ECORFAN Journal-Bolivia June 2024 Vol.11 No.20 28-34

Article

Cost-benefit analysis of an irrigation unit with treated wastewater in Chihuahua, Mexico

Análisis costo beneficio de una unidad de riego con aguas residuales tratadas en Chihuahua, México

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CONAHCYT classification:

Area: Engineering
Field: Engineering
Discipline: System engineer
Subdiscipline: Computer Sciences

https://doi.org/10.35429/EJB.2024.20.11.28.34

History of the article:
Received: January 15, 2024
Accepted: June 30, 2024

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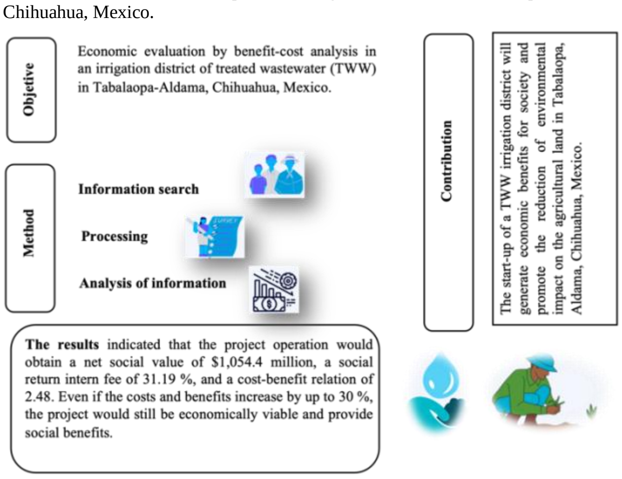
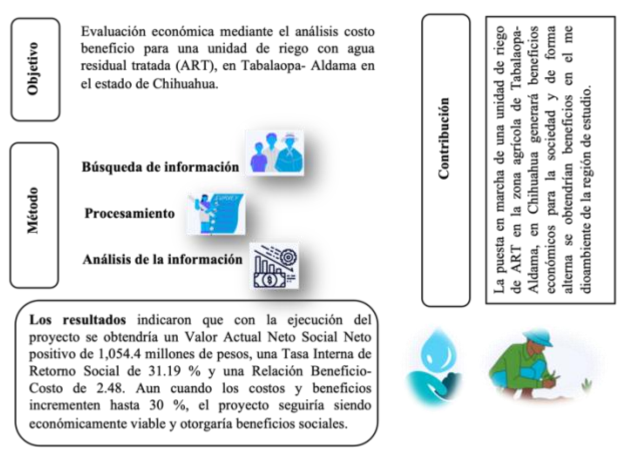
Abstract

The reuse of water in agriculture is an alternative to guarantee food security in Mexico and efficient management of this resource. The objective was to conduct an economic evaluation by benefit-cost analysis in an irrigation district of treated wastewater (TWW) in Tabalaopa-Aldama, Chihuahua, Mexico. The cost-benefit methodology was used to estimate the economic assessment of public projects. The results indicated that the project operation would obtain a net social value of $1,054.4 million, a social return intern fee of 31.19 %, and a cost-benefit relation of 2.48. Even if the costs and benefits increase by up to 30 %, the project would still be economically viable and provide social benefits. The start-up of a TWW irrigation district will generate economic benefits for society and promote the reduction of environmental impact on the agricultural land in Tabalaopa, Aldama, Chihuahua, Mexico.



Resumen

La reutilización del agua en la agricultura es una alternativa para garantizar la seguridad alimentaria en México y hacer un uso más eficiente de este recurso. El objetivo fue realizar una evaluación económica mediante el análisis costo beneficio para una unidad de riego con agua residual tratada (ART), en Tabalaopa- Aldama en el estado de Chihuahua. Se utilizó la metodología del análisis de costo beneficio para la evaluación económica de proyectos públicos. Los resultados indicaron que con la ejecución del proyecto se obtendría un Valor Actual Neto Social Neto positivo de 1,054.4 millones de pesos, una Tasa Interna de Retorno Social de 31.19 % y una Relación Beneficio-Costo de 2.48. Aun cuando los costos y beneficios incrementen hasta 30 %, el proyecto seguiría siendo económicamente viable y otorgaría beneficios sociales. La puesta en marcha de una unidad de riego de TWW en la zona agrícola de Tabalaopa-Aldama, en Chihuahua generará beneficios económicos para la sociedad y de forma alterna se obtendrían beneficios en el me dioambiente de la región de estudio.



Social benefits, profitability, water, reuse

Beneficios sociales, rentabilidad, agua, reutilización

Citation: Borja-Bravo, Mercedes, Sánchez-Toledano, Blanca Isabel, Arellano-Arciniega, Sergio, Ochoa-Rivero, Jesús Manuel. Cost-benefit analysis of an irrigation unit with treated wastewater in Chihuahua, Mexico. ECORFAN Journal-Bolivia. 2024. 11-20:28-34.

Introduction

Water is a vital and fundamental resource for sustaining life and food security on planet Earth. Unfortunately, anthropogenic activities, climate change, and population growth, among other causes, have triggered water scarcity problems that pose a risk to food production in the world. Mekonnen and Hoekstra (2016) reported that two thirds of the global population are under conditions of water deficit in quality and quantity. Therefore, it has been estimated that by 2050 there will be a population of 9.2 billion inhabitants, which represents a challenge for the sustainability of the vital liquid (Mahfooz et al., 2020).

An alternative to counteract this problem in agriculture is the use of treated wastewater (TWW) (Ochoa-Rivero et al., 2023). Currently, about 20 million hectares in 50 countries are irrigated with TWW and wastewater, which represents 40 % of food production (Mahfooz et al., 2020). To mention a few cases are countries such as Australia (Shahrivar et al., 2019), Nigeria (Inyinbor et al., 2019), Pakistan (Mahfooz et al., 2020), and Mexico (Hettiarachchi et al., 2018). The example in Mexico is the Mezquital Valley, where according to Hettiarachchi et al. (2018) and Garcia-Salazar (2019) TWWs coming from Mexico City have been used to sustain agriculture in three Irrigation Districts (ID-003, ID-100, ID-112). Undoubtedly, the use of TWW is an alternative to counteract the lack of water for irrigation and provides an option for food production, because it contains a large amount of nutrients and organic and inorganic compounds such as nitrogen (N), phosphorus (P) and potassium (K) (Alvarez-Holguín et al., 2022).

Therefore, in 2020, a project was proposed for the establishment of an irrigation unit with TWW for the Tabalaopa-Aldama agricultural area, Chihuahua, Mexico. This project contemplated the reuse of TWW from the south wastewater treatment plant (WWTP) of the city of Chihuahua. The project considered irrigating 1,887.80 ha of crops with TWW to produce forage and pecan nuts. However, water reuse entails changes in traditional water allocation structures, financing structures, consideration of water and soil quality standards, regulatory frameworks, and institutional mandates. This implies good management at all levels in order to develop a holistic approach and consistent policies for water allocation that meet the multiple needs of users (Lugo-Morin, 2009). Therefore, it is necessary, prior to any investment, to perform a financial analysis (Viñan et al., 2018).

The objective of this study was to carry out an economic evaluation using cost-benefit analysis for an irrigation unit with TWW in the Tabalaopa-Aldama agricultural land, Chihuahua, Mexico. The purpose was to determine the profitability of the project and to provide information for decision making to the stakeholders involved in water resource management in agriculture in northern Mexico.

Methodology

Description of the study area

The study area was located between the Tabalaopa-Aldama and Aldama-San Diego aquifers. The Chuviscar River is the primary water source for the agricultural land under study. This water mixes with TWW in the channel, which has supplied the agricultural land under study, with centroid coordinates of 28°43'52.80" north latitude and 105°58'14.26 west longitude (Figure 1) (Consejo Estatal Agropecuario de Chihuahua, 2020).

Box 1

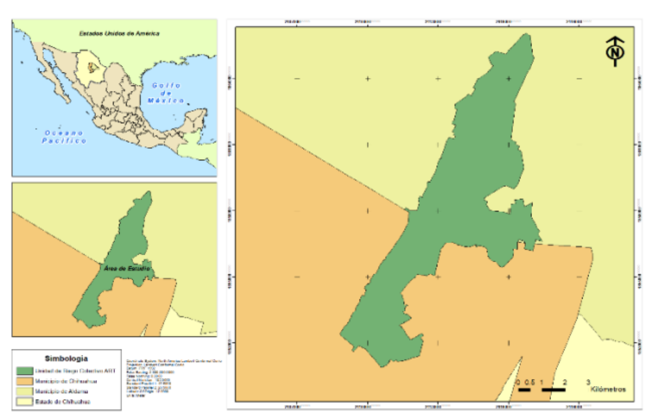


Figure 1
Location of the irrigation unit, Chihuahua.
Source: Own elaboration

Water distribution in the study area

The TWW that serves as effluent for the irrigation unit comes from the WWTP with an average daily flow of 1,875 L/s. The WWTP started operations in 2006 and treats domestic water from the city of Chihuahua, it has a secondary treatment system with final disinfection with chlorine. Discharges from the WWTP are divided into irrigation (~800 L/s), graywater (~100 L/s) and the remainder to the Chuvíscar River (Ochoa-Rivero et al., 2023).

ISSN: 2410-4191
RENIECYT-CONAHCYT: 1702902

Project cost-benefit analysis

Based on the guidelines for the preparation and presentation of cost-benefit analysis (CBA) of investment programs and projects, in section II: Types of Investment Programs and Projects, paragraph 2, item i, the project was classified as an "Economic infrastructure project" (DOF, 2020). Consequently, the CBA methodology was used, which is a tool for the economic evaluation of public projects, where the costs and benefits of the project were compared in monetary terms, based on the values, the economic profitability of the project in public investment and social benefits derived from the use of public resources were highlighted (Jacome and Carvache, 2017).

The application of the CBA consisted of five stages (Aguaza, 2012): 1) Identification of the project objective and valuation of alternatives, 2) Identification of all costs and benefits derived from project implementation, 3) Monetary valuation of costs and benefits, 4) Updating of the flow of costs and benefits to a base year by applying a discount rate, 5) Estimation of economic indicators: Social Net Present Value (SNPV), Social Internal Rate of Return (SIRR) and Benefit-Cost Ratio (BCR). Three scenarios were proposed, which considered the following: Scenario 1: increase in the initial investment of the project; Scenario 2: increase in costs and decrease in revenues making the project unviable; and Scenario 3: increases in costs and decrease in revenues by 30, 20 and 10 %, respectively. The costs and benefits used in the evaluation are shown in Table 1.

Box 2

Table 1

Costs	Benefits
Investment cost of the irrigation unit at current 2020 prices (initial investment).	Increase in water for domestic consumption in the city of Chihuahua of ~98,527 inhabitants.
Maintenance cost of the irrigation unit and was estimated at 25 cents per m^3.	Increase in the value of forage crop and pecan nut production with TWW.
Operating cost of the irrigation unit.	Economic savings due to less groundwater extraction.
Cost of public awareness campaign on the use of TWW in agriculture.	Economic savings due to the use of less fertilizer in the production of forage crops.
Cost of soil, water and crop monitoring in TWW irrigated plots.	
Cost of a training, technical assistance and technology transfer program for forage production with TWW.	

Source: Own elaboration

The information used for the evaluation was derived from secondary sources, official databases and information collected directly from farmers and key stakeholders in the study area. Once the data was collected, it was captured and analyzed in Microsoft Excel 2016.

Conversion to social costs and revenues

In the economic evaluation, social prices were used and the distortion method was considered for their estimation, where the value of costs at market price was taken as a basis and distortions such as inflation, taxes and/or subsidies were eliminated (CEPEP, 2012).

Financial evaluation considerations

The analysis considered an evaluation horizon of 50 years and a social discount rate of 12 %, which was taken from the guidelines for the preparation and presentation of cost-benefit analyses of investment programs and projects issued by the Ministry of Finance and Public Credit of Mexico (SHCP) (DOF, 2020).

Results and discussion

The project cost estimates are shown in Table 2. The investment required for the execution of the works and actions of the project was $915,076,256.60 at current Mexican pesos prices for 2020 and was the most important, incorporated the sum of the operation and maintenance of the irrigation unit. Another cost of importance was the monitoring of water, soil and crops; since according to Cisneros and Saucedo (2016) measures must be taken to avoid salinization problems and mineral accumulation in soils irrigated with TWW. Therefore, monitoring represents a preventive measure to major problems that may represent a greater economic cost in the future. The authors also pointed out that the use of TWW in agriculture brings with it changes in the way farmers produce. Therefore, it is important to make a good selection of crops accompanied by management practices, ranging from the way of sowing, irrigation management, fertilization doses and cultural practices. For this reason, it is necessary to implement a technology transfer program where knowledge and techniques are shared with farmers so that they can produce efficiently.

ISSN: 2410-4191
RENIECYT-CONAHCYT: 1702902

Box 3
Table 2
Private and social costs of the Treated Wastewater Irrigation Unit (annual cost current Mexican pesos).

Concepts	Private Value	Social Value
	$	
Costs		
Installation of the irrigation unit	$915,076,256.60	$655,814,102.17
Operation of the irrigation unit	$391,491.00	$318,872.16
Irrigation unit maintenance	$95,203.52	$82,072.00
Public awareness campaign	$139,200.00	$120,000.00
Soil, water and crop monitoring	$6,503,848.56	$5,606,766.00
Technology transfer program	$1,679,800.00	$1,355,000.00
Benefits		
Clean water for human consumption	$177,423,875.00	$171,382,199.00
Increase in the value of agricultural production	$49,258,909.63	$27,896,627.40
Savings in groundwater extraction	$7,781,209.69	$6,536,216.14
Savings in fertilizer costs	$5,424,085.52	$4,556,231.89

Source: Own elaboration

The awareness campaign was considered based on Winpenny et al. (2013) statement that the acceptance of TWW and its reuse in agriculture by society depends on the awareness and understanding of the subject. According to Rubio (2012), in Mexico there has been a predominant exclusion of the participation of rural producers in the determination of new projects, specifically in the management of water resources.

The accounting of the benefits that the implementation of the project would provide are shown in Table 2. The economic valuation of the increased availability of water for first use was considered to be the highest. However, this benefit is not only centered on the economic aspect; it also has a contribution to the environment by counteracting the overexploitation to which the Tabalaopa-Aldama aquifer is currently subjected. For Melián-Navarro and Fernández-Zamudio (2016), recovered water plays a key role in the maintenance of wetlands, resulting in the preservation of green areas, flora and fauna, aspects of intangible value for future generations.

According to data from the Chihuahua State Agricultural Council (2020), during 2020, in the study area there is an agricultural area of 1,098.5 ha irrigated with TWW, which would increase to 1,885.5 ha with the implementation of the project. This increase in the area irrigated with TWW would lead to greater economic benefits and guarantee the sustainability of agriculture in the region, since, as mentioned by Villeta (2016), the expansion and sustainability of agricultural activity only prevails if there is a constant and reliable supply of water.

For farmers, the cost of groundwater extraction represents higher production costs for their crops; on average, a farmer spent $9,853 per ha in 2020 to extract groundwater, so with the project this cost would no longer be paid if they use the TWW (distributed by gravity). Another favorable aspect for farmers would be the savings from the purchase of fertilizers; various studies indicate that the reuse of TWW in adequate quantities improves the physical condition of the soil, while providing a considerable proportion of indispensable fertilizers (Borrego-Marín and Berbel, 2019; Álvarez-Holguin et al., 2022).

According to the results obtained in the CBA, the Social Net Present Value (SNPV) was positive and greater than 0, which indicated that the execution of the project would result in a profit for society of $1,054.4 million. The Social Internal Rate of Return (SIRR) was 31.19 %, higher than the social discount rate and represents the average annual interest rate generated by the capital invested in the project during its useful life once the investment has been recovered.

ISSN: 2410-4191
RENIECYT-CONAHCYT: 1702902

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https://doi.org/10.35429/EJB.2024.20.11.28.34

The BCR was 2.48, greater than 1, which means that the benefits of the project exceed its costs and that for each Mexican peso invested, $1.48 Mexican pesos of benefit will be obtained for society, this situation is equivalent to 148 % of profitability (Table 3). With the results obtained, it can be deduced that the investment project of an irrigation unit with TWW is socially profitable for the population of the Tabalaopa-Aldama zone, since the economic welfare achieved with the project would be greater than that obtained if the project were not carried out (Contreras, 2004).

Box 4

Table 3

Project profitability indicators.

Present Value of Social Costs (PVSC)	$714,085,921
Present Value of Social Benefits (PVSB)	$1,768,562,026
Social Net Present Value (SNPV)	$1,054,476,105
Social Internal Rate of Return (SIRR)	31.19%
Benefit-Cost Ratio	2.48

Source: Own elaboration

While the results of the indicators are important for decision making, authors such as Winpenny et al. (2013) pointed out that the basic indicators should be accompanied by comprehensive data showing the results of sensitivity analysis and change values, highlighting possible worst-case scenarios. The sensitivity analysis indicates the areas of the project where reducing uncertainty could bring particular benefits, by reducing a downward variation or improving the chances of an upward movement.

In Scenario 1 it was observed that, if social costs are considered equal to current costs (Table 4), it would imply an initial investment of $915,076,256 and the project would show an SNPV of $795.21 million Mexican pesos, a SIRR of 22.41 % and a profitability of 82 %, so it would still be socially profitable.

Box 5

Table 4

Results of the sensitivity analysis of the project's economic indicators, current Mexican pesos.

Indicators			
Scenario 1	Value		
Present value of social costs ($)	973,348,075		
Present value of social benefits ($)	1,768,562,026		
Social Net Present Value ($)	795,213,950		
Social Internal Rate of Return (%)	0.22		
Benefit-Cost Ratio	1.82		
Scenario 2	Social costs	social income	
Present value of social costs ($)	1,768,562,026	714,085,921	
Present value of Social Benefits ($)	1,768,562,026	714,085,921	
Social Net Present Value ($)	0	0	
Social Internal Rate of Return (%)	0.12	0.12	
Benefit-Cost Ratio	1	1	
Scenario 3		Cost increase	
	30%	20%	10%
Present value of social costs ($)	927,804,118	856,413,571	785,065,023
Present value of Social Benefits ($)	1,768,562,026	1,768,562,026	1,768,562,026
Social Net Present Value ($)	840,757,908	912,127,455	983,497,003
Social Internal Rate of Return (%)	0.24	0.26	0.28
Benefit-Cost Ratio	1.91	2.07	2.25
		Decrease in income	
	30%	20%	10%
Present value of social costs ($)	714,085,921	714,085,921	714,085,921
Present value of Social Benefits ($)	1,237,993,497	1,414,849,621	1,591,705,823
Social Net Present Value ($)	523,907,497	700,763,700	877,619,902
Social Internal Rate of Return (%)	0.22	0.25	0.28
Benefit-Cost Ratio	1.73	1.98	2.23

Source: Own elaboration

Scenario 2 considered an increase in costs and decrease in revenues, to the point where the project becomes unfeasible, i.e., SNPV is equal to 0, BCR is equal to 1 and SIRR is equal to 12 %. The above is achieved only if costs were to increase by 147.66 % and benefits were to remain constant; the same occurs if benefits were to decrease by 59.62 % and costs were to remain constant. These results indicate that the implementation of the project would not generate any benefit to society and it is indifferent whether it is carried out or not.

Finally, in Scenario 4, the variation in costs increased and benefits decreased by 30, 20 and 10 % (Table 4). The results obtained show that even if costs increase and benefits decrease at the different levels proposed, the project would still be economically viable and would provide social benefits to the population of the study region.

ISSN: 2410-4191
RENIECYT-CONAHCYT: 1702902

Conclusions

The implementation of an TWW irrigation unit in the agricultural area of Tabalaopa-Aldama in Chihuahua will generate economic benefits for society, which is supported by the results obtained in the evaluation, where the SNPV was positive and implies that the economic welfare achieved with the project would be greater, compared to what would be obtained if the project were not carried out. The SIRR was 31.19 %, which is higher than the social discount rate used (12 %), indicating that public investment in the development of the project generates profitability. The BCR was 2.48, meaning the benefits of the project exceed its costs. For every Mexican peso invested in the project, 1.48 Mexican pesos of benefits will be generated for society. In the work carried out, the valuation of environmental benefits was not considered, so it is recommended that this topic be included in future research. The analysis of these benefits would provide valuable information for the decision of the actors involved in the management and development of projects of this type and the implementation of the first collective irrigation unit with TWW in northern Mexico.

Conflict of interest

The authors declare that they have no conflicts of interest. They have no known competing financial interests or personal relationships that could have influenced the article reported in this article.

Authors' contribution

The contribution of each researcher in each of the points developed in this research was defined on the basis of:

Borja Bravo, Mercedes: Contributed to the project idea, research method and technique. Designed the field instrument. Conducted data analysis and systematization of results.

Sánchez-Toledano, Blanca Isabel: Contributed to the project idea and research method. Conducted data analysis and systematization of results, in addition to writing the article.

Arellano-Arciniega, Sergio: Systematized the background information for the state of the art.

Ochoa-Rivero, Jesús Manuel: Supported in the application of the field and systematization instrument.

Acknowledgments

he works was funded by the Municipal Government of Chihuahua 2018-2021 within the project: COST-BENEFIT ANALYSIS OF A METROPOLITAN IRRIGATION DISTRICT (MID) WITH TREATED WASTEWATER (TWW) IN THE CITY OF CHIHUAHUA.

Abbreviations

TWW: Treated wastewater
CBA: Cost-benefit analysis
SNPV: Social Net Present Value
SIRR: Social Internal Rate of Return
BCR: Benefit-Cost Ratio

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ISSN: 2410-4191
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