CHEMICAL ENGINEERING TRANSACTIONS

VOL. 86, 2021

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors:

ISBN 978-88-95608-xx-x **ISSN** 2283-9216

DOI: 10.3303/CET2186082

Water Sustainability of the Yanacocha Lagoon: Future Scenarios for the Population of Carhuamayo, Junin, Peru

Helen P. Ninalaya Ayra, Marcel J. Lamadrid Jordan, Carlos A. Castañeda Olivera*, Elmer G. Benites Alfaro, Juan J. Ordoñez Galvez

Universidad César Vallejo, Campus Los Olivos, Lima, Peru
caralcaso@gmail.com

The misuse of water, problems of water governance, population growth, the effects of climate change such as decreased precipitation, increased temperature and the disappearance of glaciers, make water availability increasingly scarce, and as a result increased pressure on surface water resources. The Yanacocha lagoon is the main source of water supply for the population of Carhuamayo. Therefore, this research determined scenarios of water sustainability of the lagoon by 2030 for the supply of this population. To estimate the parameters of precipitation and temperature in the Yanacocha micro-basin, the method of regionalization of the period 1970 to 2019 was carried out. In addition, water sustainability scenarios were estimated based on water supply and demand related to sustainability indicators (water-soil quality and plant coverage) and the level of water culture of the inhabitants. The results showed 18 scenarios of water sustainability for 2030 between optimists, stabilization and pessimists; all of them favorable and positive, with a medium-high level of water culture in the community. Finally, the study allowed regional and local authorities to establish environmental management strategies in the mitigation of environmental, social and economic impact.

1. Introduction

One of the most precious and indispensable resources on earth is fresh water as a primary resource for human survival and development and is essential for maintaining the proper functioning of the ecological system, biodiversity and socio-economic development at the worldwide. However, population growth, natural forces and economic pressures are causing increased demand for water that exceeds the amount available (Morales et al., 2020). At the global level, the improper use of water in different activities (industrial, livestock and agricultural), population growth and the effects of climate change (decreased precipitation, increased temperature and disappearance of glaciers) alter the availability of water, generating scarcity of surface water resources. Therefore, it is necessary to predict the future of water and the sustainable development of this resource: hence, the capacity and sustainability of water resources must be assessed in order to face the crisis in water supply due to the depletion of fresh water reserves (Zhou et al., 2018).
Water sustainability is considered as the management of water resources that promotes the conservation and use of water, guaranteeing environmental, hydrological and ecological integrity. Sustainable water management is essential to meet the growing demand for this resource and achieve a safe and environmentally sustainable supply in the future, achieving an environmental, economic and socio-cultural balance (Omarova et al., 2019). However, inadequate water use and management, population growth, climate variability and pollution alter the sustainability of water resources.
Previous studies indicated that in order to determine water sustainability it is necessary to evaluate sustainability indicators such as water availability, quality and quantity, soil quality, and plant coverage, among others (Li, 2016; Pérez, et al. 2018). Lin et al. (2020) mentioned that the analysis of sustainability indicators allows for the identification of possible causes that alter and put at risk current strategies for sustainable water resource management. Other researchers evaluated the degree of water sustainability using dimensions focused on water quantity and quality, community participation (water culture) and financing, to determine the multidimensional sustainability index. The selection of sustainability indicators is based on different

Paper Received: 25 October 2020; Revised: 3 February 2021; Accepted: 13 April 2021
Please cite this article as: Ninalaya Ayra H.P., Lamadrid Jordan M.J., Castaneda Olivera C., Benites Alfaro E.G., Galvez J.J.O., 2021, Water Sustainability of the Yanacocha Lagoon: Future Scenarios for the Population of Carhuamayo, Junin, Peru, Chemical Engineering Transactions, 86, 487-492 DOI:10.3303/CET2186082

mathematical models such as the Pressure-State-Response model (Wang et al., 2019), Agent-Based model (Granco, 2019) and the Stackelberg-Nash-Cournot model (Xu et al., 2019).

In Peru, 24.8 % of the population lives in rural areas that do not have access to water through the public network, of which 14.6 % access water through rivers, lagoons or springs, 47 % from wells, 0.8 % from tanker trucks and 4.6 % from other sources (INEI, 2019). Thus, the high demand for access to water resources, the lack of management, care and irrational use of lagoons can lead to ecological imbalance altering the sustainability of water resources. Therefore, the objective of this research was to determine the sustainability scenarios of the Yanacocha lagoon by 2030 as the main water supply for the population of Carhuamayo, in addition to evaluating sustainability indicators such as water and soil quality, variation in vegetation coverage and the level of culture of the inhabitants regarding water in the community.

2. Methodology

2.1 Study area

The area of study was formed by the Yanacocha lagoon and Carhuamayo district located in Junín, Peru. The lagoon is located at 4,360 m.a.s.l. with UTM coordinates 391472.25 E - 8798961.43 N. It has an extension of 119 ha and an approximate volume of 17,830,525 m^3. Carhuamayo district is located at 4,126 m.a.s.l. with UTM coordinates 384084.31 E 8792352.26 N and has an approximate population of 6,638 inhabitants. To delimit the Yanacocha micro-basin, the 22l - 22k contour lines of the Ministry of Education - MINEDU Geoserver were used, which were processed by the ArcGIS 10.5 software.

2.2 Determination of sustainability indicators

For water, the physical-chemical parameters (pH, dissolved oxygen-DO, biochemical oxygen demand-BOD_5 and turbidity) and microbiological parameters (thermotolerant coliforms) were analyzed. Meanwhile, for the soil, the pH, organic matter, texture classes and electrical conductivity were analyzed. To determine the variation of the vegetal cover of Yanacocha micro-basin, were used the satellite images of the INPE-Brazil Geoserver, which were obtained through Landsat satellites 5, 7 and 8 of 1989, 1999 and 2019 respectively. A population survey on water culture was also carried out, with a sample of 350 inhabitants.

2.3 Treatment of the meteorological information

Precipitation and temperature data were acquired from the National Service of Meteorology and Hydrology of Peru - SENAMHI, considering the data recorded from 1970 to 2019 from five meteorological stations (Cerro de Pasco, Carhuacayan, Yantac, La Oroya and Junín). The data were worked with graphical analysis and double mass analysis, and the simple linear regression model was used for the projections of these data (Yang et al., 2020).

2.4 Regionalization of precipitation and temperature for the micro-basin

For the estimation of the pluviometric and thermal gradient of the 8 virtual stations, the method of regionalization at micro-basin level was used through the existing levels of correlation between the decadal averages of the 5 meteorological stations used and the altitude of each virtual station (Chung et al., 2020).

2.5 Determination of water balance (WB), water demand (WD) and water sustainability (WS)

The WB is the difference between precipitation and evapotranspiration (Zhang et al., 2020). For this purpose, isotherms and isoyet maps corresponding to the virtual stations at a decadal level were prepared. Also, the evapotranspiration was determined as a function of biotemperature using the Holdridge method multiplied by Holdridge's annual constant of 58.93 (Le mesnil et al., 2020). For the WD, the population data (2000 to 2015) from the National Institute of Statistics and Informatics - INEI was considered, as well as the projection of these data to 2030 using the simple linear regression model, in addition to the water allocation with the scenarios for mountainous areas of 50 l/inhab/day (MEF, 2004) and for cold climate of 180 l/inhab/day (MVCS, 2006). Finally, the calculation of WS was determined based on the hydrological balance that considers the difference between water supply and demand. In addition, for possible future variations, scenarios were established with +/-10 % of the decadal average for the period 2020 to 2030.

3. Results and discussions

3.1 Water and soil quality (environment) of Yanacocha Lagoon

According to the water analysis, the physical-chemical and microbiological parameters of the water comply with category 1, C1 (human consumption) and category 4, C4 (conservation of the aquatic environment) of the ECA-Water (MINAM, 2017). On the other hand, the soil is in good condition according to the average values of the analyzed parameters that were compared with the guide of fertilization with organic by-products (Orús, et al., 2011). These results are shown in Table 1.

Table 1: Analysis of water and soil quality

Water quality				Soil quality		
Parameters	Average	ECA / Water (D.S 004-2017) C1/ S-A1	ECA / Water (D.S 004-2017) C4 / E1	Parameters	Average	Fertilization Guide
pH (1-14)	8.23	6.5 a 8.5	6.5 a 9.0	pH (1-14)	7.71	7.3 - 7.8 (Slightly basic)
DO (mg/l)	6.30	≥ 6	≥ 5			
BOD_5 (mg/l)	2.58	3	5	Organic matter (%)	10.36	>3.5 % (Very rich)
Turbidity (NTU)	1.03	5	***	E.C. (uS/cm)	215.73	< 2 dS/m (Not saline)
Col-thermal tolerant (NMP/ 100 ml)	3.20	20	1,000	Texture class	clay - sandy/ clay - silt	-

It is important to evaluate the quality of the water resource because it is an essential element for the life and for the development of the economic activities of the population. In addition, good soil quality supports human health, habitat, animal and plant productivity, as well as improves or maintains air and water quality.

3.2 Vegetation coverage

The Table 2 shows the results of the decadal variation of the vegetation cover for the years 1989, 1999 and 2019. It was determined that the decrease in green cover from 1989 to 2019 was 29.61 %.

Table 2: Variation in vegetation coverage

Year of study	Area (ha)	Percentage (%)	Total (ha)
1989	2,590.97	59.29	4,369.71
1999	2,334.04	53.41	4,369.71
2019	1,296.80	29.68	4,369.71

The loss of vegetation cover (pasture) can be caused by intensive agricultural activities (Peruchi Trevisan et al., 2020), urban expansion in favor of infrastructure and road construction (Miller, 2012), and decrease in precipitation and minimum temperature (Rocha et al., 2020). It is important to recover green cover in order to regulate the water cycle and the supply of ecosystem services, as well as to avoid soil erosion, ecological imbalance and the reduction of biodiversity.

3.3 Level of water culture of the inhabitants of Carhuamayo

The Table 3 shows the level of water culture, of which 37.7 % and 28.6 % have a medium and high level, respectively. This is because the inhabitants are aware of the proper use of water and have respect for the lagoon and its environment.

Table 3: Level of water culture of the inhabitants

Level	Frequency	Percentage (%)	Cumulative (%)
Low	118	33.7	33.7
Medium	132	37.7	71.4
High	100	28.6	100.0
Total	350	100.0	-

This cultural level about water was inherited from their ancestors because it is their main source of supply not only for domestic, agricultural and livestock purposes, but also for identity building. Therefore, citizen awareness must be strengthened regarding the recovery and conservation of aquatic ecosystems by building a water culture that allows authorities to manage water more efficiently and effectively.

3.4 Precipitation and temperature at decadal level for the Yanacocha micro-basin

Figure 1 shows that average precipitation tends to decrease from 1970 to 2030; however, there was higher precipitation for 1982 and 1983 due to the "El Niño" phenomenon. Regarding temperature, the values of maximum temperature, average temperature and minimum temperature were around 9.5 °C, 5 °C and 0.5 °C, respectively.

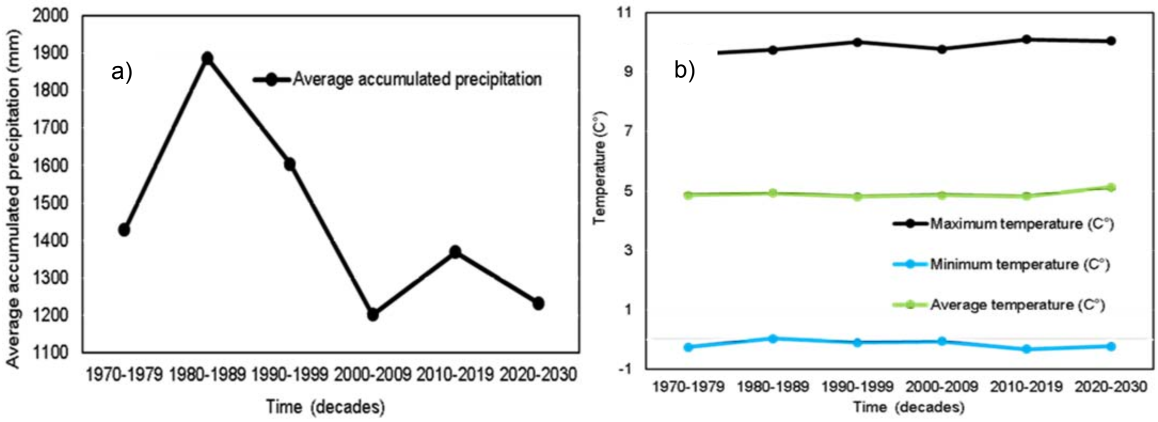

Figure 1: Trend of the meteorological parameters: a) Average decadal precipitation and b) Average decadal temperature

These effects may be influenced by climate change that manifests itself through water by altering its natural cycle that impacts its quality and quantity, resulting in decreased precipitation, changes in the seasonal rainfall regime, increased temperatures, melting of glaciers, droughts, floods, rising sea levels, among others (Harper et al., 2020). Consequently, the micro-basin is not exempt from climate change, which is influencing the future water crisis and could lead to its unsustainability.

3.5 Water sustainability of the Yanacocha lagoon from 2020 to 2030

3.5.1 Water supply (Ws) scenarios for Yanacocha Lagoon

The Table 4 shows the Ws scenarios as the product of the WB scenarios with the area of the lagoon, obtaining the water availability scenarios to 2030.

Table 4: Water supply scenarios

Ws scenarios	WB (mm)	Lagoon area (m^2)	Ws (m^3)	Scenarios
WB + 10 %.	1,077.83	1,186,329.00	1,278,655.83	Optimistic
Average WB	979.84		1,162,414.39	Stabilization
WB – 10 %.	881.86		1,046,172.95	Pessimist

It is essential to calculate water availability and its variations in space and time in order to regulate natural ecosystems, control food supply, energy production, human and environmental health; however, in the future it is expected that water resources will be subject to greater anthropic pressure.

3.5.2 Water demand scenarios in the district of Carhuamayo

The Table 5 shows the population scenarios with water allocations and WD results for 2030. The estimated scenarios showed that the average decadal WD was favorable due to the decreasing trend of Carhuamayo's population because of the constant migration from the field to the town.

Table 5: Water demand scenarios

Population scenarios (inhab)		Water allocation scenarios (m^3/inhab/y)		WD (m^3/inhab/y)	Scenarios
Po + 10 %.	7,412	MVCS MEF	65.7 18.25	486,955.26 135,265.35	Optimistic
Po average	6,738	MVCS MEF	65.7 18.25	442,686.6 122,968.5	Stabilization
Po – 10 %.	6,064	MVCS MEF	65.7 18.25	398,417.94 110,671.65	Pessimist

For the future, water demand is expected to increase along with temperatures and population, but it could be improved by policies that promote more far-reaching development.

3.5.3 Water sustainability scenarios

Eighteen water sustainability scenarios were obtained, including optimists, stabilizers and pessimists (Table 6), all with positive values. The most favorable scenario had a WD of 110,671.65 $m^{3,}$ Ws of 1,278,655.83 m^3 and WS of 1,167,984.18 m^3. All scenarios estimated water availability in the lagoon to supply the population of Carhuamayo by 2030.

Table 6: Water sustainability scenarios for Yanacocha Lagoon 2020 - 2030

Water supply		Water demand					
Ws scenarios (m^3)		Population scenarios (inhab)		Water allocation scenario (m^3/inhab/y)		WD (m^3)	WS (m^3)
Ws + 10%	1,278,655.83	Po + 10%	7.412	MVCS MEF	65.7 18.25	486,955.26 135,265.35	791,700.57 1,143,390.48
		Po average	6.738	MVCS MEF	65.7 18.25	442,686.60 122,968.50	835,969.23 1,155,687.33
		Po - 10%.	6.064	MVCS MEF	65.7 18.25	398,417.94 110,671.65	880,237.89 1,167,984.18
Ws Average	1,162,414.39	Po + 10%	7.412	MVCS MEF	65.7 18.25	486,955.26 135,265.35	675,459.13 1,027,149.04
		Po average	6.738	MVCS MEF	65.7 18.25	442,686.60 122,968.50	719,727.79 1,039,445.89
		Po - 10%.	6.064	MVCS MEF	65.7 18.25	398,417.94 110,671.65	763,996.45 1,051,742.74
Ws - 10%	1,046,172.95	Po + 10%	7.412	MVCS MEF	65.7 18.25	486,955.26 135,265.35	559,217.69 910,907.60
		Po average	6.738	MVCS MEF	65.7 18.25	442,686.60 122,968.50	603,486.35 923,204.45
		Po - 10%.	6.064	MVCS MEF	65.7 18.25	398,417.94 110,671.65	647,755.01 935,501.30

In order to maintain water sustainability, it is necessary to monitor the quality and quantity of water from source to consumption, strengthen society's awareness to improve the level of culture about water and implement strategies to consolidate actions towards sustainable development of water resources (Villena, 2018).

4. Conclusions

It was established that the quality of the water of the Yanacocha lagoon and its environment (soil) were not contaminated, while in the micro-basin there is a decrease in the vegetation coverage. In addition, the population has a medium-high level of water culture, which is reinforced by ancestral attitudes, practices and knowledge inherited about the value and importance of water conservation On the other hand, the study of the water sustainability of the lagoon showed water availability to supply the population of Carhuamayo to 2030, because the sustainability indicators are favorable. To maintain this, it is necessary to have a good management of water resources and be alert to the negative impacts of climate change.

References

ANA., 2010, Evaluación de los Recursos Hídricos Superficiales en la cuenca del río Mantaro 127.

Chung S., Park Y.W., Cheong, T., 2020, A mathematical programming approach for integrated multiple linear regression subset selection and validation. Pattern Recognition. 108, 107565.

Granco G., 2019, Evaluating environmental change and behavioral decision-making for sustainability policy using an agent-based model: A case study for the Smoky Hill River Watershed, Kansas, Sci. Total Environ. 695, 133769.

Harper S.L., Wright C., Masina S., Coggins, S., 2020, Climate change, water, and human health research in the Arctic. Water Secur. 10, 100062.

INEI, 2019, PERÚ: Formas De Acceso a Agua y Saneamiento Basico 1–68.

Le Mesnil M., Charlier J.B., Moussa R., Caballero Y., Dörfliger N., 2020, Interbasin groundwater flow: Characterization, role of karst areas, impact on annual water balance and flood processes. J. Hydrol. 585, 124583.

Lin S.S., Shen S.L., Zhou A., Lyu, H.M., 2020, Sustainable development and environmental restoration in Lake Erhai, China. J. Clean. Prod. 258, 120758.

Li R., 2016, An evaluation research into sustainable development of water resources in lakes watershed. Chem. Eng. Trans. 51, 985–990.

Miller M.D., 2012, The impacts of Atlanta's urban sprawl on forest cover and fragmentation, Appl, Geogr, 34, 171–179.

Ministerio de Economía y Finanzas (MEF), 2004, Parametros De Diseño De Infraestructura De Agua Y Saneamiento Para Centros Poblados Rurales. Foncodes 1, 30.

Ministerio de vivienda, C. y edificaciones (MVCS), 2006, Reglamento Nacional de Edificaciones. Reglam. Nac. Edif. 53, 1689–1699.

Ministerio del Ambiente (MINAM), 2017, Estándares de Calidad Ambiental para Agua (ECA). El Peru. 6–9.

Morales D., Molares S., Epele L., Ladio A., Manzo P., Alday G., 2020, An interdisciplinary approach to perception of water quality for human consumption in a Mapuche community of arid Patagonia, Argentina. Sci. Total Environ. 720, 137508.

Omarova A., Tussupova K., Hjorth P., Kalishe, M., Dosmagambetova R., 2019, Water supply challenges in rural areas: A case study from central Kazakhstan. Int. J. Environ. Res. Public Health 16.

Orús Pueyo F., Betrán Aso J., Iguácel Soteras F., López Sánchez M. V., 2011, Fertilización con subproductos orgánicos (Hacia una gestión sostenible de los nutrientes en la agricultura). Inf. Técnicas 1–72.

Pérez Rodríguez E., Linares Guerra E.M., Delgado Márquez D.L., Tielve Vento R., Pérez Díaz N., 2018, Evaluación de indicadores de sostenibilidad Pinar del Río, Cuba 732–754.

Peruchi Trevisan D., da Conceição Bispo P., Almeida D., Imani M., Balzter H., Eduardo Moschini L., 2020, Environmental vulnerability index: An evaluation of the water and the vegetation quality in a Brazilian Savanna and Seasonal Forest biome. Ecol. Indic. 112, 106163.

Rocha J., Carvalho-Santos C., Diogo P., Beça P., Keizer J, Nunes J.P., 2020, Impacts of climate change on reservoir water availability, quality and irrigation needs in a water scarce Mediterranean region (southern Portugal). Sci. Total, Environ. 736, 139477.

Villena Chávez J.A., 2018, Calidad del agua y desarrollo sostenible, Rev, Peru, Med, Exp, Salud Publica 35, 304.

Wang Q., Li S., Li R., 2019, Evaluating water resource sustainability in Beijing, China: Combining PSR model and matter-element extension method. J. Clean. Prod. 206, 171–179.

Xu J., Lv C., Yao L., Hou S., 2019, Intergenerational equity based optimal water allocation for sustainable development: A case study on the upper reaches of Minjiang River, China. J. Hydrol. 568, 835–848.

Yang X., Magnusson J., Huang S., Beldring S., Xu C.Y., 2020, Dependence of regionalization methods on the complexity of hydrological models in multiple climatic regions. J. Hydrol. 582, 124357.

Zhang X., Dong Q., Zhang Q., Yu Y., 2020, A unified framework of water balance models for monthly, annual, and mean annual timescales. J. Hydrol. 589, 125186.

Zhou J.L., Xu Q.Q., Zhang X.Y., 2018, Water resources and sustainability assessment based on Group AHP-PCA Method: A case study in the Jinsha River Basin. Water (Switzerland) 10.