POPULATION GROWTH AND WATER CONSUMPTION: 
CHACHAPOYAS CASE, 2011 - 2021

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ABSTRACT

Objective: The present research aims to evaluate the impact of population growth on the consumption of drinking water in the city of Chachapoyas during the period from 2022 to 2021 and project the trend until the year 2050.

Method: The research followed a mixed longitudinal approach of basic study, with a non-experimental design, involving descriptive, explanatory, and correlational analyses. Based on 11 yearly observations (2011-2021), data from the Municipal Company of Drinking Water and Sewerage Services (EMUSAP) were used for a 20-year projection in Chachapoyas.

Result: The results showcase Chachapoyas as an oasis amid the scarcity of drinking water. 96% of water consumption is concentrated in households, while 4% is attributed to the commercial and social sector. The 21% increase in water demand poses a challenge due to population growth and reduced water availability at collection centers. It is projected that per capita water consumption will decline to 1m³ per person by 2049. The relationship between population growth and water availability is critical, necessitating efficient resource management to ensure adequate water access in the future.

Conclusion: Authorities should focus on implementing a circular economy, wastewater reuse, and improving pipeline distribution, all of which are critical components for sustainable water management in the city of Chachapoyas.

Keywords: population growth, water consumption, sustainable management.

Received: 07/08/2023
Accepted: 01/11/2023
DOI: https://doi.org/10.55908/sdgs.v11i11.1156
**RESUMO**

**Objetivo:** A presente pesquisa visa avaliar o impacto do crescimento populacional no consumo de água potável na cidade de Chachapoyas durante o período de 2022 a 2021 e projetar a tendência até o ano de 2050.

**Método:** A pesquisa seguiu uma abordagem mista longitudinal do estudo básico, com um desenho não experimental, envolvendo análises descritivas, explicativas e correlacionais. Com base em 11 observações anuais (2011-2021), os dados da Empresa Municipal de Água Potável e Serviços de Esgoto (EMUSAP) foram utilizados para uma projeção de 20 anos em Chachapoyas.

**Resultado:** Os resultados mostram Chachapoyas como um oásis em meio à escassez de água potável. 96% do consumo de água está concentrado nas famílias, enquanto 4% é atribuído ao setor comercial e social. O aumento de 21% na demanda de água representa um desafio devido ao crescimento populacional e à redução da disponibilidade de água nos centros de coleta. Prevê-se que o consumo de água per capita diminua para 1 m³ por pessoa até 2049. A relação entre o crescimento da população e a disponibilidade de água é crítica, exigindo uma gestão eficiente dos recursos para garantir o acesso adequado à água no futuro.

**Conclusão:** As autoridades devem se concentrar na implementação de uma economia circular, na reutilização de águas residuais e na melhoria da distribuição de gasodutos, que são componentes essenciais para a gestão sustentável da água na cidade de Chachapoyas.

**Palavras-chave:** crescimento populacional, consumo de água, gestão sustentável.

### 1 INTRODUCTION

Water resources, omnipresent in nature and essential for life, play an irreplaceable role in human well-being. This vital element safeguards not only our health and disease prevention (Nicholas, 2009; Orozco, 2020) but also operates as a fundamental pillar of sustainable development for our societies, whose prosperity is closely linked to access to quality water (Maestu and Sancho, 2015). In this sense, the gradual increase in population in cities would lead to a 6% decrease in Gross Domestic Product (GDP) by the year 2050, with losses linked to agriculture, health, income, and community prosperity (World Bank, 2022), threatening to cause physicochemical alterations in water and digestive disorders in both humans and animals (Alzuguren et al., 2022).

Currently, population growth is a determining factor in the increased demand for drinking water (Montesillo-Cedillo, 2017). This population increase is further exacerbated by the concerning global water scarcity, especially evident in the Americas, posing a significant challenge for sustainable development in the region (Nieto, 2011). Addressing this crisis requires the implementation of water infrastructure designed to retain and store water to meet multiple needs in countries or regions with better water
availability, carefully considering environmental and social impacts (Inter-American Development Bank, 2015). Understanding the importance of water for life sustainability is essential, and the natural resource must be conserved and used efficiently, considering both the legislation in place and its role in social, economic, and environmental sustainability (Jung et al., 2023).

The Caribbean is a region with limited water availability compared to South America. In the case of Peru, the availability of freshwater is 1,935,621 hm3 per day, thanks to its sources from the Amazon River, the Pacific Ocean, and Lake Titicaca (Ingemmet, 2016). The average daily water consumption per person in Peru is 163 liters, exceeding the World Health Organization's recommended 100 liters per person per day (Huaquisto and Chambilla, 2019). The primary objective of potable water is to guarantee social well-being in the short and long term (Acevedo et al., 2011). Managing water consumption demand will lead to the formulation of public policies within the consumption tariff system and defining them within the framework of supply and distribution crises (García et al., 2013), enhancing water usage efficiency and raising awareness about the importance of this resource, actions that should be encouraged by effective governmental interventions (Koch et al., 2023).

The growth of urban areas in water-scarce environments poses a significant sustainability challenge (Nicholas, 2009). Additionally, industrialization and agricultural development trigger a high degree of water pollution and scarcity (Khan et al., 2023), resulting in deficient water quality for consumption and introducing new challenges for management processes and governance (Iris and Paula, 2017). Globally, nationally, and regionally, the continuous population growth has increased the demand for water due to the shortage of freshwater available in these areas (Sagar et al., 2023).

Analyzing the water service allows us to understand the relationship between population growth and water consumption, particularly in the case of Chachapoyas during the period from 2011 to 2021. Understanding the current state of the water balance is crucial, depending on both its own territory and a tributary territory that provides resources and reduces pollutants(García et al., 2014). In the Amazonas region of the Chachapoyas district, the population has increased in recent years, with a 3% intercensal growth rate. It is strongly recommended to adopt comprehensive management measures to protect and restore water resources, making informed decisions, especially in controlling water consumption as part of future policies (Rajaeian et al., 2023).
2 LITERATURE REVIEW

In a global context, water scarcity is emerging as an alarming challenge. It is estimated that by the year 2050, one-sixth of the world's population will lack guaranteed access to potable water (Arango, 2013). This has propelled the critical state of water to the global agenda (Burstein-Roda, 2018). The growing demand and the search for new sources of supply, especially for various sectors of the population dedicated to agricultural, domestic, and industrial use, have turned water scarcity into one of the major issues of the 21st century (Limache et al., 2021). Efficient water management becomes indispensable in a context of population growth and global warming, which limits the development of activities for human subsistence (Blanco et al., 2013; Sandoval-Moreno and Ochoa-Ocaña, 2010). This, in turn, directly impacts areas such as health, education, and employment, affecting family economies (Labraña et al., 2021).

Water quality is crucial for regulating vital processes such as body temperature, oxygen transportation, and toxin elimination (Hernandez-Millan, 2022). However, water pollution, with metals and pesticides among its main contributors, poses a direct threat to public health and the environment (Echeverry et al., 2015). Often, communities are forced to choose unsafe water sources due to taste preferences, increasing the risk of waterborne diseases (Monteverde et al., 2013; Perugachi and Cachipuendo, 2020). Researchers like Vidaurre et al. (2018) and Guerra and Silva (2018) emphasize the importance of conservation and surveillance policies to ensure efficient use of water resources and maintain water quality. Inadequate water consumption practices can have severe consequences for health and well-being, increasing the risk of diseases and affecting national security (Iglesias et al., 2011).

Furthermore, demographic expansion leads to water contamination risks, harming economic and environmental balance (Villena, 2018; Oliveira et al., 2019). These risks also increase the probability of a person developing various diseases and, above all, pose a risk to the national security of any society (Aranceta-Bartrina et al., 2018). This issue has become a subject of global study; the scarcity of the natural resource has limited the recovery space of demand to its ordinary cycle (Pérez-Vera and Ortiz-Torres, 2013). Consequently, the issue in the public sector is related to water consumption and population growth, which is inevitable for success in society and economic development. Generally, societies have limited awareness of the problems associated with increasing water consumption and its relationship to population growth (Holl et al., 1995). In other
words, water is a shared resource with different human actions, capable of generating a substantial impact at present and in the future. Water scarcity leads to a distortion of economic activities, whether at an individual or organizational level (Neme et al., 2021).

3 METHODOLOGY

To achieve the objectives, a mixed longitudinal approach of basic research was used, with a non-experimental design, and analyses were conducted at a descriptive, explanatory, and correlational level. The sample population consisted of 11 annual observations from the period 2011 to 2021, with a 20-year projection. The research sources were the records from the Municipal Company of Drinking Water and Sewerage Services (EMUSAP) in the city of Chachapoyas, which serves 4 neighborhoods: Laguna, Yance, Luya Urco, and Santo Domingo. Additionally, sectors such as Señor de los Milagros, Pedro Castro, Murcia, Santa Rosa de Lima, Santa Rosa de Luya Urco, Pozo Yanayacu, Santo Toribio de Mogrovejo, Higos Urco, Villa Sachapuyos, and Tuctilla were considered. The correlational approach allowed determining the degree of relationship between the dependent variable (consumption of drinking water) and the independent variable (population growth).

To collect data on population growth and consumption of drinking water, two techniques were used: interviews with officials from EMUSAP S.A. and documentary review. Regression analysis was also employed to build an optimal econometric model that would forecast the events of water consumption demand by 2050 in relation to the population growth in the city of Chachapoyas. To determine the significance relationship between consumption of drinking water and population growth in the city of Chachapoyas, the Ordinary Least Squares (OLS) model was used. This model is an equation that allows us to estimate parameters or coefficients by assuming the minimum error. It was constructed based on a simple linear regression, here Y represents the consumption of drinking water and X is the population with access to water service in the city of Chachapoyas.

The equation is as follows: \[ Y = B_0 + B_1X + u_t. \]

Where C represents the consumption of drinking water in cubic meters, and X the population with coverage of the drinking water service. The data processing of the
specified econometric model will be carried out using the statistical package Eviews, to analyze the relationship between the independent variables and the dependent variable.

4 RESULTS AND DISCUSSION

In the Amazonas region, Chachapoyas is the only province that has high-quality drinking water suitable for human consumption. According to the company Emusap S.A., water consumption is classified into three sectors: The social sector, which includes public fountains and fire hydrants; The commercial sector, which involves distributing drinking water to pharmacies, educational centers, universities, clinics, and hotels; The domestic sector, responsible for distributing drinking water to households.

Additionally, the sewerage service is also divided into three sectors; The social sector, which is related to public restrooms; The commercial sector, which refers to the distribution of sewerage in pharmacies, educational centers, universities, clinics, and hotels; The domestic sector, responsible for distributing sewerage facilities in households.

Figure 1: Consumption of drinking water and sewerage services in the main sectors

In Figure 1 reveals a striking reality in Chachapoyas: the domestic sector accounts for 96% of water and sewerage consumption, leaving the commercial and social sectors with modest percentages of 2.9% and 0.60%, respectively. A surprising difference, as in 2011, water consumption amounted to 6,461 cubic meters, but by 2021, it skyrocketed to 7,844 m³, a steep increase of 1383 m³ in just ten years, showing an insatiable appetite for water.
But the tension doesn't end there. The demand for drinking water consumption by Chachapoyas residents continues to rise, even exceeding the total billed amount. In 2020, a Decree of Urgency (DU) No. 084-2021 dramatically affected the situation, reducing water consumption by a heart-wrenching 21%. This hit the Chachapoyas citizens hard, as the decree was implemented in response to the Covid-19 pandemic. As for the sewerage service, 95.9% of the impact falls on the domestic sector, while the commercial and social sectors barely reach 3.4% and 0.64%, respectively. The situation in Chachapoyas presents a real water challenge. The consumption of water and sewerage keeps us attentive to social, economic, and political situations in the coming years.

In this context, the company Emusap is a public entity with private rights, dedicated to providing drinking water and sewerage services for the benefit of society, thereby contributing to improving the quality of life for the population. For the conservation of the Tilacancha basin, the Law on Mechanisms for Ecosystem Services Compensation (Merese) was established in collaboration with the Peruvian Association for the Conservation of Nature (APECO). In this scheme, two actors are identified: the "compensators," who are people located in the upper parts of the basin responsible for caring for the water, and the "contributors," who are people in the lower parts who waste this valuable resource.

The Merese Law stipulates that compensators must pay a specified amount for contributors to conserve water sources through conservation actions. Additionally, three projects have been developed to support water conservation. These projects include supporting the potato and dairy production chain, aiming to make their activities more efficient so that people are not motivated to enter the conservation area. The protection of the buffer area of Tilacancha is also carried out. In this project, maintenance and surveillance are provided for water sources, and work has been done with a projection of 3 hectares in the Tilacancha sector. This collaborative approach and protection of the Tilacancha basin through the Merese Law are significant steps towards water conservation and the sustainable development of the region. The contribution of compensators and the implementation of projects with an environmental focus are essential to ensure adequate water supply and preserve this valuable resource for future generations.
In Figure 2, it can be observed that the water coverage in the year 2020 was only 63% due to measures taken for Covid-19, which involved the decision not to carry out household installations. This measure was adopted to ensure the protection of staff and the community. However, by the year 2021, the coverage increased to 73%, indicating an improvement in access to the service.

The per capita water consumption has not varied significantly in recent years. In 2011, it was 4.2 m$^3$ per person, while in 2019, it slightly decreased to 3.78 m$^3$. However, in 2020, due to the social confinement during the Covid-19 pandemic, where all household members stayed at home, the consumption increased to 4.2 m$^3$ per family. But by the year 2021, this figure decreased to 3.38 m$^3$ per family.

It is projected that, due to the gradual increase in the population and the reduction of water in the collection centers, the per capita water consumption for the year 2049 will be only 1 m$^3$ per person. This poses a significant challenge to ensure sufficient and equitable access to the water resource for future generations. Given the main risk associated with the use of freshwater, it is crucial that local authorities in this area find ways to increase the physical efficiency of water in the water reservoir area. This will ensure the delivery of this vital resource in an amount that satisfies human needs in the future (Asthana, 2022).
The figure 3 shows the evolution of the total population and the population with access to sewage in the city of Chachapoyas. On average, the coverage of drinking water was 93% between the years 2011 and 2017. However, in the year 2020, due to the emergence of Covid-19, the water coverage decreased dramatically to 63%. This was because installations of this service were not carried out in homes, leading to a reduction in water consumption and an increase in the population without access to drinking water.

The projections for the years 2021 to 2049 show that by the year 2037, the population without access to water will be equal to the population with water service. Furthermore, it is projected that water consumption will increase by the year 2049, reaching the same coverage as the drinking water service. This growing trend in water consumption demand raises concerns for the service supply in the city of Chachapoyas.

These observations highlight the challenges of population growth and water scarcity, emphasizing the importance of implementing a circular economy, i.e., the reuse of wastewater to increase available water resources (Guerra-Rodríguez et al., 2020). Additionally, the use of rainwater is presented as an economic and rational practice that helps combat the water crisis, especially when planning usage appropriately considering the combined aspects of quantity and quality of rainwater (Motta et al., 2023). The rapid demographic expansion has impacted water consumption patterns for various uses, creating an increasingly intense competition among traditional users in the agricultural sector, rapidly growing cities, and natural ecosystems (Bustillos, 2004).

Regarding the analysis of population growth, the Ordinary Least Squares (OLS) model was used for linear regression $Y = B0 + B1X + ui$. Time series were analyzed, and it was found that the study variables did not meet the stationarity conditions, both in population growth and water consumption in the district of Chachapoyas. Non-normally
distributed residuals, white noise issues, and failure to meet stationarity conditions were observed. For this purpose, variables were analyzed one by one, where Y represents potable water consumption and X is the population with sewage access. Logarithmic and derivative transformations were applied to both variables to try to improve stationarity. We analyzed the population with sewage access, which is shown in the following graph:

Figure 4: Partial autocorrelation (pac) and autocorrelation (ac) plot of population

Partial autocorrelation provides us with information about the numbers of autoregressive, also known as AR models. It can be observed that there are lags that fall outside the confidence level for both the normal autoregressive and moving average models. This indicates that there is no normal distribution of the lags, even with the use of fourth-order derivatives and logarithmic transformation in the population of the city of Chachapoyas.

It was identified that the variable "population" is non-stationary, and the autocorrelation coefficients are high, gradually decreasing to zero. Due to the presence of autocorrelation and errors in the distribution, the best ARIMA model was estimated (Chavez, 1997). It was determined that the possible values for the AR terms could be 1, 3, 4, or 5, while the values for the MA terms could be 1, 2, 3, or 4. Consequently, the possible ARIMA models that can be considered are:

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Note: Date of Stata
Different specifications of the ARIMA model were conducted, and a comprehensive diagnostic was performed to verify its validity. Finally, it was found that the appropriate specification for the ARIMA model is (5,0,4) (Amaris et al., 2017). This model demonstrated the presence of white noise and a normal distribution of the lags, as can be seen in the following graph.

Consequently, the resulting specific model is an autoregressive moving average model, indicating a stationary time series. The analysis and identification of the appropriate ARIMA model are essential to obtain accurate and reliable results in forecasting and analyzing the population time series in the city of Chachapoyas. The (5,0,4) model has been selected as the best fit, allowing for projections and informed decision-making regarding population behavior in the future.

![Residue of Partial autocorrelation (pac) and autocorrelation (ac) plot](image)

Note: Figure of Stata.

The result is obtained from the Stata program of the ARIMA model (5, 0, 4). The final parameter estimates for the ARIMA model (5, 0, 4) show that the residuals have a random process following a normal trend with zero mean and a slight tendency towards the right side of the fit (Gallego-Nicasio et al., 2018). Furthermore, the statistical significance of the population growth model from 2011 to 2021 is consistently highlighted, indicating that the population is continuously growing.

In this way, it can be said that there is no precise fit. Additionally, it is worth noting that the evaluation and analysis process do not discriminate the influence of the El Niño and La Niña phenomena. However, the analyses were conducted in years when these phenomena have occurred. Now, the water consumption in the city of Chachapoyas was analyzed. Several lags were identified in the study variable, and different analysis
techniques were employed, such as generating logarithms, differences, and ARIMA models.

Figure 6: Partial autocorrelation (pac) and autocorrelation (ac) plot of Water

Note: Figure of Stata.

Figure 6 presents the analysis of the ARIMA model applied to the historical records of water consumption volume in the city of Chachapoyas. Various analyses were conducted to determine the type of model that would best fit the series. However, after diagnosing several measures, the exact appropriate model could not be determined. Logarithmic assignments, derivative generation, and different ARIMA methods were tested, but no autoregressive partial component was found. Additionally, it was identified that there is no white noise, implying that the lags do not follow a normal distribution, and the series is not stationary.

This analysis suggests the need for further research to accurately understand whether water consumption has an impact on population growth in the city of Chachapoyas. On the other hand, the increasing demand for water poses a threat to the supply in the city, and, moreover, a considerable increase in the volume of generated wastewater has been observed. In this context, proper wastewater treatment plays a crucial role in preserving the quality of the environment (Hernández-Chover et al., 2022). This should be a topic discussed regarding the need to protect drinking water as a human rights issue due to the evidence of water scarcity, which is of paramount importance for human life (Amorim and Ribeiro, 2019). Furthermore, water is a cross-cutting element of sustainable development, and in the challenge of eradicating poverty, the implementation of a public water policy as a common good of nature becomes crucial (Victoria et al., 2018).
5 CONCLUSIONS

Population growth over the years has been positive, but water supply is decreasing due to climate change and other contaminating factors caused by humans. This has generated uncertainty among the population about whether, at some point, water distribution will be sufficient to meet all existing demand. Therefore, this work aims to answer this question about possible water shortages due to population growth.

The inhabitants most affected by access to drinking water are those living in informal settlements, according to Ojeda et al. (2020). These settlements lack adequate water infrastructure, and this is also the case in the "16 de octubre" settlement, where they do not have access to drinking water due to two reasons. Firstly, it is located in a very high area where it is not possible to transport water through connections, and secondly, the area faces problems related to the terrain, preventing the service provider company from participating without resolving pending conflicts with the municipality.

According to the model obtained in this research, there is a direct relationship between water consumption and population growth. Every additional variation in thousands of people living in the city of Chachapoyas results in a decrease of 20.8 cubic meters in drinking water consumption per person. In the long run, this could represent a shortage of drinking water for the population, given that the population continues to increase over time. For this reason, the company EMUSAP S.A. must implement certain strategies that will contribute to water savings through storage or reuse of the water resource and raise awareness among citizens about the importance of water for the sustainability of human activities.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to all the reviewers of the journal, and I sincerely appreciate your efforts, dear reviewers, in reviewing our manuscript titled "Population Growth and Water Consumption: Chachapoyas Case, 2011 – 2021," and subsequently considering it for publication in the said journal.
FUNDING

This research did not receive any specific grant from funding agencies in the public, commercial, or non-profit sectors.
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