find the global optimum (profit maximization, cost minimization, and equilibrium point). Likewise, an analysis was carried out on the optimization model using nonlinear programming and genetic algorithms to determine the selection operators' efficiency in restricted non-linear problems.

4. Discussion

4.1. Conceptualization of the elements of the economic system for the fight against poverty based on water

In South America, the Inca culture developed. One of the most important cultures in the world whose cultural richness was based on values such as community work, also known as the "ayni" and the "minka". The Incas built large hydraulic works with the primary purpose of supplying food to the entire population. The importance of institutions like the PEPMI lies in need to revalue the cultural richness that, in some way, was being forgotten. In the field of intervention, they can be observed as problematic situations: inadequate irrigation infrastructure (inland canals that filter water), little farmer organization, and little knowledge of irrigation techniques [4]. This situation can even be complex if the following characteristics exist: conflicts, undefined access rights to water, water scarcity, and geological problems [3].

To solve these problematic situations, PEPMI implements irrigation improvement projects whose objective is to provide the population in the project area with the possibility of improving production and, therefore, improve their quality of life through access to more and better education, health, etc. services.

4.1.1. Production systems modeling in irrigation improvement projects

Consistent with the fifth discipline [5], a work in which the author concludes that one of the causes of project failure is the lack of a systems approach. If we review the experience of the projects implemented in Chumbivilcas-Espinar, in which there were

problems of regional recession, after a few years of economic growth, it can be seen that, as part of the bigger system, the "market" is an exogenous component that is always present in the environment of the system. So, it is necessary to carry out an adequate market study and, for simulation purposes, to determine its feedback mechanisms. In figure 1, it can be seen through a block diagram, the main identified subsystems. Given the complexity of these projects' implementation, approximately 285 variables and 90 feedback loops have been observed and properly grouped into subsystems, as shown in Figure 3 [1].

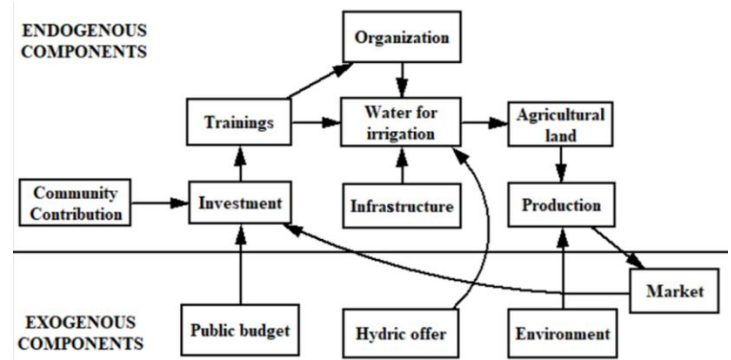


Figure 3: Block diagram of the proposed model for the agricultural production system

Figure 1 also identifies the necessary elements that participate in an economic theory (producers, consumers, goods markets, state intervention, etc.), having, in this case, water as the engine for the fight against poverty [13] or as "Theory of the economic and social value of water" states in a perfect market where there are several buyers and sellers, each commodity in the economy will be given its value [19]. As previously mentioned, the sustainability of projects is based on the strengthening of organizations and profitability. It is, then, necessary to know the profitability to identify the elements that participate under the economic theory defended by various authors [13].

4.2. Formulation and validation of the simulation model

The first objective of the work is to know the future behavior of the production system of the irrigation improvement projects implemented by the PEPMI. So, the planners will have a tool that allows them to know if they are making the right decisions or if the millionaire investments in infrastructure can cause short-medium or long-term adverse effects such as a recession. These phenomena have occurred in the provinces of Chumbivilcas-Espinar and the northern mountain range of Lima [20]. The causal diagrams made in the conceptualization phase have to be converted to mathematical logic models based on Forrester diagrams. For which the Vensim Personal Learning Edition (PLE) software has been used.

4.2.1. Subsystems formulation

Each of the subsystems shown in figure 1 are explained below:

A. Water supply

Determining the future supply of water is one of the main tasks to know. This to guarantee the water supply at the head of the plot. To achieve this, the historical information of the Pampaconga project has been considered. After analyzing the information, it has

been considered to perform a probability function for each month, using discrete probability distribution functions based on histograms. Requirements for the Monte Carlo simulation method [21]. Due to the limitations of Vensim Personal Learning Edition (PLE), the treatment of each probability function has been carried out in Excel and the results added in lookup functions in the implemented model.

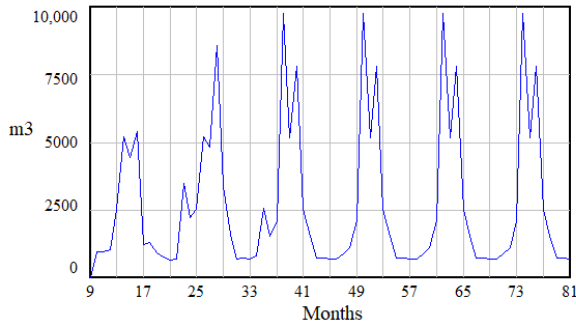


Figure 4: Projection of water availability due to rainfall

As shown in Figure 4, the hydrological year in Peru begins in September (month 9), and the high peaks represent the El Niño phenomenon. With climate change, this phenomenon will be increasingly present in the Peruvian Andes. When this occurs within the project's scope, the loss of production, and even irrigation infrastructure and all kinds of infrastructure is almost inevitable [22].

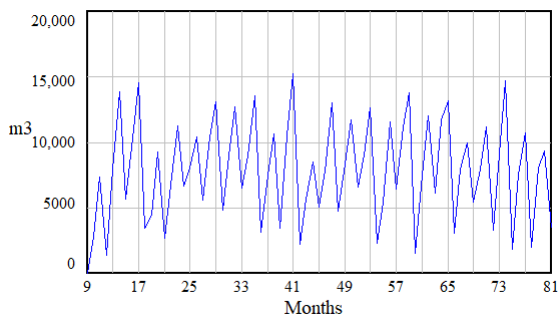


Figure 5: Projection of total water availability

The total water availability is made up of the rains and the flow of the rivers. These are exogenous variables that cannot be influenced. The projection of water availability is shown in Figure 5.

B. Investment

This subsystem is born from the public budget and external debt. For external indebtedness, there is German technical cooperation. According to the experiences of the first works implemented, the farmers showed resistance to change, to use and manage the modern irrigation infrastructure implemented by PEPMI. In addition, there is also the possibility of conflicts between communities over access to water and/or land. This demonstrates the high social component of the irrigation projects implemented [3]. Sometimes the engineer has to act as a sociologist to meet its goals [12]. To overcome these problems, the

multidisciplinary team includes anthropologists, professionals who serve as important interlocutors between farmers and PEPMI.

In conclusion, the resistance to the change presented to use the new and free irrigation infrastructure was due; because farmers only use the infrastructure in whose construction they have participated. Therefore, project financing includes the community contribution, which is approximately 15 to 20% of the total project budget. This amount guarantees the participation of community members in the works to be built [3].

Another characteristic to take into account is that the Peruvian government considers irrigation improvement projects as social programs. And, given the appearance of economic problems, as the global pandemic caused by Covid-19, these programs are the first to reduce the public budget.

In the conceptualization of the production model in its interaction with the market, the investment subsystem receives feedback from the market, specifically, of the profit obtained from the sale of the products and the availability of financing that predisposes the advance of trainings and irrigation subsystems infrastructure.

C. Trainings

Training is an essential component to guarantee the sustainability of the project in its component of strengthening organizations and in terms of increasing productivity in the components of water management and the application of irrigation and cultivation techniques.

The PEPMI, being a state project, depends on the monthly budget. According to the monthly budget, it has the necessary factors to carry out the training: operational equipment, material, and workforce.

Figure 6 shows the Forrester diagram that explains the availability of resources to conduct the trainings.

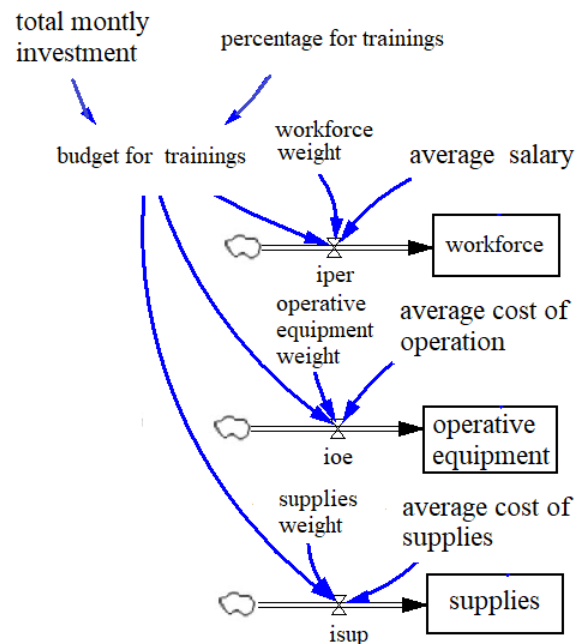


Figure 6: Forrester diagram: Availability of resources for training

The equations that govern the Forrester diagram in Figure 6 are as follows:

$$IPER = (BT*WW)/AS \tag{1}$$

where:

IPER: Personal ratio.

BT: Budget for trainings.

WW: Workforce weight = 0.5.

AS: Average salary = S/ 2000.00.

Percentage for trainings = 0.15.

$$IOE = (BT*OEW)/ACO \tag{2}$$

where:

IOE: Operative equipment ratio.

BT: Budget for trainings.

OEW: Operative equipment weight = 0.3.

ACO: Average cost of operation = S/ 1000.00.

$$ISUP = (BT*SW)/ACS \tag{3}$$

where:

ISUP: Supplies ratio.

BT: Budget for trainings.

SW: Supplies weight = 0.2.

ACS: Average cost of supplies = S/ 300.00.

The trainings are carried out according to the availability of resources. The progress ratio is calculated according to the input targets programmed versus those available. And the total training per month predisposes the increase of water management, efficiency in the application of irrigation techniques, efficiency in the application of cultivation techniques, and strengthening of organizations that are governed by the following equations:

$$WM = 0.065*TPM \tag{4}$$

$$EAIT = 0.06*TPM \tag{5}$$

$$EACT = 0.07*TPM \tag{6}$$

$$SO = 0.065*TPM \tag{7}$$

where:

TPM: Trainings per month (the objective is 4 per month).

WM: Water management.

EAIT: Efficiency in the application of irrigation techniques.

EACT: Efficiency in the application of cultivation techniques.

SO: Strengthening of organizations.

As can be seen in Figure 7, in month 28, approximately the objective is achieved. This indicates that the trainings have made

the farmer achieve 100% adequate water management. Similar behavior is observed in the variable's efficiency in applying irrigation techniques, efficiency in applying cultivation techniques, and strengthening organizations.

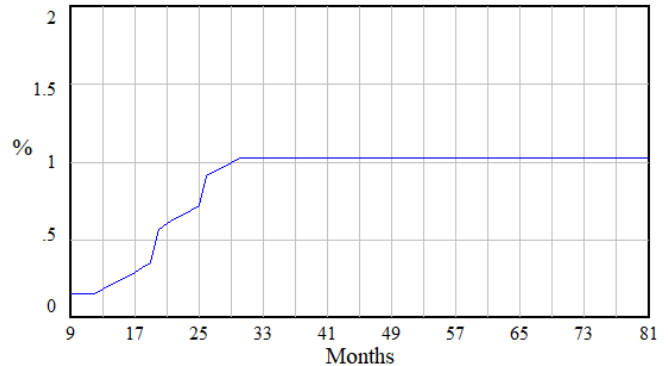


Figure 7: Advancement in water management

D. Irrigation infrastructure

Irrigation infrastructure is the component with the highest cost, depending on the size of the project. Its importance lies in the possibility of transporting water for kilometers without loss due to seepage and optimizing its storage and availability through dams and reservoirs. Advantages that the channels made on land do not have due to the high filtration rate. Irrigation infrastructure is also important to face adverse weather phenomena such as droughts, as it allows managing water scarcity, guaranteeing harvest (crop safety) and counteract adverse weather phenomena such as frost and hailstorms, since having a permanent water supply crops can recover, and, in areas where optimal conditions exist, the number of crops per year can be increased. What is also known as an increase in land use, which is the first step to fight poverty.

Then, the countries need to provide adequate irrigation infrastructure to manage the scarce water resource. This is because the imminent effects of climate change will affect primary sectors such as fisheries and agriculture, such as by 6% to the Peruvian GDP for the year 2030. One of the author's conclusions in [23] is that the emission of polluting gases and, therefore, the effects of climate change will continue. This situation evidently increases the total utility of water as part of managing scarcity and climate variability. Then, new efficient irrigation techniques such as dripping and sprinkling should also be considered. These aspects are already being considered in the making of water and irrigation laws.

Figure 8 shows the Forrester diagram that explains the availability of resources to carry out the irrigation infrastructure.

The equations that govern the Forrester diagram in Figure 8 are as follows:

$$\text{Percentage for infrastructure} = 0.85$$

$$ITS = (BI*TSW)/TSS \tag{8}$$

where:

ITS: Technical stuff ratio.

BI: Budget for infrastructure.

TSW: Technical stuff weight =0.06.

TSS: Technical stuff salary = S/ 2000.00.

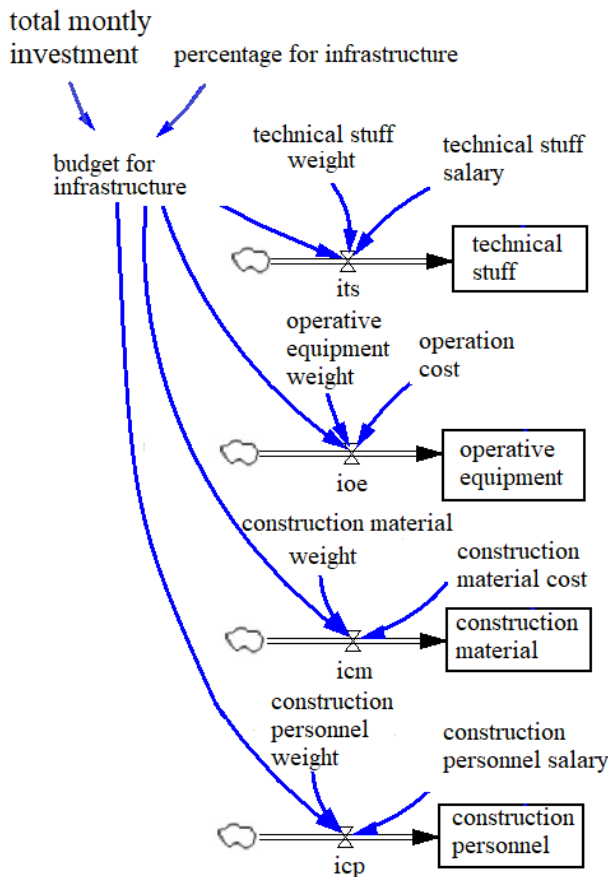


Figure 8: Forrester diagram: Availability of resources for irrigation infrastructure

$$IOE = (BI*OEW)/ACO \quad (9)$$

where:

IOE: Operative equipment ratio.

BI: Budget for infrastructure.

OEW: Operative equipment weight = 0.24.

ACO: Average cost of operation = S/ 4000.00.

$$ICM = (BI*CMW)/CMC \quad (10)$$

where:

ICM: Construction material ratio.

BI: Budget for infrastructure.

CMW: Construction material weight =0.11.

CMC: Construction material cost = S/ 15.00.

$$ICP = (BI*CPW)/CPS \quad (11)$$

where:

ICP: Construction personnel ratio.

BI: Budget for infrastructure.

CPW: Construction personnel weight =0.59.

CPS: Construction personnel salary = S/ 800.00.

Once the necessary resources are in place to carry out the irrigation infrastructure, the progress of the works depends on the availability of resources versus what is programmed and the weather conditions that allow the construction to continue. The construction progress is shown in Figure 9.

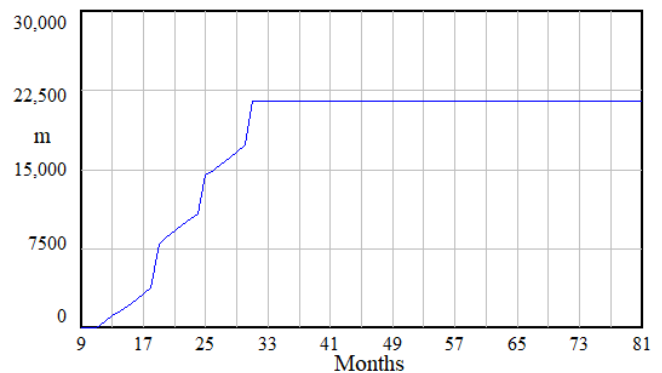


Figure 9: Progress in the construction of irrigation infrastructure

E. Water for irrigation

According to the progress of the irrigation infrastructure and the administration of water, the water for irrigation is determined according to the water demand calculated in the study phase. Figure 10 shows the Forrester diagram that explains the interaction of variables that determine the availability of water for irrigation.

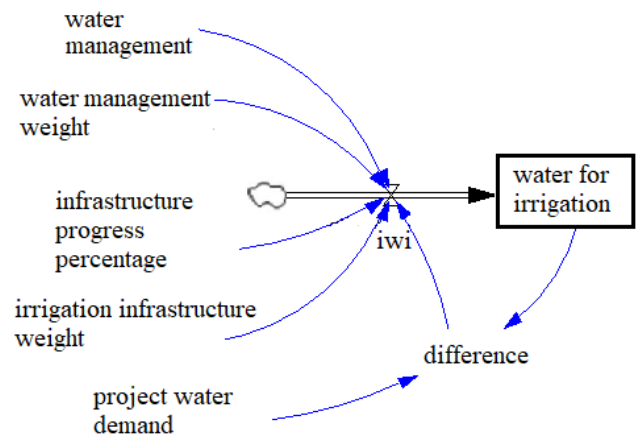


Figure 10: Forrester diagram: Water for irrigation

The equations that govern the Forrester diagram in Figure 10 are as follows:

$$IWI = [(D*WMW)*WM] + [(D*IIW)*IPP] \quad (12)$$

where:

Project water demand: 17,172.00 m³

$D = PWD - WI$

PWD : Project water demand.

WI : Water for irrigation.

WMW : Water management weight

WM : Water management.

IIW : Irrigation infrastructure weight

IPP : Infrastructure progress percentage

$$\text{Water for Irrigation (t)} = \int IWI(t) dt \quad (13)$$

where:

IWI : Water for irrigation rate

Figure 11 shows the increase in irrigation water until the project water demand is met, an important parameter that also serves to design the irrigation infrastructure (channels, reservoirs, canoes, rapids, etc.). The expansion of the agricultural frontier has a similar behavior within the project's scope as planned.

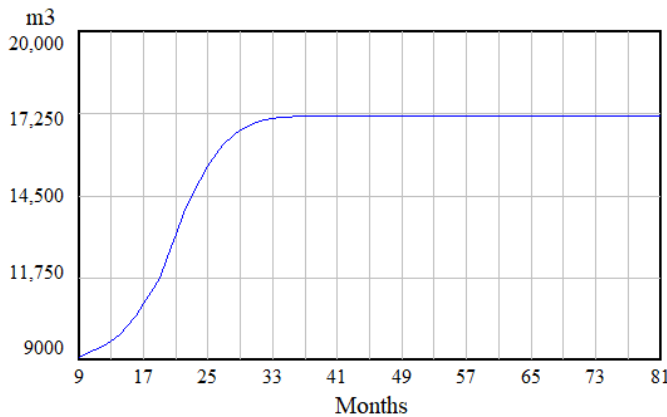


Figure 11: Increase in water for irrigation

F. Production function

The proposed simulation model for production in irrigation improvement projects includes the variables of water, supplies, training, machinery, and the human factor, whose interaction determines the quality and quantity of the cultivated land [1]. This is expressed in equation 14:

$$\text{Adequate land for cultivation} = \quad (14)$$

$$0 \quad ; \quad WF \leq 0$$

$$\frac{[WF*WWF+SF*SFW+TF*TFW+MF*MFW+HRF*HRFW]*PL}{HRFW} \quad ; \quad WF > 0$$

where:

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WF : Water factor.

WWF : Water factor weight (0.6).

SF : Supply factor.

SFW : Supply factor weight (0.1).

TF : Trainings factor.

TFW : Trainings factor weight (0.15)

MF : Machinery factor.

MFW : Machinery factor weight (0.1).

HRF : Human resource factor.

$HRFW$: human resource weight (0.05).

PL : Production land.

Note that, in extreme situations, without the water factor, production will be zero. Otherwise, it will be proportional in terms of the existence of the other production factors that have been considered. Figure 12 shows the production achieved. Note that, starting in month 33, there is a significant increase due to the already available new irrigation infrastructure, training, supplies, etc.

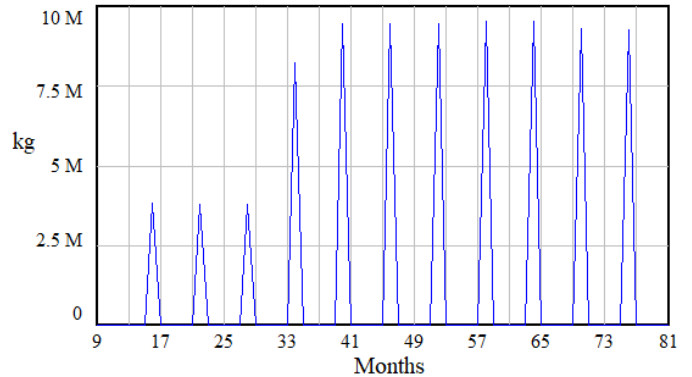


Figure 12: Production volume

G. Market

Once the production model has been obtained to determine the sustainability of the project, we must determine if there is a profit for the farmer due to sales in local markets. At this point, the proposed work requires to know the behavior of the market whose proposed model is of perfect competition [13].

Therefore, the present research becomes a broader study of the regional economy and an economic theory approach to fighting poverty, in this case, based on water as the main engine. Whose total utility in the medium term will allow farmers to access better living conditions such as health, housing, education, etc. Among these factors, we must highlight the greater and better access to education of the Andean population, as it will allow access to better economic income. About education, the winner of the last Nobel Prize in economics, in his work in Kenya,

concludes that better innovations must be made that allow more people to benefit economically from education [24].

H. Price determination

The interaction of supply and demand (which we have considered dividing into current demand and potential demand) and the seasonality of both allows us to know the product's sale price. Compared to the original work [1], in the present, we are going to present a new model described in equation 15.

$$Price = AP + [AP*(1-(SM+SMF))] \tag{15}$$

where:

AP: Average price.

SM: Satisfied market.

SMF: Stocks in the Market Factor.

$$Satisfied\ Market = Production\ volume / Current\ demand \tag{16}$$

Figure 13 shows the sale price behavior, in which it can be seen that the price reaches S/ 1.23 in times of scarcity and S/ 1.00 when there is overproduction. To carry out a sensitivity analysis, a scenario was constructed. The project's production increases by 30%, and due to market capacity (demand) occurs overproduction and, therefore, the sale price drops to S/ 0.66 per kg. These results, in a real environment, could occur in a few months or years. Note that the simulation is for 72 months, and, during the year, there are various seasons. This has been considered from the conceptualization of production and the market model. It represents an advantage and differentiates our proposal in relation to other production and market models such as the spider web.

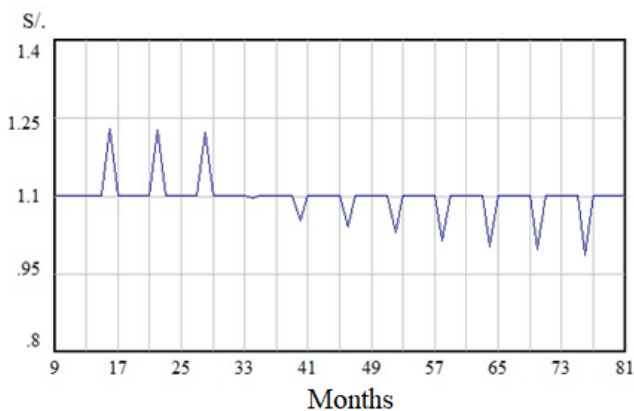


Figure 13: Sale price behavior obtained in simulation

4.3. Production optimization

Another aspect contemplated in economic theory is the maximization of producers' profits, who need to maximize the difference between total income and total cost. The break-even analysis allows us to know the minimum level of sales we must reach to avoid losses. Regarding the minimization of costs, the author in [25] recommends that this is the area we should focus

on because it is difficult for producers to influence the sale price. Who governs us and defines the sale price is the market. Therefore, it is essential to reduce costs by implementing modern management techniques within organizations to obtain greater benefits. To define the optimization models, as observed through this work, we have the great restriction of the market (competition, seasonality, weather conditions, etc.). Therefore, it has been determined that the optimization of production is a restricted problem of the non-linear type. The objective function to maximize utility is shown in equation 17.

$$Max\ Z = 16\epsilon X_1 X_2 - 11.14 X_1 \tag{17}$$

Subject to:

$$X_3 \leq 3600 + 16X_1 \quad ; \text{ Stock on the market}$$

$$X_3 - 16X_1 \leq 3600$$

$$X_2 \leq AP + AP*[1 - 16 X_1 / (X_3 + X_4)] \quad ; \text{ Sale price}$$

Replacing and solving:

$$Being: AP = S/ 1.10 \text{ (Average price)}$$

$$X_2 \leq 2.2 - 17.6 X_1 / (X_3 + 1.1 X_4)$$

$$X_1 \leq 400 \quad ; \text{ Arable area}$$

$$X_4 = 0.1$$

Solving, it is obtained that the maximum profit is S/ 5 784,000.00 and the sale price results S/ 1.6 (X₂).

5. Conclusions

The new proposed simulation model allows for understanding the behavior of the production process of irrigation improvement projects. In this paper, the systems dynamics methodology has been used mainly for its formulation. The new model allows the projection of data in the future and, in this way, determine the impact of the decisions that are made and if they do not lead to long-term problems. In the conceptualization phase, it has been possible to identify endogenous and exogenous variables; Among the exogenous variables, the behavior of regional markets stands out, determining the sale price of products. For the validation of the model, the Anderson-Darling normality test has been used for all the identified subsystems (training, strengthening of organizations, irrigation water, farmland, etc.). We obtained from the normality tests values higher than $\alpha = 0.05$.

The production factors that we identify for irrigation improvement projects are water, inputs, training, machinery, labor, and land. The respective weights can be seen in equation 14. The irrigation infrastructure and water management determine the availability of water. All these factors in the model determine the amount of cropland and the production volume to obtain. However, to measure the profitability of production, it is necessary to know its efficiency concerning the regional economy. That's why we formulate models that allow understanding of the market's behavior and sales prices in the region. The proposed models also make it possible to carry out sensitivity analyzes and

detect the appearance of regional recession phenomena. All these models have been expressed in a formal language, a requirement of epistemology for the generation of knowledge. Then our study becomes a perspective of economic theory for the fight against poverty based on water and its correct use.

For the formulation of optimization models, the nonlinear programming techniques based on objective functions and restrictions have been considered. The dimensions evaluated were: profit maximization, cost minimization, and breakeven point. The proposed production and market models have become constraints or objective functions as appropriate in the optimization model. To validate the optimization model, it has been verified that they comply with the Kuhn Tucker conditions. The optimization problem has also been analyzed using genetic algorithms, whose application has made it possible to know that the sexual selection operator is the most efficient for achieving global and local optimums.

The difficulties we had were access to information and the models' calibration, which is a process difficult and slow in which VENSIM has been very helpful. In future works, we will apply the proposed models in the Titicaca lake basin, and we will contrast them with time series.

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