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Analysis of the water-food nexus for food security in a high Andean Community

M-A Fiestas[1], S-N Gonzalez[1] and L-A Gomez-Cunya[1]

1 College of Engineering, Peruvian University of Applied Sciences, Prolongación Primavera 2390, Monterrico, Santiago de Surco, Lima, Perú
E-mail: u201622577@upc.edu.pe; u201618120@upc.edu.pe; luis.gomez@upc.edu.pe

Abstract. Water and food are facing increasing demand worldwide. This increase is significant in mountainous regions where glaciers are melting, and water availability is in danger. Food demand has also increased with the population growth. This study sought to evaluate relationships between water supply and food demand in a community located in the Peruvian Andes mountainous region. The developed methodology reveals a practical way to identify future problems with food availability. Water supply was evaluated using historical precipitation data. On the other hand, water demand was estimated using meteorological data. Irrigated areas were determined using 2019 agricultural data from the local government. Food consumption was evaluated using a 2019 per capita regional consumption. Results show a water deficit for the current agricultural demand for ten out of the twelve months. The potato was the main crop being produced in the community, among sixteen studied crops. A high percentage of the time, many products were found do not satisfy local demand. For example, the potato was found to secure only fifty-five percent of the total local-demand fifty percent of the time. Current results can help the management of food security.

1. Introduction

Food security measures the well-being of people and societies [1]. The variability of climatic events represents a danger for human well-being [2], [3] and human food security [4]. Water availability and unequal access are problems for communities that mainly depend on food self-production. Food production depends on water availability. So, the water-food nexus is crucial for food security [1]. Food insecurity threatens human development and causes multiple nutritional and health problems [5]. Whit a worldwide growing population, the food demand is high. For example, in 2016, hunger and poverty have increased in Latin America [6]. In Perú, food production is at low levels due, among other factors, to climate variability. Water availability is a big issue [7] because of water stress [8]. This scarcity is causing food insecurity in approximately one-third of the population [9].

Agriculture is the main economic activity in Andean communities since it directly influences the living conditions of its people by increasing jobs and reducing poverty [10]. Severe minimum temperatures affect the crops growing in the areas surrounding these communities. And there is evidence that climate variation can disrupt the way of living of these communities, and even it can cause economic and cultural changes [11]. The region's location and altitude influence the type of agriculture. In some areas, the population engaged in crop agriculture can reach 95%. Besides, agriculture in the Andes is livestock-oriented [12]. A meaningful way to revitalize a community is by developing a local food economy[13]. Hence, growth in agricultural incomes is significant for poverty reduction [14].

Many Andean communities mainly eat what they locally produce. So, their diet depends on what they locally grow. The number of tubers in the diet at the rural level is around 160 kg per capita, three times

greater than that of the urban population. In these communities, potato is the leading food for consumption and represents more than a third of the annual per capita consumption [15]. Research showed water availability influencing tuber yield [16]. Hence, water resources management for food production is crucial to face and adapt to climate changes [17].
The objective of this study was to evaluate the food demand and production of three neighboring Andean communities. The analysis includes different probability water supply scenarios, calculation of food production and food demand, and their balance. The outcomes of this study allowed visualizing the food availability in a local community. The results would help for the optimal management of water and food safety.

2. Methodology

2.1. Location and description of the Study Area

The study area is in the Peruvian Andes. It belongs to the Huancavelica region, and it extends from 74°20′W to 74°30′W Longitude and 12°35′S to 12°50′S Latitude (Figure 1). The study area communities are La Merced, Churcampa, and San Miguel de Mayocc. The estimated population in 2017 was 6,911 [18].
The agricultural water supply comes from an adjacent catchment (Figure 1). The drainage area of the intake basing is 43.08 Km^2, and the water flows through an open channel. The potential agricultural land was about 13.78 Km^2.

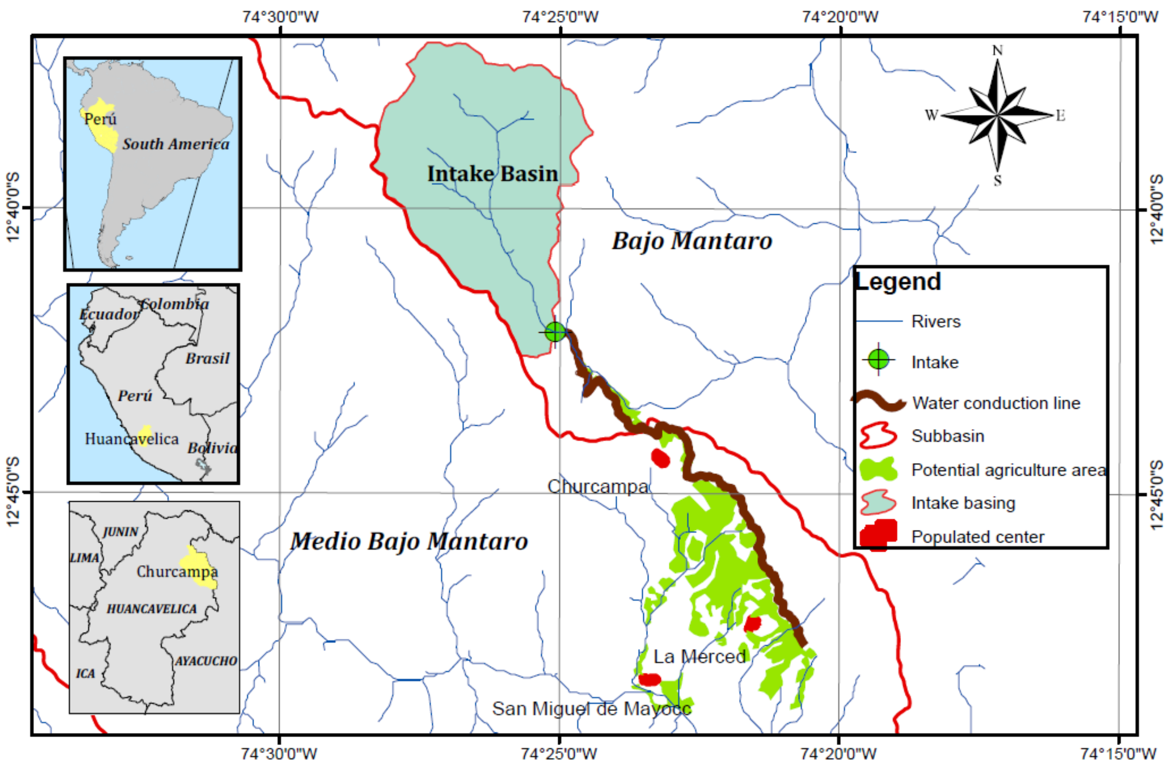

Figure 1. Study area. Intake basin, conduction of water transfer, Andean communities, and potential agricultural land.

2.2. Data and Analysis

The average rainfall in the intake basin was estimated at 831.5mm using historical data from 1999 to 2019. Researchers used rainfall data from four meteorological stations. [19] (Table 1).

Table 1. Meteorological stations.

Station	Latitude	Longitude	Altitude mnsm	Province	Department
Salcabamba	12 ° 12 'S	74 ° 46 'W	4,547	Tayacaja	Huancavelica
Acobamba	12 ° 50 'S	74 ° 33 'W	3,399	Acobamba	Huancavelica
Lircay	12 ° 58 'S	74 ° 43 'W	3,303	Hangars	Huancavelica
Huanta	12 ° 54 'S	74 ° 16 'W	2,485	Huanta	Ayacucho

The agrological data (Table 2) belongs to the three communities and ranges from 2018 to 2019 [14]. The first column shows the total cultivated area for each crop. The second column shows the per capita food consumption (PFC), and the third column corresponds to the crop yield in the Huancavelica region to which the communities belong.

Table 2. Cultivated areas, per capita food consumption, and crop yield, As reported for 2018-2019[20]

Crops	Area (Ha)	PFC (Kg/year)	Crop yield (tons/ha)	Crops	Area (Ha)	PFC (Kg/year)	Crop yield (tons/ha)
Dry grain pea	66	7.4	1.65	Olluco	8	31.9	5.63
Dry grain beans	62	12.7	1.9	Green grain pea	8	35.3	3.81
Starchy corn	87	53.2	1.78	Sweet potato	2	N/A	N/A
Wheat	52	8	1.59	Corn	20	19.9	10.35
Potato	108	169.4	12.12	Yucca	2	N/A	N/A
Dry grain barley	74	38.3	1.58	Avocado	11	2.8	7.71
Quinoa	84	1.9	1.05	Tuna	7	7.6	4.91
Broad beans	37	14.2	1.63	Alfalfa	14	N/A	N/A

The total available water resulted from adding the total runoff supplied by the intake basin plus the effective precipitation. The average monthly runoff in the intake basin was estimated using the Lutz Scholz method [21] because this method has shown promising results for the Peruvian highland Andes [22],[23]. The three communities used all available water transferred from the adjacent catchment. The effective precipitation resulted from applying the USDA method [24].
Then water supply exceedance probabilities were estimated using the empirical Weibull equation (Equation 1). The 25%, 50%, 75%, and 100% exceedance probabilities were arbitrarily selected for further analysis and result comparison.

$$P_e = m/(n+1) \qquad \text{(Equation 1)}$$

Pe is the exceedance probability, m is the value position after a decreasing sorting, and n is the sample size.
The average monthly crop water demand (Table 3) resulted from the Penman and Monteith method [25]. The temperature resulted from the neighboring meteorological stations' data. The remaining variables needed for the process were obtained from the CropWat 8.0 software [26].

Table 3. Potential evapotranspiration using the Penman and Monteith method.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo (mm/month)	127	109	108	109	105	99	103	113	127	142	148	138

Crop production resulted from the four-water-supply exceedance probability scenarios. Next, the food consumption was evaluated using 2019 per capita food consumption data. Lastly, the balance of food production and demand resulted from the analysis. Excesses or deficits for the different water supply scenarios resulted from calculating the ratio between production and consumption.

3. Results

Results showed that current crop production would likely satisfy the demand only during February and March with a 100% probability (Table 4). The most critical months are June and November, in which the likelihood of satisfying the demand is only 23% and 16%, respectively.

Table 4. Probability of crop production satisfying current food demand.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Demand (MMC)	0.64	0.21	0.14	0.2	0.11	0.07	0.06	0.07	0.07	0.12	0.5	0.54
% Time	91%	100%	100%	77%	63%	23%	69%	54%	85%	94%	16%	84%

3.1. Food consumption in neighboring districts (2019)

The most consumed crop was the potato (Fig. 2). Its consumption was around 1216.4 tons/year, representing about 42% of the total demand. Starchy corn and dry grain barley followed the demand with 381.7 tons/year and 275.2 tons/year, respectively. On the other hand, the least consumed foods were avocado and quinoa, with 20.3 tons/year and 13.4 tons/year. The total demand for the cultivated crops in the three communities was 2890.9 tons/year.

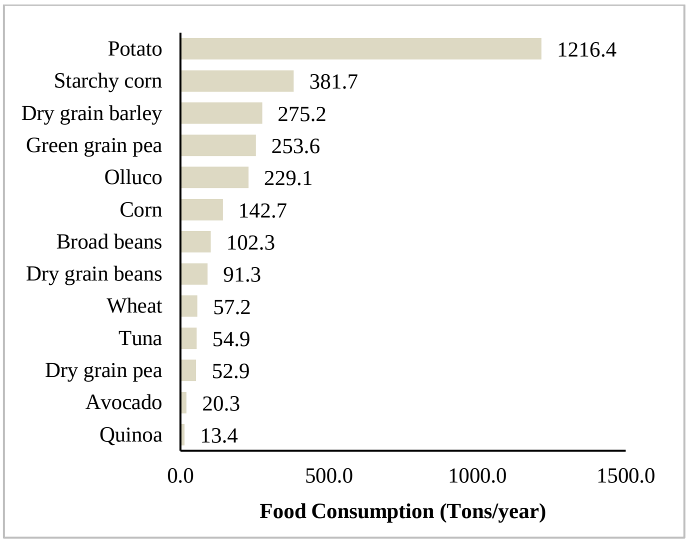

Fig. 2. Food Consumption within the three communities (tons/year), 2019.

3.2. Probability scenarios of food production

The annual food production correlates inversely to the probability of water supply availability (Figure 3). For example, a water supply in the scenario of 25% probability (i.e., only 25% of the time) yields higher food production. As a result, there is a 25% probability of producing 3376 tons/year of the listed crops. A similar analysis yields a total output of 1250 tons/year, 548 tons/year, and 379 tons/year with probabilities of 50%, 75%, and 100%, respectively. The highest annual production in all scenarios corresponds to potatoes. Next in food production was corn, starchy corn, dry grain peas, dry grain barley, and dry grain beans. Foods with lower production are the green grain pea, the prickly pear, and the olluco. In addition, an important fact is that the total output decreases at 1/3 when changing the scenarios from 1 to 2.

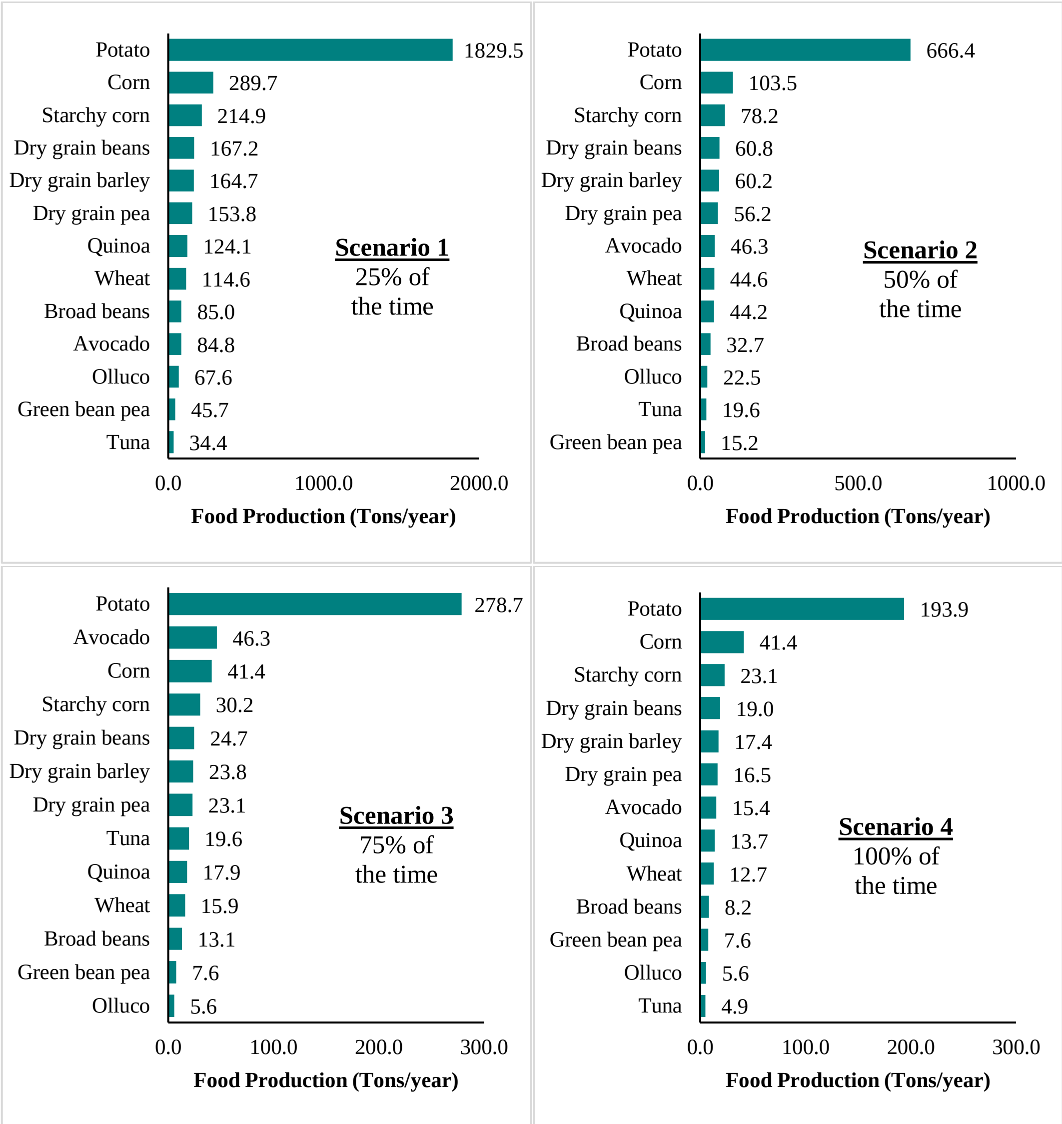

Fig. 3. Food production (Tons/year) at 25%, 50%, 75% and 100% probability scenarios of water availability.

3.3. Balance of food production and demand

Results revealed that, for 100% probability of available water, the production was insufficient to satisfy self-consumption except for quinoa (Table 5). Quinoa and avocado were the only crops meeting self-consumption demands for a 75% probability of available water. For a 50% probability of open water, the need for dry grain peas, avocado, and quinoa was satisfied. Finally, there was only a 25% probability of surpassing the food demand for various crops, including potato crops.

4. Conclusion

This study evaluated the food production and consumption for various probabilities of water supply scenarios. The results showed that the main crops consumed by the population of the studied communities are potatoes, starchy corn, and dry grain barley. This result confirms that the number of tubers consumed in rural areas is higher than in urban areas [15]. Also, the results showed that food production is not enough to satisfy self-consumption. Even for a 25% probability of water availability, food production does not fully meet the demand for self-consumption of some crops. The amount of water decreases as its persistence increases so does food production. If the ecosystems that support these

Andean family farming continue to deteriorate, domestic production may be insufficient to satisfy domestic consumption [27].

Table 5. Balance food production and demand for scenarios 1- 4 (25%, 50%, 75%, and 100% probability of water availability).

Crops	Production / Demand			
	Scenario 1	***Scenario 2***	***Scenario 3***	***Scenario 4***
Dry grain pea	290.90%	106.40%	43.80%	31.30%
Green grain pea	18.00%	6.00%	3.00%	3.00%
Dry grain beans	183.20%	66.60%	27.10%	20.80%
Broad beans	83.10%	32.00%	12.80%	8.00%
Starchy corn	56.30%	20.50%	7.90%	6.00%
Wheat	200.30%	77.90%	27.80%	22.30%
Potato	150.40%	54.80%	22.90%	15.90%
Dry grain barley	59.80%	21.90%	8.60%	6.30%
Olluco	29.50%	9.80%	2.50%	2.50%
Quinoa	928.90%	330.60%	133.80%	102.30%
Corn	203.00%	72.50%	29.00%	29.00%
Tuna	62.70%	35.80%	35.80%	9.00%
Avocado	418.80%	228.40%	228.40%	76.10%

For this reason, the population of these communities would depend on the importation of their main consumed crops, as long as they can afford it. Otherwise, they would only share their own produced food, and the rural population would still be worse nourished than the urban population. Future work can include how the changes in water availability affect neighboring communities and how food security is guaranteed at a local scale.

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