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Scarcity in the Land of Plenty

Water and Sanitation Division

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Scarcity in the Land of Plenty

By Jesse Madden Libra, Julien Sylvain Marinus Collaer, Darcia Datshkovsky, and María Pérez-Urdiales

JANUARY, 2022

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1. Introduction

Latin America and the Caribbean (LAC) is a water-rich region. It contains approximately one-third of the world's freshwater resources and is home to only about 8.5% of the world's population (World Bank, 2017).

The region's estimated annual renewable freshwater resources are approximately 22,342 cubic meters (m^3) per capita, which suggests abundance, especially when compared with regions like South Asia (1,106 m^3 per capita) and the Middle East and North Africa (604 m^3 per capita) (World Bank, 2017).[1] **High-level metrics like these are often used by researchers in global analyses of water scarcity, resulting in the LAC region being classified as low-risk by many in the field (Dolan *et al.*, 2021).** While this classification may seem sensible, it obscures much of the regional variation and resultant issues with water scarcity and stress that exist throughout the LAC region.

Calling attention to this problem is difficult. Areas of high population density and economic activity can generate high water demand in a relatively concentrated land area, causing pockets of scarcity within larger territorial divisions. These pockets often go undetected when they are located within the broader context of a water-rich country or region such as LAC, especially when estimates of water scarcity rely on national-level data or are calculated and displayed based on land area. **Estimates that do not take subnational variation in population distribution into account can lead to misguided conclusions about water scarcity within a country or region, which in turn can lead to serious social and economic repercussions.**

Traditional methods of measuring water scarcity focus on supply-based metrics, such as the Falkenmark indicator and criticality ratios. The Falkenmark indicator, also known as the water stress index, measures water scarcity by calculating the total water resources per capita in each region (Falkenmark *et al.*, 1989), while criticality ratios measure scarcity as the proportion of total annual water withdrawals relative to total available water resources (Falkenmark, 1997). **These measures fall short** because **they do not account for the accessibility of water resources and are generally measured at a country level, obscuring regional variability in water availability and demand**. A country may have ample water resources, but extraction may not be viable, or resources may be so polluted as to render them unusable.

In recent years, the development of water scarcity indices has given a more sophisticated view of water scarcity by disaggregating traditional metrics and incorporating elements such as infrastructural capacity, water management practices, measures of water quality, and environmental flow requirements into comprehensive indices of water scarcity (Dolan *et al.*, 2021; Vanham *et al.*, 2018; Hofste *et al.* 2019; GCAM-LAC; World Data Lab, 2021). Models such as the IDB's Global Change Analysis Model for Latin America and the Caribbean (LAC-GCAM) use a water stress

1. See Appendix A.

indicator calculated by dividing water demand by runoff, with demand and runoff being derived from models that incorporate various policy drivers. **While these metrics are useful for understanding water stress geographically, they often do not adequately represent the temporal or quality-driven variations in water scarcity.** They also often neglect to effectively communicate the human element—some incorporate population as a driver of demand, but population magnitude is rarely incorporated as a measure of impact (Jaeger *et al.*, 2013). Measures that do incorporate population as a measure of impact, for example Worldwater.io, rely on a disaggregated Falkenmark indicator for their measures of water stress without considering water quality or policy, and aggregate population numbers for the public at the state level.

This study uses the Aqueduct 3.0 Water Risk Framework created by the World Resources Institute (WRI) as a base for creating population-based information on water risk for the Inter-American Development Bank's member countries within the LAC region. The WRI framework includes indicators such as baseline water stress, seasonal variability, quantity-based physical water risk, quality-based physical water risk, and overall water risk, which incorporate regulatory capacity, making it a comprehensive set of metrics for understanding overall water risk as well as a useful tool for viewing the components of water scarcity for a given area.

The Aqueduct 3.0 Water Risk Framework allows for a geographic visualization of water scarcity and risk on a global level; however, it does not communicate the impact of areas of water risk on existing populations. This study augments the Aqueduct 3.0. Water Risk Framework to create a population-based water risk dataset that has a detailed level of disaggregation, giving us visibility on the actual population living with water risk. The flexibility of the dataset allows us to explore populations living with various components of water risk, such as physical water stress, seasonal variability, water quality stress, and many more, while allowing us to view statistics about populations living with different categories of water risk at a subnational level. In this report, we analyze these data to expose pockets of particularly high risk, examine the drivers of water risk in select high-risk pockets, analyze future projections, and offer policy recommendations.

The data raise concerns with respect to water risk in the LAC region. Despite its overall abundance, **an estimated 35% of the region's population currently lives in areas facing moderate-high to extreme baseline water stress. In a business-as-usual scenario, this number is expected to increase to 43% by 2040. With the incorporation of water quality and water management practices, which both have substantial impacts on access, the baseline estimates of the population in the LAC region living with medium-high to extreme water risk rises to 65%.** This is a staggering number, especially for the most water-rich region in the world. It should be noted that these estimates are conservative, as large portions of these population percentages are the result of major urban centers being in water-stressed regions, and urbanization rates in the LAC region are expected to increase substantially over the next 20 years.[2]

Our results shed light on current and future populations living in areas of water risk across the region. This information should be used by policymakers to prioritize and encourage investment in infrastructure and new technologies in areas where significant populations are affected by water stress.

2. See section 2.1 for discussion.

2. Data Sources

The data used to create estimates of populations living in areas of water stress and risk come from three main sources: population data are obtained from the WorldPop project, estimates of water scarcity come from WRI's Aqueduct 3.0 Water Risk Framework, and administrative boundaries from the Database of Global Administrative Areas (GADM).

2.1 The WorldPop Project

Building a dataset that combines natural resource information with demographic and economic information has traditionally been a difficult task due to geospatial differences between natural and administrative boundaries. Water availability is usually aggregated using drainage basins as the unit of analysis, while information about population and economic activity is usually organized according to political and administrative boundaries.

This project overcomes this challenge by relying on georeferenced population estimates collected by the WorldPop project. The WorldPop project develops peer-reviewed research and methods for the construction of high-resolution geospatial data concerning population distribution, demographics, and dynamics, with a focus on low- and middle-income countries (Sorichetta *et al.*, 2015).

For this study, we use 2020 population estimates from the WorldPop dataset of population counts. The WorldPop dataset contains population data at a resolution of 1 square kilometer (km^2), derived from unconstrained top-down methods and adjusted to match national population estimates prepared by the Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat (WorldPop, 2018). This high level of resolution allows for population estimates to be calculated within virtually any geospatial boundary.

The WorldPop dataset presents a unique opportunity for analytics due to its high level of disaggregation, but it does present some limitations. WorldPop does not provide future projections to 2030 or 2040, so the 2020 population estimates were used for all WRI periods (baseline and 2020, 2030, and 2040 projections). The analysis presented for these years provides a baseline of the proportion of the population impacted by water stress under the assumption that demographic trends will not drastically change.

The population of the LAC region is expected to grow by 90 million people by 2040, but this population growth is not expected to be geographically uniform. Eighty percent of the population of the LAC region currently lives in urban areas but urbanization rates are expected to increase to 84% by 2030, 87% by 2050, and 91.5% by 2100 (Rud, 2019). As a result of increasing urbanization throughout the LAC region, the projections for 2030 and 2040 of population proportions living in areas of water stress are likely underestimated.

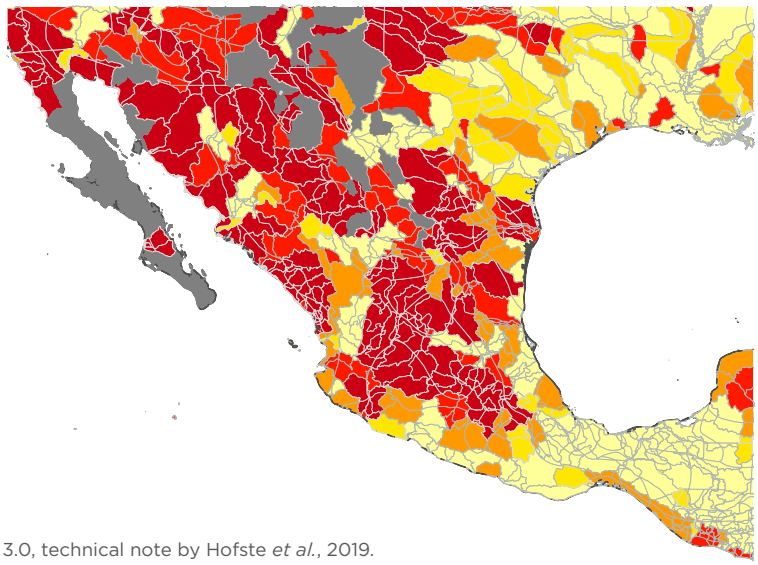
2.2 Aqueduct Global Maps 3.0

Aqueduct Global Maps 3.0 is a geospatial dataset consisting of data generated by the Aqueduct Water Risk Framework. The Framework is a global water risk mapping index developed by WRI that aims to help companies, investors, governments, and other users understand where and how water risks and opportunities are emerging worldwide (Hofste *et al.*, 2019). The Framework uses best-available data and a robust, peer-reviewed methodology to create a high-resolution, customizable global geospatial database of water risk. The data and methodology behind Aqueduct are available for download on WRI's website.[3]

Our methodology uses the Aqueduct 3.0 Water Risk Atlas. The dataset contains a global vector layer composed of polygons that represent a composite of watersheds, aquifers and high-level administrative boundaries. Each polygon is associated with current water stress and risk indicators and projections of water stress under a number of scenarios. Figure 1 shows an example of these composite polygons.

This study uses the **Aqueduct Global Maps 3.0 Data set**, which is divided into two subsets of data: baseline data, and future projections. The baseline data includes several indicators that are then combined to create a multifaceted measure of baseline water risk, referred to as overall water risk in this study. These indicators include elements like water stress, seasonal variability, water quality risk, and aspects of regulatory risk.[4] This study focuses on five of these measures: baseline water stress, seasonal variability, the compound metric of quantity-based physical water risk (risk related to water quantity), the compound metric of quality-based physical water risk, and overall water risk. The future projections data contains estimates of a subset of the variables in the baseline dataset for 2020, 2030, and 2040 following three different climate change scenarios: partial mitigation, business-as-usual, and business-as-usual under a pessimistic economic scenario. The evaluation of the future projections data focuses on the population living in areas of medium-high to extreme water stress under the business-as-usual scenario. The future projections data only incorporates water stress; it does not include water quality, flood risk, or regulatory risk.

FIGURE 1: Example of Water Stress Polygons, Composites of Watersheds, Aquifers, and Administrative Boundaries



Source: Aqueduct Global Maps 3.0, technical note by Hofste *et al.*, 2019.

3. https://www.wri.org/data/aqueduct-global-maps-30-data
4. The different indicators are listed by category in Appendix B.

2.3 Database of Global Administrative Areas

To allow the data to be disaggregated during analysis by more granular administrative boundaries than the country level, it was necessary to subdivide the polygons from the Aqueduct Global Maps 3.0 dataset by administrative boundaries.

The GADM global data version 3.6 was used for this task. The GADM is a high-resolution database of country administrative areas, with a goal of "all countries, at all levels, at any time period." Polygon boundaries are at the municipal level, and each feature includes fields detailing the larger administrative entities of which it is a part.

3. Methodology

Using the data sources discussed above, we created a dataset of the total population for parcels of land that represent granular combinations of administrative and hydrological boundaries. This dataset was then used to calculate the size of populations living in areas of water stress at various levels of the analysis.

QGIS 3.16 was used to perform the geographic information system (GIS) analysis. The Aqueduct 3.0 baseline data were disaggregated by municipal political boundaries from the GADM, creating unique features for each combination of WRI basin and administrative entity. The WorldPop 2020 population data were aggregated for each of these unique features, creating population totals at the feature level.[5]

Population sums at this detailed level of disaggregation were then used to create overall regional population estimates, country-level population estimates, and subnational estimates of people living in areas of different categories of water stress, seasonal variability, quantity-based physical water risk, quality-based physical water risk, and overall water risk.

This process was repeated for the water stress projections from WRI's Aqueduct future projections, and 2040 under the business-as-usual scenario, resulting in the indicators shown in Table 1.

TABLE 1: Indicators and Scenarios Covered in This Study

Indicator	2017	2020 BAU*	2030 BAU	2040 BAU
Water stress	⊗	⊗	⊗	⊗
Seasonal variability	⊗			
Quantity-based physical water risk	⊗			
Quality-based physical water risk	⊗			
Overall water risk	⊗			

Note: *BAU = business-as-usual.
Source: Author's own elaboration

5. Further data processing details are provided in Appendix C.2.

4. Results

For comparison purposes, we report the results of the different risk categories under the different water risk forces and scenarios.

First, we address quantity-based physical water risk, examining contributing factors like water stress (defined as the ratio of total water withdrawals to available renewable surface and groundwater supplies), seasonal variability (variation in availability over the course of a year), and quantity-based physical water risk (a composite index of various physical water metrics focusing on water quantity).[6] We then examine quality-based physical water risk and, finally, overall water risk, which incorporates quantity- and quality-based physical water risk, as well as regulatory risk. We then briefly examine projected water stress in the LAC region for 2020, 2030, and 2040.

4.1 Quantity-based Physical Water Risk

In order to understand quantity-based physical water risk, it is important to first highlight the great level of heterogeneity of the LAC region, which is one of the most diverse regions in the world with respect to water resources. The LAC region's large latitudinal range and topographic variation make it home to a multiplicity of climates and biomes; in fact, the region contains both the driest and wettest drainage basins on earth (the Atacama and the Amazon, respectively). This variation results in a disparity in the distribution of water resources; three river basins in South America (Orinoco, Amazonas, and de la Plata) collect about two-thirds of the annual average runoff of the entire region, while approximately 22% of the land area in the LAC region is considered arid or semi-arid (Guzmán-Arias & Calvo-Alvarado, 2016; Verbist *et al.*, 2010). This large variation exists even within country boundaries, making it essential that water scarcity be viewed through a subnational lens. For example, Mexico's four largest basins cover 10% of the country's geographic area but capture 50% of annual average flow volume, while water availability per capita per year in southern Chile (55,640 m3) is more than 100 times that of the more densely populated north (510 m3) (Guzmán-Arias & Calvo-Alvarado, 2016; OECD, 2017).

Balancing mismatched water availability and demand with seasonal and interannual variability is an important component of water stress. Pockets of severe water stress are common throughout the LAC region where areas of high population densities and levels of economic activity—areas such as the central Valley of Mexico, Peru's Pacific coast, Bolivia's Altiplano plateau, and the Northeast region of Brazil—interlock with small river basins, erratic weather patterns, and dwindling natural storage in wetlands, aquifers, and glaciers (Buytaert & Breuer, 2013). As a result, the percentage of the population that is affected by water stress is much higher than what simply looking at the geographic distribution of areas under water stress would suggest. Given the multifaceted nature of water risk and the quantity-based physical water risk indicator, we next explore the different contributing factors.

6. See Appendix B.

4.1.1 Baseline Water Stress

Baseline water stress is a component of physical water stress, defined as the ratio of total water withdrawals to available renewable surface and groundwater supplies (Hofste *et al.*, 2019). This ratio is then transformed into a discrete indicator divided into six categories: low (if total water withdrawals represent less than 10% of the total available renewable surface and groundwater resources), low-medium (for values between 10% and 20%), medium-high (for values between 20% and 40%), high (40% and 80%), extremely high (if it represents more than 80%), and arid and low water use (basins with baseline available water < 0.03 m/year and baseline gross total withdrawal < 0.012 m/year).

Table 2 shows the population, percentage of population, land area, and percentage of land area falling under each water stress category.[7] Around 35% of the LAC region's population lives in areas experiencing medium-high to very high water stress, while only 18.9% of the land area in the region falls under this categorization. This contrast between the perception of water stress when viewed through the lens of land area versus population demonstrates the importance of taking a population-based approach. Figure 2 represents the percentage of the population affected by each of the baseline water stress categories. The size of the pie charts is proportional to the size of the population. The countries with the highest percentages of their population living in areas of medium-high to extreme water stress are Chile (81.8%) and Mexico (79.2%), followed by Venezuela (54.2%), Brazil (29.9%), and Peru (26.5%).

Drilling down further into data from the two countries with the highest percentage of the population living in water stress— Chile and Mexico— gives us greater insights into these concentrated pockets of vulnerability. In Chile, for example, population centers like Santiago and Valparaíso, which together account for more than 50% of the country's population, exhibit high water stress with demand being practically on par with available resources (OECD, 2017). Regions that host important economic activities, such as mining and agriculture, also suffer from water stress (Arica and Parinacota, and Antofagasta, for example).

In Mexico, large portions of the population of various states are located in areas of extreme water stress. Semi-arid and arid states that rely heavily on groundwater are particularly at risk, including states such as Aguascalientes, Zacatecas, Sonora, Baja California, and Chihuahua. The State of Mexico and Mexico City together represent 20%

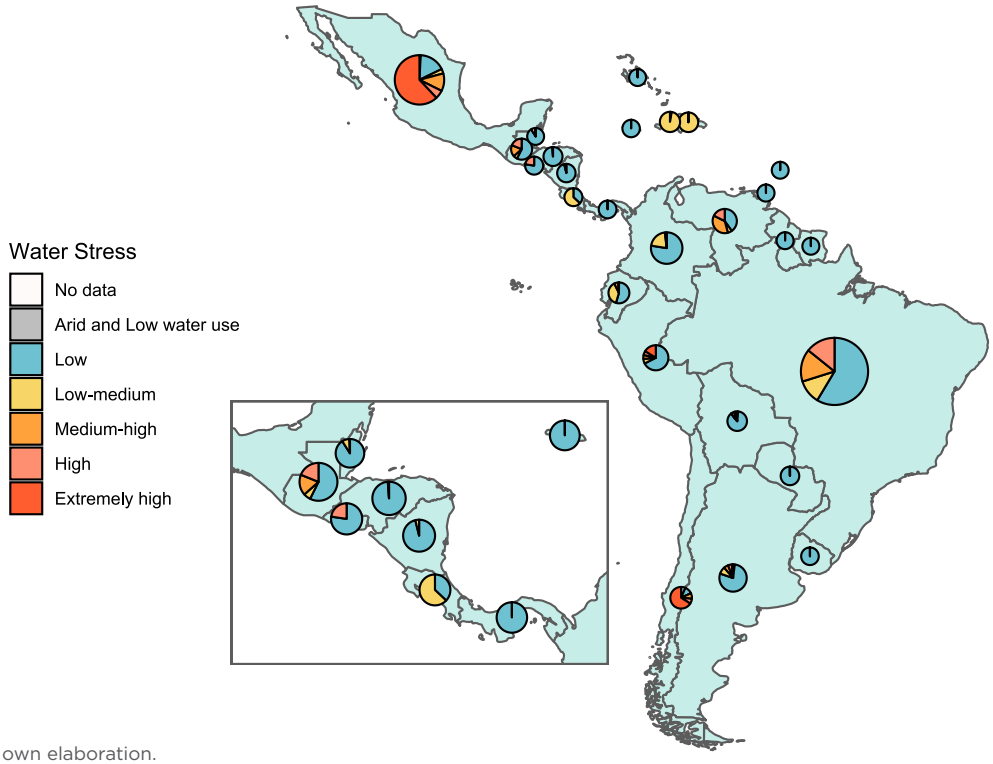
TABLE 2: Populations Living in Areas of Different Baseline Water Stress Levels throughout the LAC Region (2017)

Category	Population	%	Land Area	%
Arid and low water use	3,796,382	0.6%	3,860,103	1.2%
Extremely high (>80%)	107,610,230	15.9%	15,869,598	5.1%
High (40-80%)	54,869,519	8.1%	14,699,845	4.7%
Medium-high (20-40%)	74,065,723	10.9%	27,856,257	9%
Low-medium (10-20%)	87,852,162	13.0%	23,406,359	7.5%
Low (<10%)	349,045,626	51.5%	223,197,542	72.0%
No data	122,259	0.0%	1,197,175	0.4%
Total	677,361,900	100.0%	310,086,879	100.0%

Source: Author's own elaboration

7. See Appendix C.

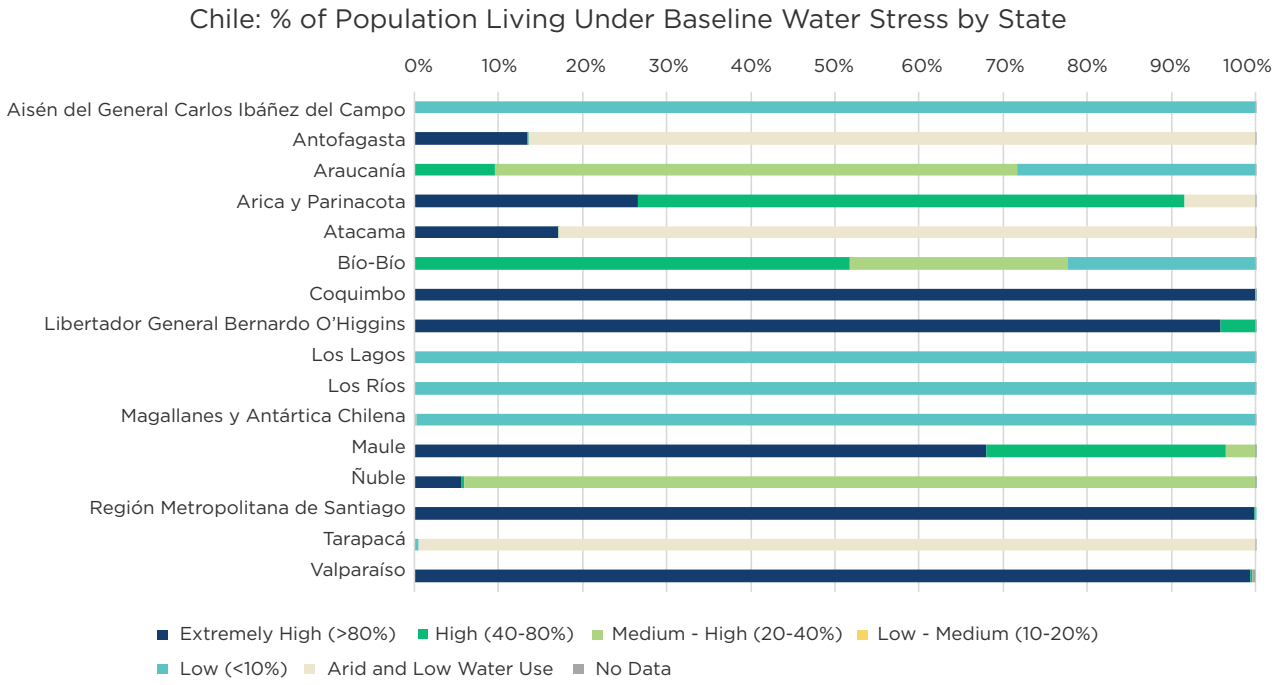
FIGURE 2: Populations Living in Areas of Different Baseline Water Stress Categories, by Country



Source: Author's own elaboration.

of the country's population. Of that 20%, 97% live in areas of extremely high water stress. The metropolitan area of Mexico City (*Zona Metropolitana de la Ciudad de México*; ZMCM), which consists of Mexico City proper and portions of the State of Mexico, has a much higher water demand than exists naturally in the basin itself and, as a consequence, imports about a third of its water supply from outside basins. The rest of its water supply is provided by groundwater, which is extracted faster than natural recharge rates and has resulted in extreme aquifer drawdown, subsidence, and damage to existing infrastructure (Gutierrez, 2019).

FIGURE 3: Chileans Living in Areas of Different Baseline Water Stress Categories, by Region[8]



Source: Author's own elaboration.

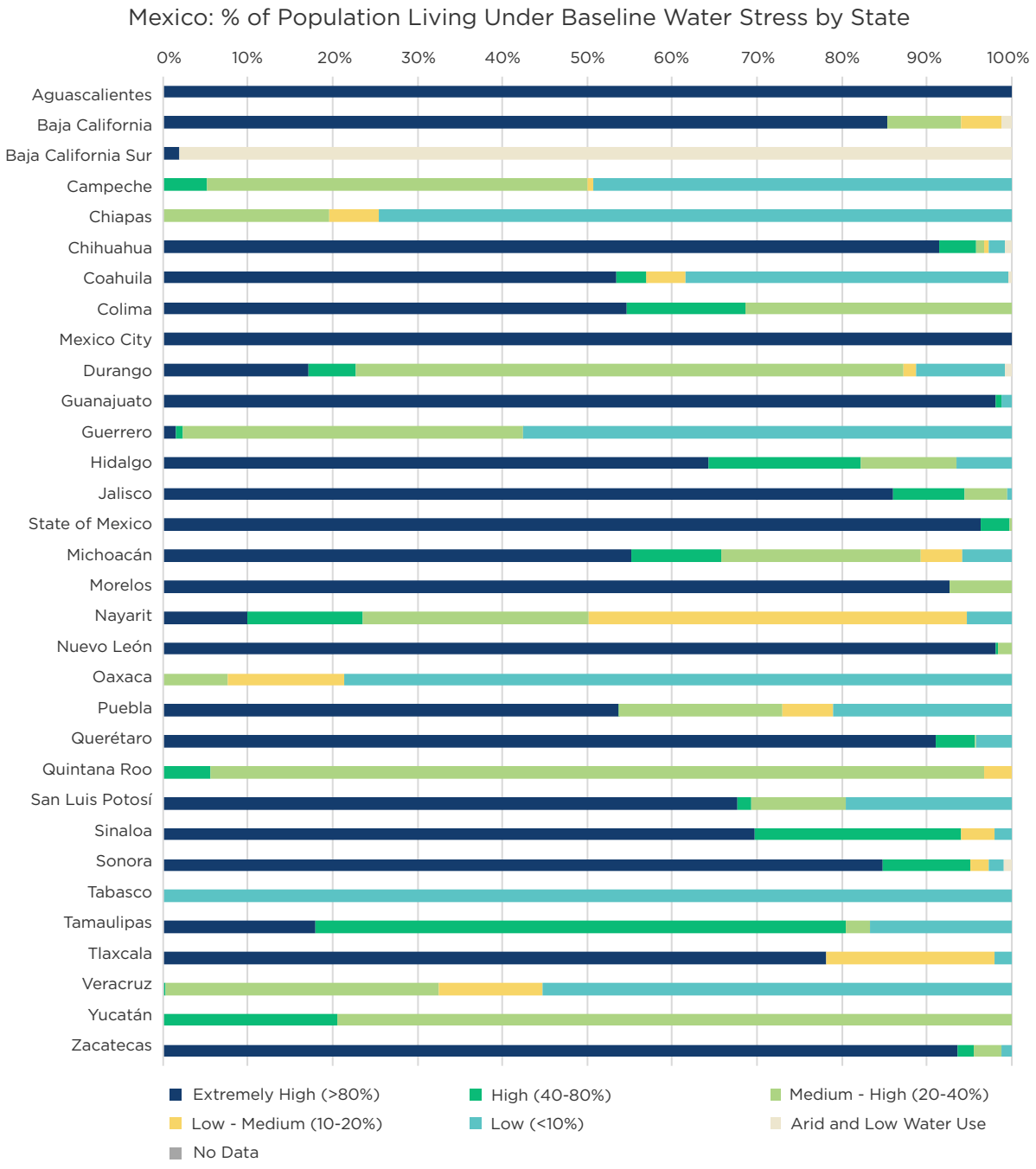
4.1.2 Seasonal Variability

Seasonal variability is another contributing factor to quantity-based physical water risk, as issues with water resource distribution throughout the LAC region are compounded by the extreme temporal variations experienced by much of the region. In the subregion of Mexico, Central America, and the Caribbean, 49.3% of the streamflow takes place between August and October, but only 7.3% from February to April. In South America, seasonal rainfall variation is less drastic, but still significant: 34.6% of streamflow between May and July, and 17% between November and January (Mejía, 2014).

Figure 5 shows the spatial distribution of seasonal variation in water availability at a subnational level, with countries like Chile, Peru, Brazil, and Mexico demonstrating particularly high geographic variation (Hofste *et al.*, 2019). The large differences in seasonal variation in water availability within and between LAC countries are partly due to heterogeneity in precipitation patterns. The severity of seasonal variation in precipitation differs dramatically throughout the region, with some areas experiencing extremely high seasonal variability while others experience relatively consistent precipitation patterns year-round. Areas like Northern and Central Mexico, Northern Chile, southern coastal Peru, much of Brazil, and western Venezuela experience a wet season followed by a dry season due to two monsoon systems in the region: the South American Monsoon System (SAMS) and the North American Monsoon System (NAMS). The SAMS creates extreme seasonal variability in Central Brazil, Northern Chile, Paraguay, Bolivia, among others where the wet season usually starts around mid-October and ends in mid-April (Silva & Kousky, 2012). The NAMS, which affects Northern Mexico, results in precipitation from July to mid-September.

8. See Appendix D for mapping to former region numbers.

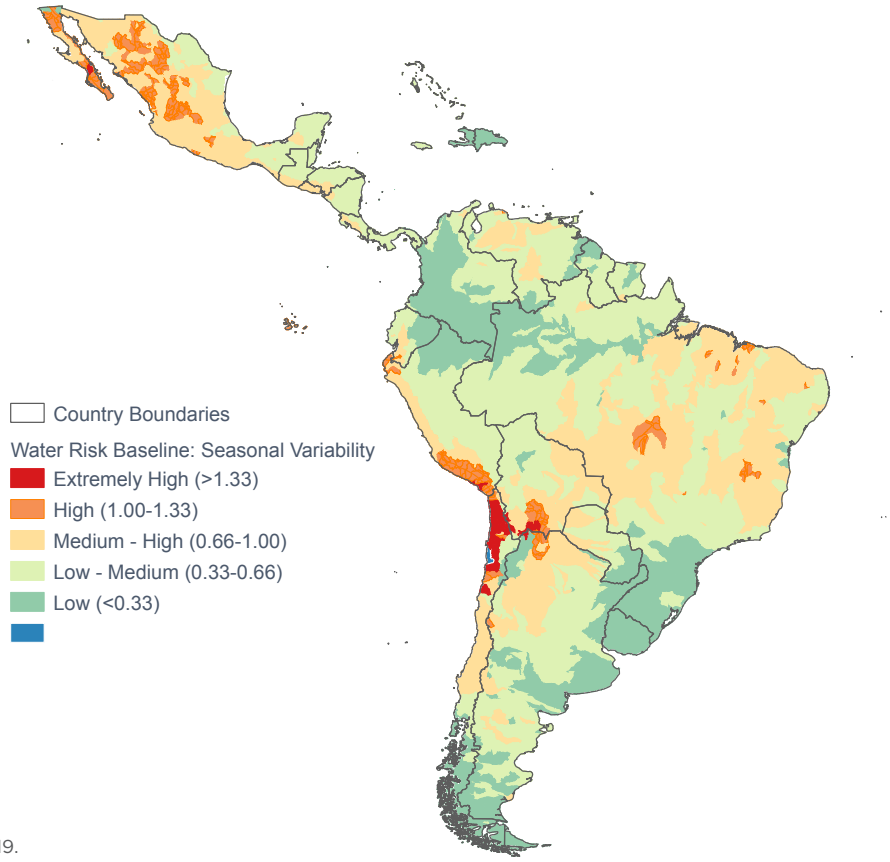
FIGURE 4: Mexicans Living in Areas of Different Baseline Water Stress Categories, by State



Source: Author's own elaboration.

Seasonal variation in precipitation, which is a key contributor to seasonal water availability, creates several challenges from a water management perspective, including water quality and water access issues (Kostyla *et al.*, 2015). Water systems must account both for periods of drought, where secondary sources of water might be necessary, and periods of flooding, where wastewater may overwhelm the regular stormwater system and pollute freshwater supplies (López, 2020).

FIGURE 5: Seasonal Variation in Water Availability



Source: Hofste *et al,* 2019.

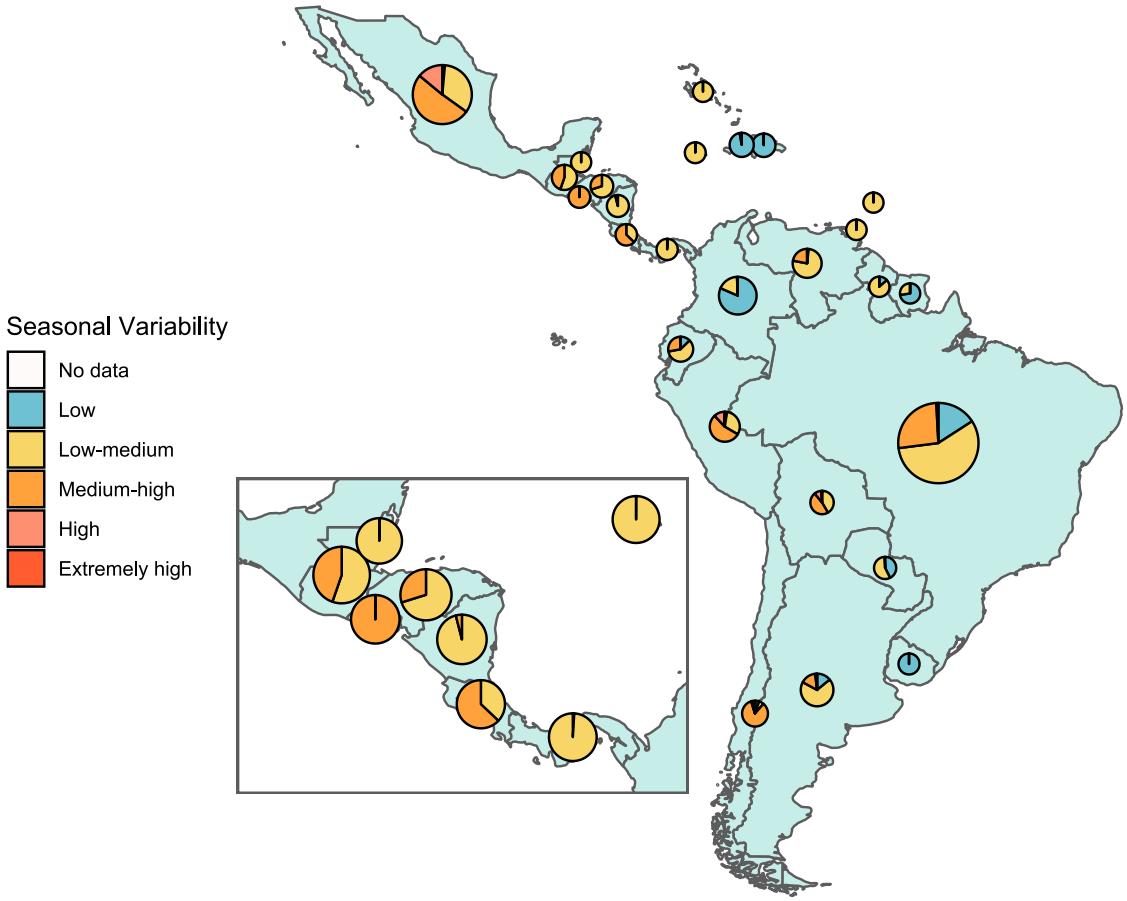
Since seasonal variability in precipitation can be quite extreme, it presents multiple challenges even in areas with low seasonal variation and little water stress. In Panama's 2018 Multi-Purpose Household Survey, 25% of Panamanian households reported water failures during the dry season compared with 19% in the wet season (INEC Panama, 2018). This is a significant policy problem as, throughout the region, approximately 35% of the population lives in areas of medium-high to extremely high seasonal variability. Mexico, Peru, Chile, Bolivia, and various Central American countries are particularly affected by this issue, as can be seen in Figure 6.

TABLE 3: Populations Living in Areas of Different Levels of Seasonal Variability in Water Availability throughout the LAC Region

Category	Population	%
Extremely high (>1.33)	1,061,992.28	0.2%
High (1.00-1.33)	27,932,361.08	4.1%
Medium-high (0.66-1.00)	210,103,157.56	31.0%
Low-medium (0.33-0.66)	305,384,758.51	45.1%
Low (<0.33)	132,722,841.24	19.6%
No data	156,789.46	0.0%
Total	677,361,900.13	100.0%

Source: Author's own elaboration.

FIGURE 6: Populations Living in Areas of Different Levels of Seasonal Variability in Water Availability, by Country



Source: Author's own elaboration.

4.1.3 Total Quantity-based Physical Water Risk

There is much more to water stress and risk than just physical availability. The WRI variable of overall physical risk incorporates both baseline water stress and seasonal variability, along with baseline water depletion, interannual variability, groundwater table decline, riverine flood risk, coastal flooding, and drought risk. Incorporating all of these factors creates a more comprehensive view of quantity-based water risk throughout the LAC region, but also paints an even more severe picture. Over half of the LAC region's population (52.5%) lives in areas experiencing medium-high to extremely high quantity-based physical water risk. This increase in severity can also be observed at the country level in Figure 7.

The incorporation of interannual variability, groundwater table decline, riverine flood risk, coastal flooding, and drought risk drastically increases the proportion of the population living in areas of significant water risks in most Caribbean nations. This is in part due to the islands' vulnerability to cyclones and storm surges, which increases the risk of both riverine and coastal flooding. Many countries in the region, such as Jamaica and the Dominican Republic, are also over-reliant on groundwater for potable water supply, which has resulted in groundwater table decline and saltwater intrusion (Cashman, 2013).

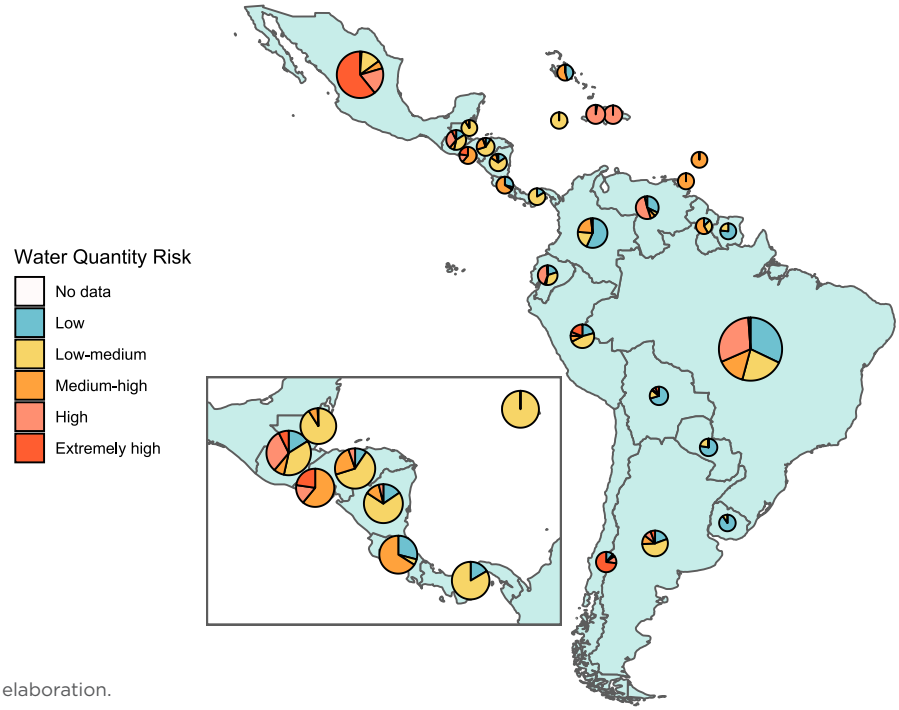
Central American countries also appear much more vulnerable when looking at quantity-based physical water risk compared with the baseline water stress, due to Central America's high interannual variability and flood risk. This is primarily due to its geography, which makes it vulnerable to hydrometeorological phenomena such as tropical cyclones, convective systems, mid-summer droughts (also known as *canícula* or *veranillo*), among others (Maldonado, 2016).

TABLE 4: Populations Living in Areas of Different Quantity-Based Physical Water Risk Levels throughout the LAC Region (2017)

Category	Population	%
Extremely high (4-5)	116,993,313	17.3%
High (3-4)	160,469,651	23.7%
Medium-high (2-3)	77,641,091	11.5%
Low-medium (1-2)	157,685,603	23.3%
Low (0-1)	164,556,116	24.3%
No data	16,126	0.0%
Total	677,361,900	100.0%

Source: Author's own elaboration.

FIGURE 7: Population Proportion by Country That Lives Under Different Classifications of Quantity-Based Physical Water Risk



Source: Author's own elaboration.

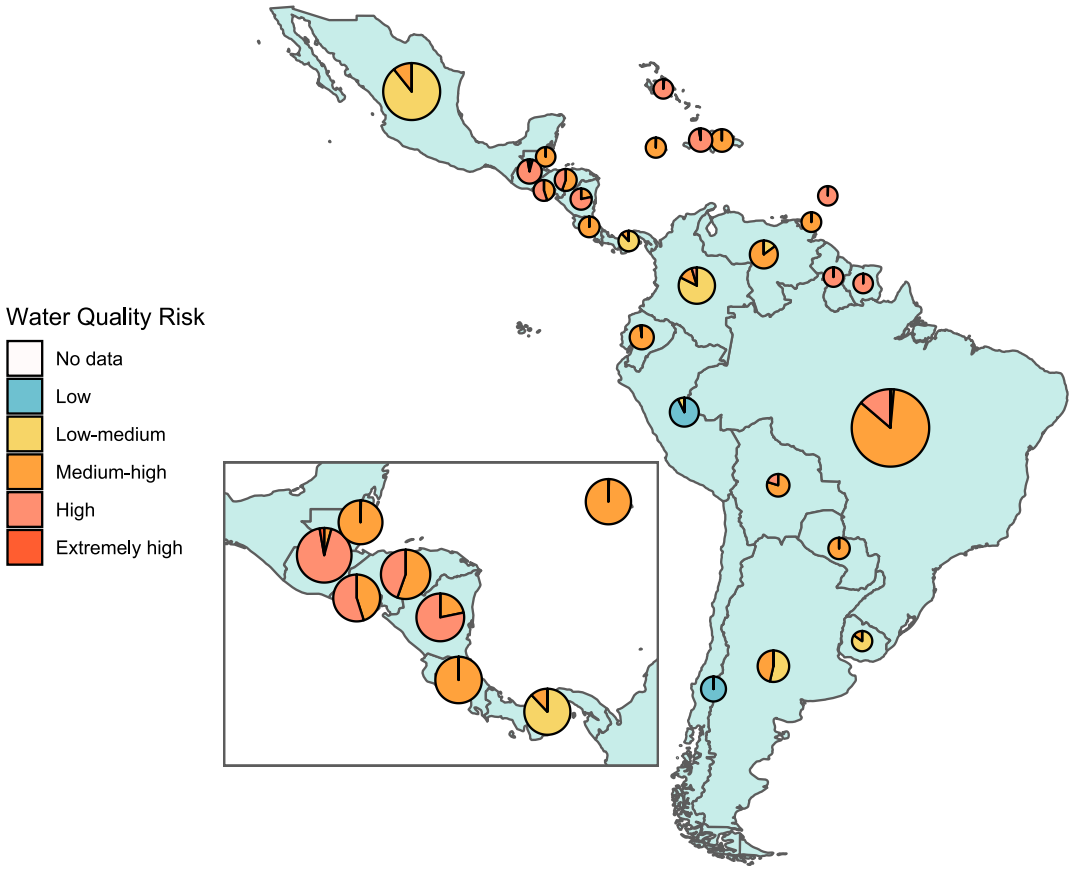
4.2 Quality-Based Physical Water Risk

Throughout the LAC region, water pollution poses a major threat to water availability: 60% of the population lives in areas of medium-high to extremely high quality-based physical water risk. The data used to calculate quality-based physical water risk for the WRI Aqueduct metric takes two variables into account: untreated connected wastewater and coastal eutrophication potential. Untreated connected wastewater is the percentage of domestic wastewater that is connected to a sewerage system and not treated to at least a primary treatment level, while coastal eutrophication potential is a measure of nitrogen, potassium, and silica loading in surface water bodies. Eutrophication can be caused by many factors, including discharge of untreated wastewater, runoff of industrial fertilizers, and industrialized animal production. Figure 8 sheds light on this type of risk at the country level, showing a substantial increase in the population affected by higher risk in countries with relatively abundant water resources, such as Brazil, Honduras, Nicaragua, Jamaica, and Belize.

Water quality is a big problem in the region. Wastewater management is an area with large data gaps, but the data that does exist show low rates of sewerage connection (Figure 9) and low rates of sewage treatment (Figure 10). In many countries, less than half of the population have sewer connections. Throughout the LAC region, approximately two-thirds of wastewater goes untreated while aging infrastructure means wastewater systems often leach contaminants into groundwater (Xie *et al.*, 2016).

Water quality issues in the LAC region go beyond the inputs included in the quality-based physical water risk metric from Aqueduct. Saltwater intrusion and improper disposal of solid and industrial waste also contribute to poor water quality throughout the region. While water quality standards exist, fines for violations are often lower

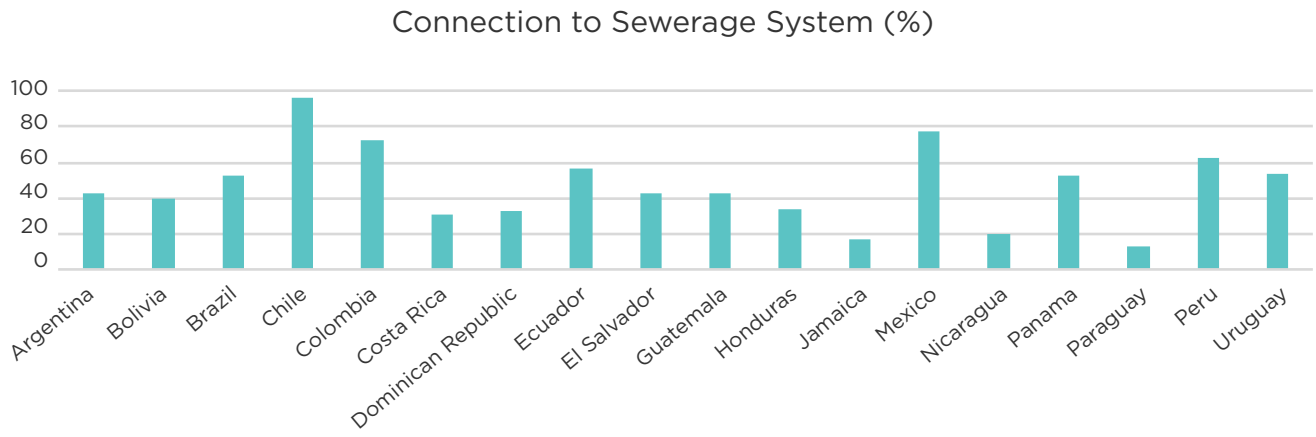
FIGURE 8: Population Proportion by Country That Lives Under Different Classifications of Quality-Based Physical Water Risk



Source: Author's own elaboration.

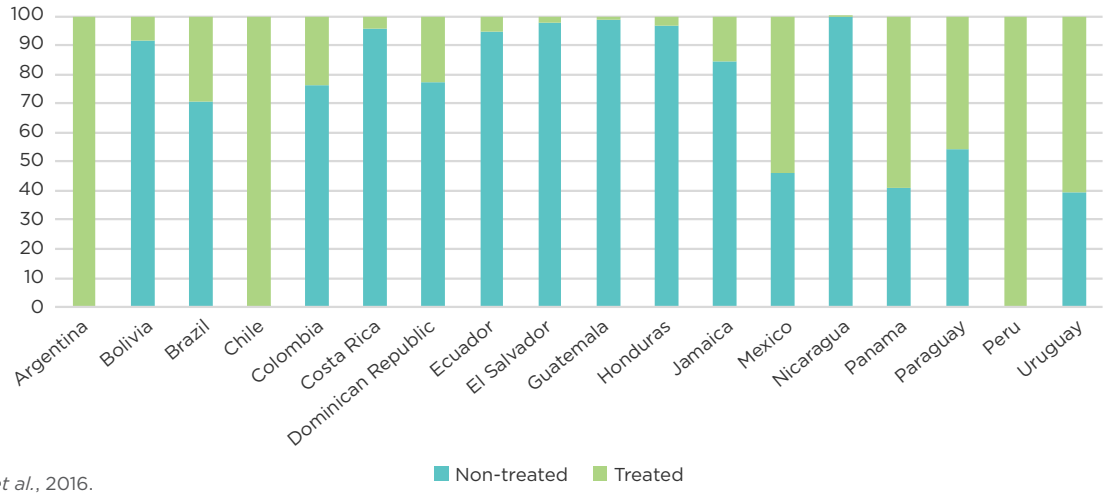
than the cost of proper water treatment and disposal or are not properly enforced due to a lack of capacity on the part of enforcement institutions (Pinheiro *et al.*, 2020). **Poor water quality renders water unfit for many uses and increases the cost of treatment to return water to a quality level fit for human consumption.** The ubiquity of water quality issues throughout the LAC region results in water stress in many areas that do not suffer from a physical lack of water. Guatemala, for example, has relatively abundant water resources (approximately 6,788 m^3/capita/year), but, due to low sewer connection rates, low water treatment rates, and widespread use of fertilizers and pesticides on plantations, most water is unfit for consumption (World Bank, 2017; Kondash *et al.*, 2021).

FIGURE 9: % of Homes Connected to Sewer Systems in the LAC Region



Source: Xie *et al.*, 2016.

FIGURE 10: % of Wastewater Treated throughout the LAC Region



Source: Xie *et al.*, 2016.

4.3 Overall Water Risk 2017

The last indicator considered in this analysis is overall water risk, which is a comprehensive measure of water risk that incorporates the inputs of quality-based physical water risk and quantity-based physical water risk (discussed in the previous sections), along with regulatory and reputational risk. Regulatory and reputational risk consists of three sub-indicators: the percentage of the population without access to improved water, the percentage of the population without access to sanitation, and the Peak RepRisk ESG Indicator.[9] The incorporation of regulatory and reputational risk involves factors like the capacity of the governments to provide infrastructure, the strength of regulatory agencies meant to protect the environment, and the government's general adherence to international norms such as human rights. Accounting for water management and regulatory capacity, water quality and quantity-based physical water risk, more than 60%

9. See Appendix B for more information.

TABLE 5: Population That Lives in Areas of Different Overall Water Risk

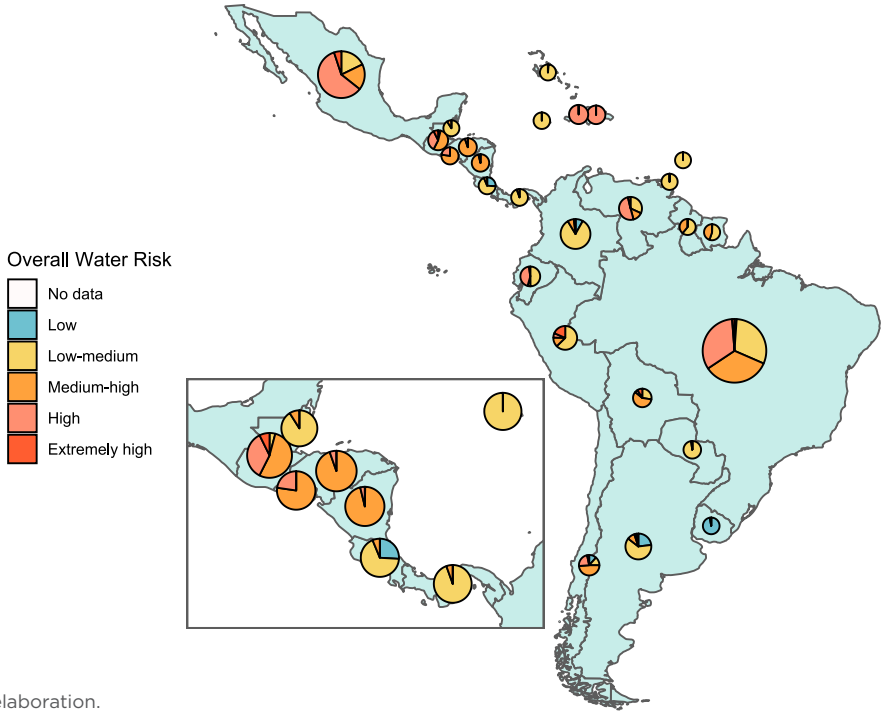
Category	Population	%
Extremely high (4-5)	22,019,147	3.3%
High (3-4)	224,228,227	33.1%
Medium-high (2-3)	165,369,492	24.4%
Low-medium (1-2)	240,723,127	35.5%
Low (0-1)	25,016,000	3.7%
No data	5,909	0.0%
Total	677,361,900	100.0%

Source: Author's own elaboration.

of the LAC region's population lives in an area with medium-high to extremely high water risk. Figure 11 shows a large increase in the proportions of country populations living in areas of water risk in comparison to other components of water risk examined in this study, underscoring the importance of using multidimensional indicators in assessments of water risk. Lastly, the distribution of municipalities with more than 250,000 people under medium-high to high overall water risk in the regions is represented in Figure 12.

Infrastructure is a relevant factor related to regulatory and reputational risk in the LAC region as government willingness to invest in infrastructure is necessary to achieve high levels of improved water access. Water distribution and wastewater infrastructure throughout the region is insufficient to meet the existing population's needs. Only an estimated one-third of wastewater is treated to even a primary level, while leakage rates in distribution networks average between 20% and 50% of total water. Additionally, the expansion of distribution and wastewater networks to new communities is often neglected as cities grow, as are "last mile" connections (Fay *et al.*, 2017). For example, in Guayaquil, Ecuador, 30,000 households remain without connections 30 years after sewerage pipes were installed in their neighborhoods. Approximately one-third of these households reported that money was their key impediment to connect (Fay *et al.*, 2017).

FIGURE 11: Populations Living in Areas of Different Overall Water Risk Levels, by Country



Source: Author's own elaboration.

FIGURE 12: Municipalities with Over 250,000 People Under Medium-High to High Overall Water Risk[10]

Source: Author's own elaboration.

10. See full list of municipalities in Appendix E.

4.4 Looking Ahead

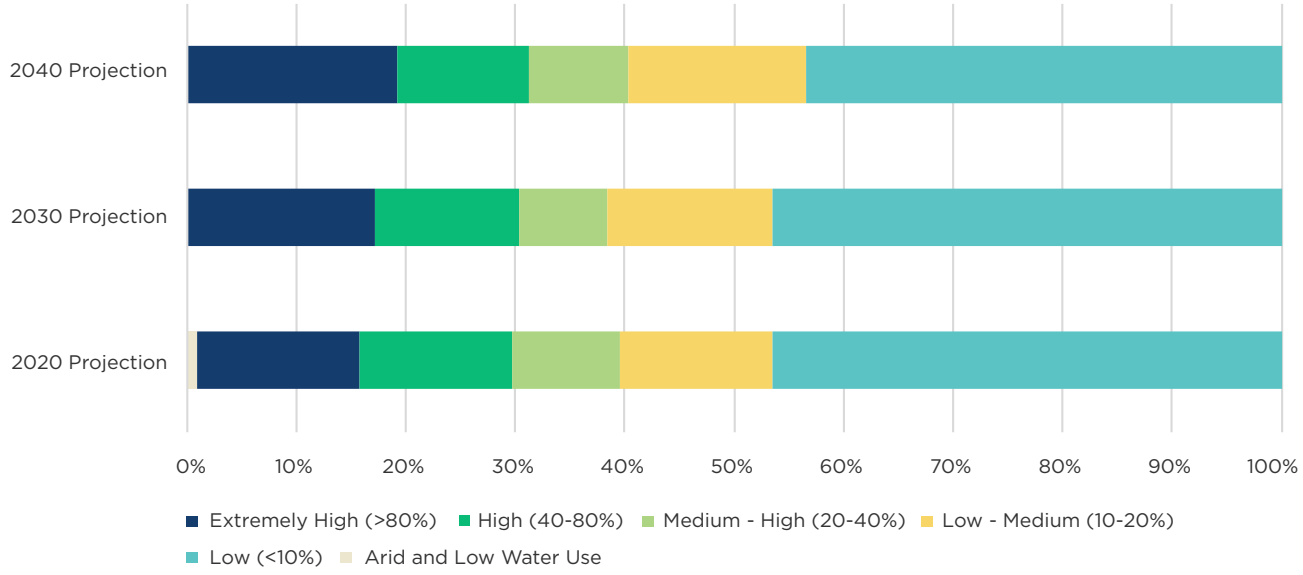
Under a business-as-usual scenario, assuming no major demographic shifts, approximately 40% of the population of the LAC region will be living in areas of medium-high to extremely high water stress by 2040, with the population living in areas of extreme water stress rising from 15% to 19% (Figure 13). However, this likely represents an optimistic estimate as the business-as-usual scenario is unlikely due to three main challenges: first, the population of the region is expected to increase along with urbanization rates (CELADE, 2019); second, climate change is projected to cause larger shifts in water availability than previously thought, via changes to seasonal precipitation patterns, diminishing storage in glaciers, and water quality issues due to sea-level rise; and, third, declining infrastructure may compromise existing water resources and, therefore, exacerbate water risk throughout the region.

To deal with these challenges, significant investments in infrastructure and new technologies will be necessary, both in terms of improving the efficiency of use of existing freshwater resources, and expansion of water supply via technologies like desalination and water reuse.[11]

4.4.1 Population

Not only is the population of the LAC region expected to grow by 90 million people by 2040, but this population growth will not be geographically uniform, putting even more pressure on water resources in specific areas. **Eighty percent of the LAC region's population currently lives in urban areas**, but urbanization rates are expected to increase to 84% by 2030, 87% by 2050, and 91.5% by 2100 (Rud, 2019). According to the United Nations, in 2016, 12.7% of LAC residents resided in just five cities with 10 million inhabitants or more (the metropolitan areas of Mexico City, São Paulo, Rio de Janeiro, Buenos Aires, and Lima) (United Nations, 2016). Growing populations in urban settings will create more demand and put even more pressure on already stressed water distribution and wastewater systems.

FIGURE 13: Projections of Population Proportion Within the Region Living in Areas of Medium-High to Extreme Water Stress



Source: Author's own elaboration.

11. Behavioral changes promoted via pricing and non-pricing policies will also be required, but these are beyond the scope of this analysis.

4.4.2 Climate Change

Climate change is set to have severe consequences throughout the region, where increased tropical storm intensity, saltwater intrusion, retreating glaciers, and more extreme El Niño events are all expected to contribute to decreased physical supply and degradation of freshwater quality. Generally, annual precipitation patterns are expected to shift, and interannual variability is expected to increase. These shifts promise to change the dynamics of current water management, affecting water availability for human consumption, industry, and ecosystems.

The Caribbean, where increases in the severity of tropical storms and hurricanes have already been noted, is particularly vulnerable. Stronger storm surges and sea level rise, as predicted by the Intergovernmental Panel on Climate Change (IPCC), are poised to cause more extreme flooding and to worsen saltwater intrusion, resulting in damage to already degraded water distribution networks and degradation of water quality (Masson-Delmotte *et al.*, 2021; Magrin *et al.*, 2007).

Glacial melt constitutes an important water source for major South American population centers such as Lima, Quito, La Paz, and Santiago. Glaciers throughout the Andes, however, are in retreat (Masson-Delmotte *et al.*, 2021). These glaciers are often crucial in drought years and dry seasons when glacial melt is used to supplement deficiencies in precipitation. Santiago, for example, obtains 80% of its freshwater supply from the Maipo basin, in which glacial melt constitutes an estimated 16% of total runoff annually. In the dry summer months, though, glaciers are estimated to contribute more than 50% of the basin's runoff (Ayala, 2020). As glaciers continue retreating and glacial melt flows decrease, population centers that rely on glacial melt will become increasingly vulnerable. Climate change is also expected to increase the frequency and extremity of drought due to the increased frequency and intensification of the El Niño-Southern Oscillation, making the reliance on glacial melt in times of drought particularly concerning (Wang *et al.*, 2019).

Considering this predicted scenario, the percentage of population living with water stress in the LAC region is likely to increase in the coming decades, as climate change may negatively affect all water risk indicators considered in this analysis.

4.4.3 Declining Infrastructure

Looking forward, issues with water infrastructure are expected to worsen. Population centers with large distribution and wastewater networks are experiencing infrastructure decline due to aging pipes and insufficient maintenance. In Mexico City, for example, it is estimated that more than 40% of water in the distribution network is lost due to leakage and illegal connections, the equivalent of 130 liters/person/day (Gutierrez, 2019; Arreguín-Cortes & Ochoa-Alejo, 1997). Similar water infrastructure issues are faced by other metropolitan areas, such as Buenos Aires, Belo Horizonte, Valparaíso, where leakage is estimated at 41%, 36%, and 43%, respectively (OECD, 2017; OECD, 2019).

Several utilities in the region have developed strategies to tackle these issues. In Brazil, where the expansion of sewer systems tends to be limited primarily by cost, some utilities have taken steps to make sewer connections more economically viable for poor households by enabling payment installments, pro-poor tariffs, and community-based connections. For example, the utility for the state of Bahia in Brazil, EMBASA, created an innovative condominial approach to sewer connections in low-income neighborhoods to build low-cost joint sewage facilities (Fay *et al.*, 2017).

However, the investment in water infrastructure is generally low despite the deficient state of water infrastructure throughout the region. Between 2008 and 2015, only 11% of infrastructure investment went to water and sanitation, representing approximately 0.3% of regional GDP (Serebrisky *et al.*, 2018). This investment is overwhelmingly from public funding, with private contributions averaging 3% of total water and sanitation investment across the region between 2008 and 2015. Public-private partnerships (PPPs) such as

Cidade Saneada in Brazil, led by BRK Ambiental, can be a solution to infrastructure investment needs. IDB Invest finances a project by this Brazilian PPP which will expand, renovate, and improve wastewater infrastructure in Recife, a region with high economic vulnerability. The project is expected to increase access to sanitation services to 90% universal coverage by 2037 (IDB Invest, 2019).

However, if the lack of investment continues, these challenges will compound. As increasing urban populations put more stress on distribution systems that are already insufficient and traditional sources of water supply become less reliable, inefficiencies in these systems will have a large impact on water security and expose a larger percentage of the population to water stress.

4.4.4 New Technologies

The adoption of new technologies in water management will be key, both for improving water infrastructure management and supplementing supply shortfalls through more cyclical water management. Smart Water Infrastructure Technologies (SWIT) promise to improve the efficiency of water distribution and wastewater systems, while water reuse and technologies like desalination can augment supply.

In the realm of water distribution management, SWIT promise targeted identification of leaks and inefficiencies in existing systems, allowing for precise intervention. Utilities throughout the LAC region have started to turn to these technologies, investing in smart meters, District Metered Areas, and GIS technology. In São Paulo, the Department of Water and Sewage (*Departamento de Água e Esgoto*; DAE) of Americana has opted to invest in smart meters to improve leak detection in recent years, while MIYA Bahamas has successfully reduced leakage rates from 60% in 2012 to 17% in 2019 through smart data collection and prioritizing leak detection (Blackman, 2019; IDB Invest, 2019).

Innovative solutions that address supply deficiency, such as desalination and water reuse technologies, could create a more cyclical paradigm in water management and be used to supplement the gap between supply and demand. While water reuse is still in its infancy throughout the LAC region, a 2019 background paper by the World Bank estimated that the market potential for water reuse and related products in the region is between $3 billion and $62 billion (World Bank, 2019). Water reuse can be especially successful in partnership with industry, where revenue from the sale of treated wastewater can cover the bulk of operations and maintenance costs, as in the case of the partnership between the Tenorio Wastewater Treatment Plant and a Federal Electricity Commission Power Plant in San Luis Potosi, Mexico (World Bank, 2018), or the partnership between the utility of Arequipa (SEDAPAR) and the mining company Cerro Verde in Arequipa, Peru (Rodriguez, 2020). This model is especially viable in areas of water scarcity or where industrial tariffs are high.

Use of these technologies can provide some relief for areas of high water risk by managing existing resources efficiently and augmenting supply. **These technologies require sizable investments but also have the potential for high returns, both monetarily and in terms of water savings.**

5. Conclusions and Policy Recommendations

This study creates and analyzes a population-based water risk database that accurately informs the actual population living with water risk thanks to its high level of disaggregation.

We explore the population living with various components of water risk, namely water stress, seasonal variability, water quality risk, and overall water risk, which incorporates quantity-based physical water risk, water quality-based risk, and aspects of water management. **Our results show that despite having abundant water resources, the LAC region is prone to water scarcity.** The region is highly urbanized and its population centers are often located in areas without sufficient water resources, meaning that large proportions of populations could be vulnerable to water scarcity despite the fact that many countries may have ample water resources within their borders.

- **Approximately 35% of the population in the LAC region lives in areas where total withdrawals represent at least 20% of the available renewable surface and groundwater supplies.** Chile and Mexico have the highest percentage of their populations in these areas (81.8% and 79.2%, respectively). Our analysis finds that it is crucial to focus on population-based metrics rather than land-based ones, given that the population is not evenly distributed across the region.

- **Water resource distribution is highly heterogeneous geographically as well as temporally,** strongly contributing to greater water stress. The subregions of Mexico, Central America, and the Caribbean show the highest seasonal variability in water resource availability. This variability generates certain challenges in terms of water management as water systems need to be robust enough to accommodate extreme events such as periods of drought, which imply relying on secondary sources of water, and periods of flooding, which put pressure on regular stormwater systems and pollute freshwater supplies. These extreme events may thus increase water risk, underscoring the importance of investment in improving the resilience of existing water systems.

- **Around 60% of the population in the region is affected by medium-high to extremely high quality-based physical water risk,** based on the level of untreated connected wastewater and the potential for coastal eutrophication. In particular, approximately two-thirds of wastewater in the LAC region goes untreated and contaminants are often leached into the groundwater due to aging infrastructure.

Considering quantity- and quality-based physical water risk as well as regulatory and reputational risk, more than 60% of the population in the region lives in areas with medium-high to extremely high water risk. One of the main factors influencing this result is the state of the water distribution and wastewater infrastructure, which is insufficient to meet the needs of a growing population, especially in urban areas. As water stress is expected to become more severe in certain areas, the dataset can be used to guide land-use policy aimed at balancing urban development and preserving water availability and quality. Moreover, it also provides relevant information to policymakers for better targeting infrastructure investments, focusing on municipalities with high water risk levels or high levels of a specific subvariable, and large populations (see Appendix E for a list of municipalities with more than 250,000 people and medium-high to extreme water risk).

In the coming years, the situation is likely to worsen. The percentages of the population living under water stress in the future, as predicted by this study, are conservative estimates. The population data used in this study do not account for population growth or the predicted increase in urbanization rates, while the water stress estimates represent a business-as-usual climate scenario. In recent reports, the IPCC has indicated that climate change impacts may be more extreme than anticipated, while further degradation of infrastructure and increased urbanization rates promise to put additional strain on existing systems. In this context, integrated water resources management may play a fundamental role in expanding water quantity and quality (García *et al.*, 2021). Revamping existing infrastructure to reduce water loss and make "last-mile" connections will be key; this highlights the need for a substantial increase in investment in the sector. Investments should focus on increasing connections and the adoption of technologies such as SWIT, which can generate efficiency gains in the water distribution and wastewater systems, or desalinization and water reuse technologies, which can increase supply.

PPPs will be crucial to achieve the necessary investments in infrastructure, while improving the quality of public services at a reasonable cost (García *et al.*, 2021). There is great potential to increase the level of participation of the private sector, given that only 6% of private investment in infrastructure in the region is devoted to water and sanitation. However, the current challenging regulatory framework will need to be reformed to attract private investment (Castrosin *et al.*, 2021). This policy recommendation is in line with the results obtained from the overall water risk, in which we observe that reputational and regulatory aspects jeopardize access to water for millions of people in the LAC region.

Appendix A: Renewable Freshwater Resources

The Latin America and the Caribbean (LAC) region appears to have abundant water resources based on an analysis of high-level metrics.

TABLE A.1: Annual Renewable Internal Freshwater Resources per Region

Region	Annual renewable internal freshwater resources per capita
North America	15,678
East Asia & Pacific	4,268
Europe & Central Asia	11,282
Latin America & the Caribbean	22,342
Middle East & North Africa	604
South Asia	1,106
Sub-Saharan Africa	3,699

*Cubic meters per year.
Source: World Bank 2017.

Appendix B: Aqueduct 3.0

The Aqueduct Global Maps 3.0 Data provides several indicators organized in three groups as shown in Table B.1 as part of its water risk baseline.

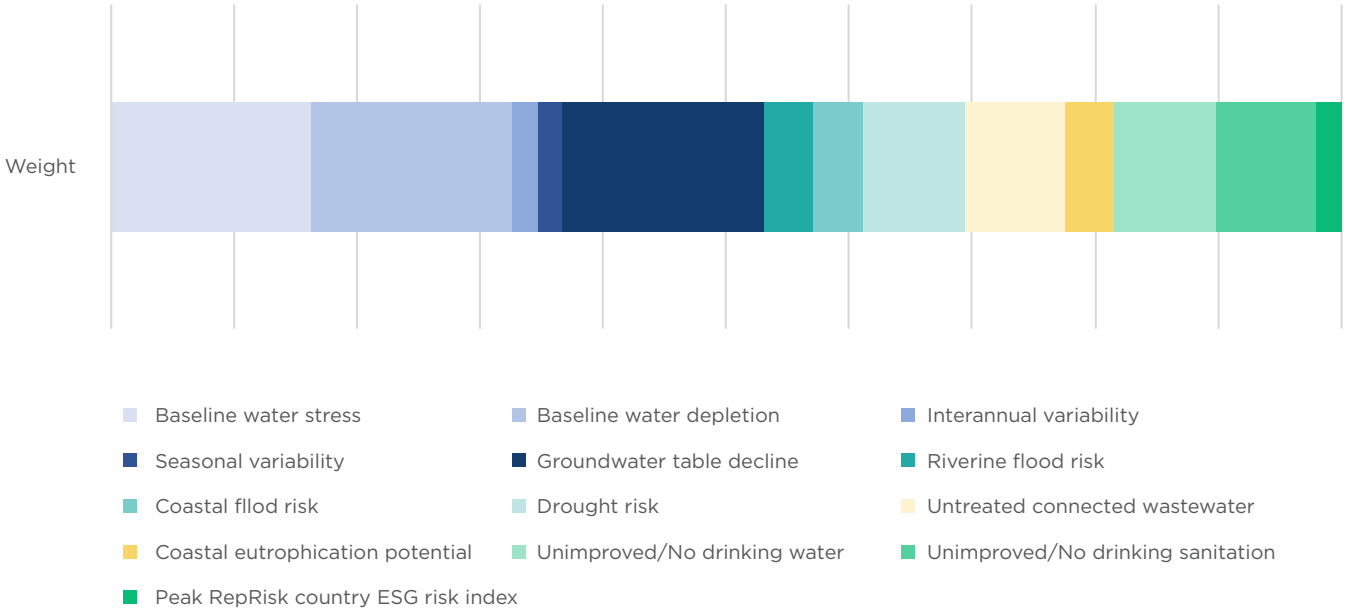
Detailed information on the inputs for each indicator can be found in Hofste *et al.* (2019). Each indicator contributes to the overall water risk indicator as shown in Figure B.1.

TABLE B.1: Description of Inputs for Each Index Within Wri's Aqueduct 3.0's Framework and Calculation of the Overall Water Risk Indicator

	Compound Indicator	Indicator	Weight
Overall Indicator: Overall water risk	Physical risk quantity	Baseline water stress	4
		Baseline water depletion	4
		Interannual variability	0.5
		Seasonal variability	0.5
		Groundwater table decline	4
		Riverine flood risk	1
		Coastal flood risk	1
		Drought risk	2
	Physical risk quality	Untreated connected wastewater	2
		Coastal eutrophication potential	1
	Regulatory and reputational risk	Unimproved/no drinking water	2
		Unimproved/no drinking sanitation	2
		Peak RepRisk country ESG risk index	0.5

Source: Hofste *et al.*, 2019.

FIGURE B.1: Weights of Contributing Indicators to Overall Water Risk



Source: Hofste *et al.*, 2019.

Appendix C: Methods Details

C.1 Data Files

- Aqueduct Global Maps 3.0 Data (baseline and future projections)
- Database of Global Administrative Areas (GADM), Global Data Version 3.6
- WorldPop TIFF files for the following countries:
  - Argentina
  - The Bahamas
  - Barbados
  - Belize
  - Bolivia
  - Brazil
  - Chile
  - Colombia
  - Costa Rica
  - Dominican Republic
  - Ecuador
  - El Salvador
  - Guatemala
  - Guyana
  - Haiti
  - Honduras
  - Jamaica
  - Mexico
  - Nicaragua
  - Panama
  - Paraguay
  - Peru
  - Suriname
  - Trinidad and Tobago
  - Uruguay
  - Venezuela

C.2 Data Processing

This study used QGIS 3.16 to perform the GIS analysis. The data processing first implied data cleaning, wherein the WRI shapefiles were cleaned to address bad geometries that inhibited processing. Areas outside of the LAC region were removed to improve processing time. The WRI data was then disaggregated using the Intersection tool to create polygons with unique political and basin attributes, and the WorldPop data was summed at the polygon level. This data was then exported and analyzed using R and Excel to give total population and population percentages throughout the LAC region living under water stress.

The data processing steps followed for the analysis are:

1. The WRI shapefiles were cleaned using the Fix Geometries tool in QGIS.
2. The administrative boundaries were limited to the LAC region through administrative name selection and deletion. Countries not included in the WorldPop data country list were eliminated.
3. The Intersection tool was used to create disaggregated polygons with unique watershed and political boundary attributes. This was done to more easily allow for reevaluation of the data under various analysis scenarios and speed processing.
4. The WorldPop country raster files were combined into a virtual raster file using the Create Virtual Raster tool. Settings

of the output file were adjusted to use real values rather than estimates to cross check that the process was successful.

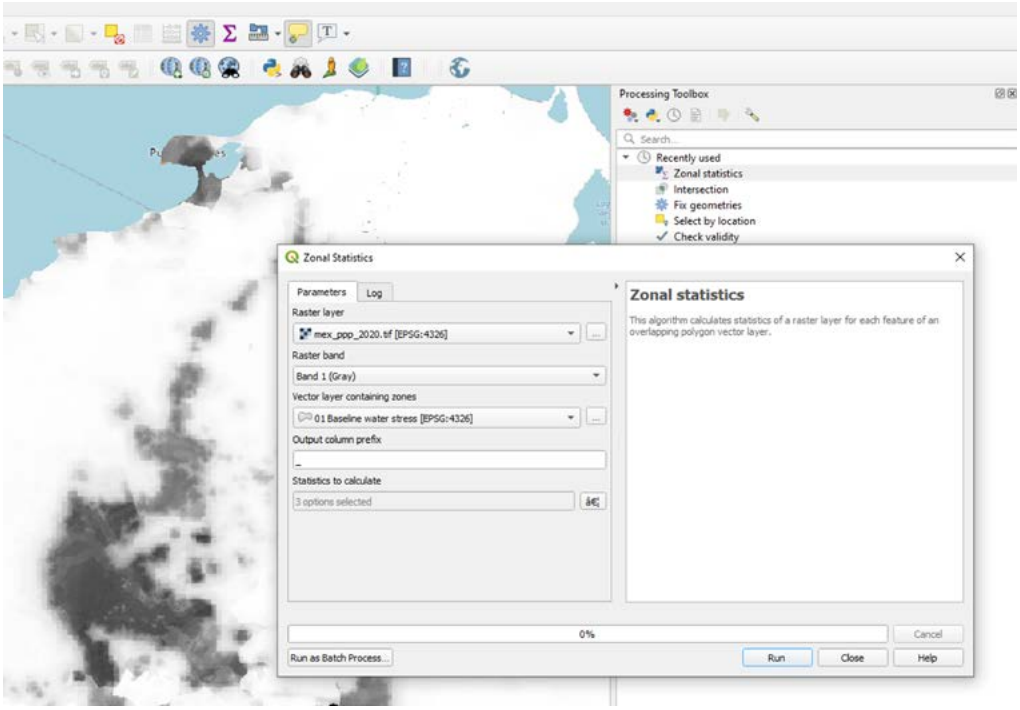
5. The Zonal Statistics tool was used to get the sum of the population data for each polygon.

6. The attribute table was exported to a csv and loaded into R and Excel for further data analysis.

7. The population sum data from the Zonal Statistics output was summed across various administrative and water stress levels to obtain the total population living under different water stress levels within different countries and administrative areas.

The populations were then summed for the region and by country, according to the different risk categories under the different scenarios and risk focuses (water stress, seasonal variability, quantity-based physical water risk, quality-based physical water risk, and overall water risk.). Table C.1 sums up the analysis categories.

FIGURE C.1: The Zonal Statistics Algorithm Calculates Statistics of a Raster Layer for Each Feature of an Overlapping Polygon Vector Layer

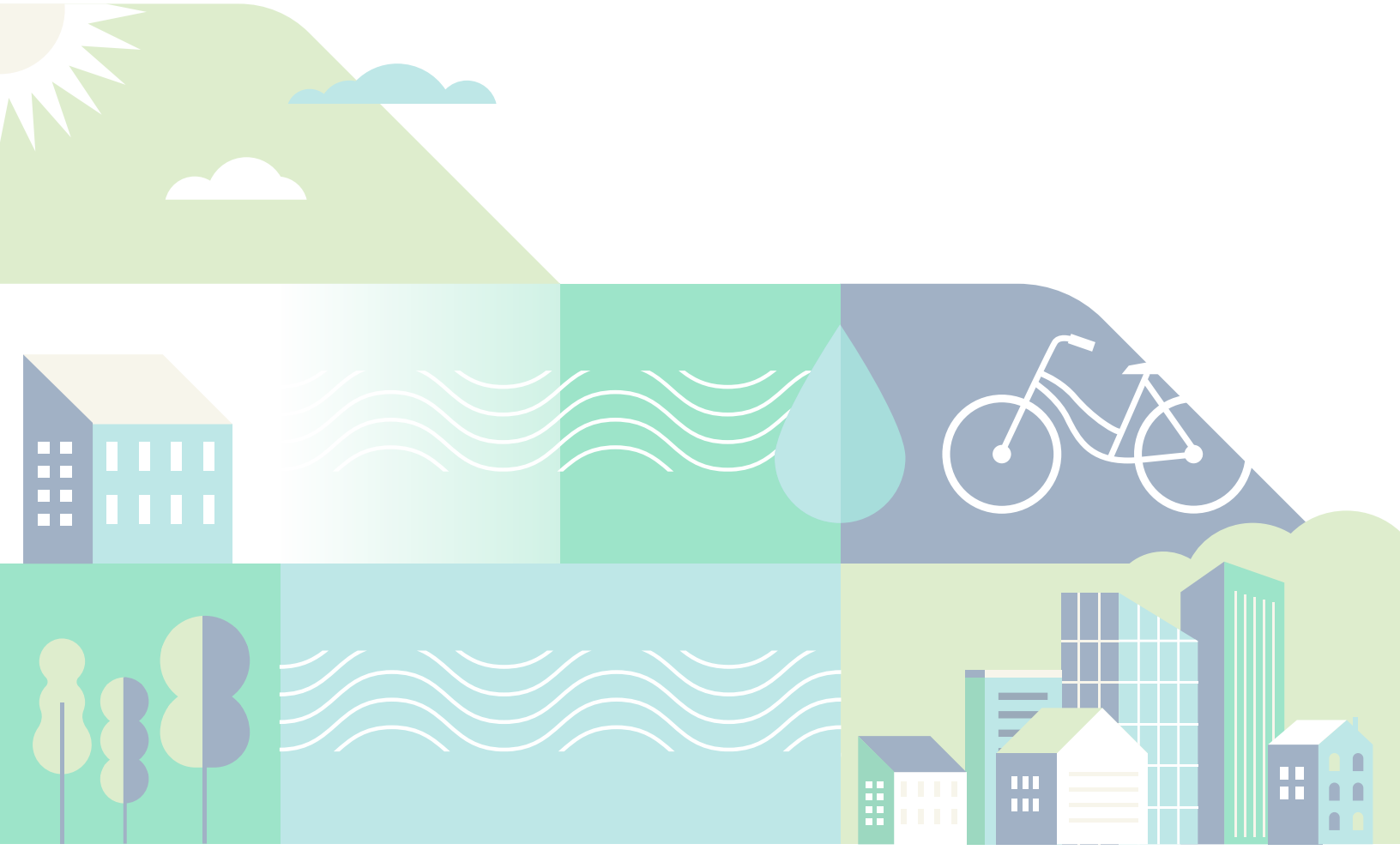


Source: Author's own elaboration.

TABLE C.1: Indicators and Scenarios Covered in This Study

Indicator	2017	2020 BAU*	2030 BAU	2040 BAU
Water stress	⊗	⊗	⊗	⊗
Seasonal variability	⊗			
Quantity-based physical water risk	⊗			
Quality-based physical water risk	⊗			
Overall water risk	⊗			

Note: *BAU = business-as-usual.
Source: Author's own elaboration



Appendix D: Mapping of Chilean Regions to Former Administrative Numbers

TABLE D.1: Chilean Regions and Former Numbers

Region	Former Number
Arica and Parinacota	XV
Tarapacá	I
Antofagasta	II
Atacama	III
Coquimbo	IV
Valparaíso	V
Metropolitan	RM
O'Higgins	VI
Maule	VII
Ñuble	XVI
Biobío	VIII
Araucanía	IX
Los Ríos	XIV
Los Lagos	X
Aysén	XI
Magallanes	XII

Source: The Chilean government, Subsecretaría de Desarrollo Regional y Administrativo (SUBDERE).

Appendix E: Hydrological and Administrative Boundaries

TABLE E.1: Hydrological and Administrative Boundaries by Municipality Name with More Than 250,000 People and Medium-High to Extreme Water Risk

Water Risk	Country	State	Municipality	Population
Extremely High (4-5)	Mexico	Chihuahua	Chihuahua	803,645
Extremely High (4-5)	Mexico	Baja California Sur	La Paz	731,855
High (3-4)	Mexico	Nuevo León	Apodaca	2,103,563
High (3-4)	Venezuela	Distrito Capital	Libertador	2,043,299
High (3-4)	Mexico	Guanajuato	León	1,799,710
High (3-4)	Mexico	Nuevo León	Monterrey	1,713,063
High (3-4)	Venezuela	Zulia	Maracaibo	1,699,805
High (3-4)	Mexico	Baja California	Tijuana	1,666,548
High (3-4)	Mexico	Nuevo León	General Zuazua	1,535,540
High (3-4)	Mexico	México	Tultitlán	1,494,548
High (3-4)	Mexico	Distrito Federal	Iztapalapa	1,277,426
High (3-4)	Ecuador	Guayas	Guayaquil	1,241,263
High (3-4)	Mexico	México	Nezahualcóyotl	1,200,407
High (3-4)	Dominican Rep.	Santo Domingo	Santo Domingo Este	1,153,053
High (3-4)	Mexico	México	Tepotzotlán	1,122,953
High (3-4)	Mexico	Querétaro	Querétaro	1,101,656
High (3-4)	Mexico	México	Toluca	1,003,734
High (3-4)	Dominican Rep.	Distrito Nacional	Distrito Nacional	999,090
High (3-4)	Mexico	Aguascalientes	Aguascalientes	983,000
High (3-4)	Mexico	San Luis Potosí	San Luis Potosí	975,912
High (3-4)	Mexico	Distrito Federal	Gustavo A. Madero	963,999
High (3-4)	Mexico	México	Naucalpan de Juárez	947,359

TABLE E.1: Hydrological and Administrative Boundaries by Municipality Name with More Than 250,000 People and Medium-High to Extreme Water Risk (*Cont.*)

Water Risk	Country	State	Municipality	Population
High (3-4)	Mexico	Sonora	Hermosillo	917,536
High (3-4)	Brazil	São Paulo	Guarulhos	891,592
High (3-4)	Mexico	Baja California	Mexicali	872,872
High (3-4)	Dominican Rep.	Santo Domingo	Santo Domingo Norte	856,080
High (3-4)	Mexico	Distrito Federal	Alvaro Obregón	819,286
High (3-4)	Mexico	México	Ecatepec de Morelos	812,671
High (3-4)	Mexico	Nuevo León	Juárez	810,024
High (3-4)	Dominican Rep.	Santiago	Santiago de los Caballeros	807,065
High (3-4)	Venezuela	Carabobo	Valencia	805,469
High (3-4)	Brazil	São Paulo	São Bernardo do Campo	791,950
High (3-4)	Mexico	Coahuila	Saltillo	780,105
High (3-4)	Mexico	Tamaulipas	Reynosa	765,359
High (3-4)	Mexico	Michoacán	Morelia	762,209
High (3-4)	Mexico	Jalisco	Guadalajara	752,021
High (3-4)	Mexico	Nuevo León	García	748,308
High (3-4)	Mexico	Sinaloa	Culiacán	721,911
High (3-4)	Brazil	Paraíba	João Pessoa	721,437
High (3-4)	Brazil	São Paulo	Ribeirao Preto	700,003
High (3-4)	Brazil	São Paulo	Osasco	679,860
High (3-4)	Mexico	Jalisco	Tonalá	675,289
High (3-4)	Mexico	Distrito Federal	Venustiano Carranza	665,018
High (3-4)	Mexico	México	Atizapán de Zaragoza	660,845
High (3-4)	Mexico	Distrito Federal	Tláhuac	657,251
High (3-4)	Brazil	São Paulo	Campinas	656,922
High (3-4)	Mexico	Guanajuato	Irapuato	656,076
High (3-4)	Venezuela	Miranda	Sucre	653,042
High (3-4)	Mexico	México	Cuautitlán Izcalli	649,835
High (3-4)	Guatemala	Guatemala	Villa Nueva	636,160
High (3-4)	Mexico	México	Almoloya de Juárez	626,783

TABLE E.1: Hydrological and Administrative Boundaries by Municipality Name with More Than 250,000 People and Medium-High to Extreme Water Risk (*Cont.*)

Water Risk	Country	State	Municipality	Population
High (3-4)	Mexico	Jalisco	Tlajomulco de Zúñiga	625,064
High (3-4)	Brazil	Rio de Janeiro	Rio de Janeiro	624,722
High (3-4)	Mexico	México	Atenco	610,479
High (3-4)	Mexico	Distrito Federal	Azcapotzalco	609,011
High (3-4)	Brazil	São Paulo	Santo André	598,965
High (3-4)	Haiti	Ouest	Port-au-Prince	592,205
High (3-4)	Brazil	Rio de Janeiro	Rio de Janeiro	584,994
High (3-4)	Mexico	Guanajuato	Celaya	580,596
High (3-4)	Dominican Rep.	Santo Domingo	Santo Domingo Oeste	579,555
High (3-4)	Mexico	México	Nicolás Romero	579,293
High (3-4)	Mexico	Distrito Federal	Miguel Hidalgo	560,763
High (3-4)	Venezuela	Zulia	San Francisco	548,552
High (3-4)	Mexico	Distrito Federal	Cuauhtémoc	535,116
High (3-4)	Mexico	Morelos	Cuernavaca	528,991
High (3-4)	Mexico	México	Huixquilucan	516,526
High (3-4)	Mexico	Jalisco	Tlaquepaque	515,440
High (3-4)	Mexico	Distrito Federal	Benito Juárez	509,586
High (3-4)	Mexico	Nuevo León	San Nicolás de los Garza	505,832
High (3-4)	Chile	Valparaíso	Valparaíso	502,002
High (3-4)	Brazil	Sergipe	Aracaju	501,364
Medium-High (2-3)	Chile	Región Metropolitana de Santiago	Santiago	2,512,177
Medium-High (2-3)	Chile	Región Metropolitana de Santiago	Cordillera	1,815,291
Medium-High (2-3)	Chile	Región Metropolitana de Santiago	Cordillera	1,739,884
Medium-High (2-3)	Brazil	Rio Grande do Sul	Porto Alegre	1,381,532
Medium-High (2-3)	Mexico	Chihuahua	Juárez	1,350,394
Medium-High (2-3)	Bolivia	Santa Cruz	Andrés Ibáñez	1,249,571
Medium-High (2-3)	Brazil	Maranhão	São Luis	1,185,084

TABLE E.1: Hydrological and Administrative Boundaries by Municipality Name with More Than 250,000 People and Medium-High to Extreme Water Risk (*Cont.*)

Water Risk	Country	State	Municipality	Population
Medium-High (2-3)	Nicaragua	Managua	Managua	1,140,577
Medium-High (2-3)	Mexico	Jalisco	Guadalajara	1,070,846
Medium-High (2-3)	Mexico	Jalisco	Zapopan	1,000,757
Medium-High (2-3)	Honduras	Francisco Morazán	Distrito Central	990,984
Medium-High (2-3)	Chile	Región Metropolitana de Santiago	Cordillera	983,761
Medium-High (2-3)	Mexico	Yucatán	Mérida	912,621
Medium-High (2-3)	Chile	Región Metropolitana de Santiago	Maipo	765,531
Medium-High (2-3)	Bolivia	Cochabamba	Cercado	733,896
Medium-High (2-3)	Mexico	Durango	Durango	702,877
Medium-High (2-3)	Brazil	São Paulo	São José dos Campos	644,046
Medium-High (2-3)	Brazil	São Paulo	Sorocaba	633,241
Medium-High (2-3)	Brazil	Paraná	Curitiba	565,007
Medium-High (2-3)	Colombia	Córdoba	Montería	551,109
Medium-High (2-3)	Honduras	Cortés	San Pedro Sula	514,728
Medium-High (2-3)	Brazil	Bahia	Salvador	511,365
Medium-High (2-3)	Mexico	Tamaulipas	Matamoros	501,576
Medium-High (2-3)	Brazil	Paraná	Curitiba	501,290

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