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Integrating water-quality analysis in national household surveys: water and sanitation sector learnings of Ecuador

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To respond to the global Sustainable Development Goals framework, Ecuador through the National Institute of Statistics and Censuses (INEC) has been strengthening its monitoring system since 2016, specifically on SDG 6.1 and 6.2. The World Bank Group, UNICEF Ecuador Country Office and WHO/UNICEF Joint Monitoring Programme provided initial support. Additional parameters were included in household surveys, including a water sample analysis to detect presence or absence of *E. coli* bacteria, and the SDG indicators were adapted to the national context. Ecuador collected water-quality data in two national household surveys in 2016 and 2019, including water quality at household's point of consumption for the 2019 survey. This opens opportunities to extend the analysis beyond access to safely managed drinking water services, toward comparison of water quality between source and point of consumption, and analyzing correlations with other parameters, such as handwashing with soap, water treatment, and safe storage and open defecation. This article describes the principal findings of the extended analysis carried out by INEC, as well as the opportunities to present the results for sector advocacy and decision-making purposes. This study concludes that alignment of the national monitoring systems to the SDG 6.1 framework provided strong evidence that water quality is the principal bottleneck in the water sector in Ecuador. Water-quality testing at the point of consumption was evidenced, as well as the importance of household water treatment and possible effects of other hygiene practices like handwashing with soap and open defecation on water quality at the point of consumption.

npj Clean Water (2020)3:23 ; https://doi.org/10.1038/s41545-020-0070-x

INTRODUCTION

At the conclusion of the MDG era in 2015, worldwide, 2.4 billion people still did not use improved sanitation supplies, and 663 million did not have access to improved sources of drinking water (UNICEF and WHO, 2015)[1]. Recent data indicate that, for children under 5 years, water and sanitation related diseases are one of the leading causes of death (https://www.who.int/gho/child_health/mortality/causes/en/). Every day, around 800 children die from preventable diseases caused by poor water quality, and lack of sanitation and hygiene (https://www.unicef.org/wash/).

Despite the importance of monitoring the quality of the main source of drinking water, according to the United Nations Children's Fund (UNICEF) and the Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP), water contamination is much more common at its point of consumption than at the source, indicating that water quality may deteriorate after its collection through its manipulation at household level (http://mics.unicef.org/methodological_work/3/WATER-QUALITY).

According to the latest JMP report "Progress on household drinking water, sanitation and hygiene 2000–2017", 117 countries have estimates on the safe management of drinking water services, which represents 38% of the global population. These estimates show that 5,300 million people in the world have access to safely managed drinking water services; in addition, 1,400 million people use at least basic services; 206 million people use limited services, 435 million use unimproved sources, and 144 million still use surface water sources (JMP, 2019)[2].

Ecuador's total population is 17 million people, from which 68.1% is urban, and 31.9% rural. The country can be subdivided into four regions: the coast region, the Andean highlands, the Amazon basin, and the insular region (Galapagos islands). Important geographical, socio-cultural, and administrative differences exist between these regions. Following the National Constitution (2008), the Organic Code of Territorial Organization, Autonomy and Decentralization (2010), and the Organic Water Resources Law on Water Uses and Exploitation (2014), the National Secretary of Water (SENAGUA) is the sector governing body at the national and deconcentrated level, while the Agency for the Water Regulation and Control (ARCA) is the sector regulator for water and sanitation services. Drinking water and sanitation services are a public utility, competency of the Municipal Governments, and rendered by municipal public enterprises. In rural areas, municipalities often delegate drinking water service provision to small community organizations. Considering that there are 221 municipal governments in Ecuador, and an estimate of 7,000 community water service providers in rural areas (IADB, 2018)[3], quality of service provision is highly fragmented, diverse, and dynamic across the country; such situation requires a strong monitoring and regulation capacity to assure that quality of services comply with the national standards for drinking water and sanitation.

The technical norm INEN 1108 designed by the Ecuadorian Service for Normalization (INEN) establishes the physical, chemical, and microbiological parameters, and ranges that define the standard of potable water in Ecuador. Municipal government's drinking water service providers are required to comply with these requirements (INEN, 2014)[4]. For fecal coliforms monitoring, service providers are expected to implement water sampling with frequencies depending on the size of the population served, as established by the WHO Guidelines for drinking water quality

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(2014)[5]. However, the water and sanitation sector in Ecuador is lacking implementation of a clear framework for water-quality control and surveillance.

In 2016, the National Institute of Statistics and Censuses (INEC) of Ecuador engaged in strengthening the design of their household surveys to enable the monitoring of Sustainable Development Goal (SDG) targets 6.1 and 6.2. This process included the construction of new indicators aligned with the SDGs, the revision of the survey questionnaires, as well as the inclusion of water-quality testing (subsample of 4,442 households), measuring presence/absence of *E. coli* at the level of the water provision source. Through the 2016 National Survey on Employment, Unemployment, and Subemployment (ENEMDU), it was possible to take the revised questionnaires to a national scale, allowing for SDGs 6.1 and 6.2 indicators to be officially reported for the first time. As a result of this initiative, in early 2017 Ecuador published baseline estimates for SDG 6.1 and 6.2 (Pozo et al.)[6].

The inclusion of an indicator on drinking water quality within the National Development Plan "*Toda una vida*" 2017–2021[7] enforced the national monitoring systems to continue regular water-quality monitoring in national household surveys to measure progress. As such, the 2019 ENEMDU survey adopted identical questions for measuring SDG 6.1 and 6.2, including again water-quality testing through the same methodology (subsample of 7,331 households), but extending the number of water samples per household from only at source level to source and point of consumption level, as suggested by UNICEF's Multiple Indicator Cluster Survey methodology (https://mics.unicef.org/tools#survey-design). As such, Ecuador disposes of two data points in time (2016 and 2019) on water quality at household level sources, and an additional data point on water quality at household's point of consumption (2019), which opens opportunities to extend the analysis beyond access to safely managed drinking water services, toward comparison of water quality between source and point of consumption and analyzing correlations with other parameters, such as handwashing with soap, water treatment, and safe storage and open defecation.

This article describes the principal findings of an extended analysis carried out by INEC, focusing on temporality of water-quality monitoring, factors determining restricted access to safely managed drinking water, evidence on drinking water contamination from service provision to point of consumption and finally an analysis of the associated factors related to water quality at the point of consumption. The main objective of this study is to contribute to in-depth national sector analysis and to serve as an advocacy tool for sector decision-makers, informing them on the principal challenges toward the national SDG 6.1 2030 goal. This research initiative aims as well to contribute to the global discussion on SDG 6.1 monitoring from a country-level monitoring and data analysis perspective; considering that the inclusion of water-quality testing in household surveys—a key parameter for monitoring SDG 6.1—is still at an initial stage in the majority of countries, these findings and lessons learned from Ecuador pretend to contribute to survey design, planning, and analysis in other countries.

The present document is structured as follows: "Results" shows the main findings; "Discussion" outlines the discussion, the major conclusions and finally, "Methods" explains the methodological aspects involved in the statistical operations.

RESULTS

This section explains the main results of the extended statistical analysis on the evolution of household drinking water and it's different disaggregated components. Table 1 displays the comparison between 2016 and 2019 national population distribution along with the water, sanitation, and hygiene service levels (see "Methods" for definitions of service levels). At the national level, 70.1% of households had access to safely managed water services in 2016. The gap between urban (79.1%) and rural (51.4%) was 27.7%. In 2019, 67.8% of households have access to safely managed water services, which constitutes a not statistically significant decrease; the gap between urban (76.9%) and rural (48.5%) was 28.4%.

Comparing 2016 versus 2019 water quality at the household's source level

Comparing water-quality data at the source level between 2016 and 2019 data collection, a significant decrease in water quality of −5.9% (p-value = 0.0002) has been found; water quality was worse in 2019 compared with 2016. A regional disaggregation shows that exclusively the coast region contributes to this decrease. Similarly, disaggregating the variable for the area of residence, it is observed that the rural area shows a statistically significant decrease of −9.5% (p-value = 0.0004) in water quality comparing 2019 with 2016 data collection, while the urban area shows also a statistically significant negative tendency of −4.3% (p-value = 0.0263) (Fig. 1). Other statistically significant tendencies identified between the 2016 and 2019 data points are related to availability, and the disaggregation by area of residence and region shows that this tendency is significant and positive for national (p-value = 0.0001), rural (p-value = 0.0002), and urban (p-value = 0.0471) areas and the Andean highlands (p-value = 0.0001).

Using the data from the Guayaquil meteorological station from the Oceanographic Institute of the Army (INOCAR, www.inocar.mil.ec), it is found that the precipitation was almost six times higher in March 2019 than in December 2016, noting as well that December 2016 presented less precipitation than usual, and March 2019 exceeded the average precipitation for that month. Guayaquil has the highest population density area in the coastal region (According to the 2010 Population and Housing Census, 30% of the coastal region population lives in the city of Guayaquil), and most prone to flooding in the rainy season (INAHMI 2017, www.serviciometeorologico.gob.ec). National meteorological data from Ecuador show that December is generally considered the last month of the dry season, while March is the month with the highest precipitation of the rainy season (es.climate-data.org).

Factors determining restricted access to safely managed drinking water (safe water)

The safely managed water indicator is made up of four factors (source type, quality, accessibility, and availability). Safely managed water service, following the indicator as nationally defined by INEC, requires the source type to be improved, absent of *E. coli* contamination (quality), piped on-premises (accessibility), and available during the last 2 weeks (availability). Each of them—exclusively or in combination—explains part of the 32.2% of the population that is excluded from access to safely managed drinking water. This percentage represents the gap to cover in Ecuador to achieve the 2030 SDG target 6.1, which is nationally defined at 98% of the population.

Figure 2 shows a Venn diagram to understand the contribution of each factor to the gap. This analysis provides evidence that the household's main barrier to access safely managed drinking water is water quality. Figure 3 shows that the second component that contributes most to the limitation in access to safely managed water is the source type, and more specifically the lack of access to an improved source of water supply. The other two components (accessibility and availability), while relevant, have a marginal role in explaining the limitation of access to safely managed water in Ecuador.

Further analysis has been done to estimate how much of the gap would be closed if the water quality issue would be solved in Ecuador. Figure 4 shows the estimates on how much the indicator

Table 1. Comparison between 2016 (baseline) and 2019 national population distribution along with water, sanitation, and hygiene service levels, Ecuador.

Service ladder	Water			Sanitation			Hygiene		
	2016	2019	*p*-value	2016	2019	*p*-value	2016	2019	*p*-value
Safely managed	70.1%	67.8%	0.1328	41.8%	42.2%	0.1555			
Basic									
BASIC 1	3.5%	1.9%*	0.0009	44.2%	48.5%**	0.0000	85.5%	89.1%**	0.000
BASIC 2	18.3%	21.5%**	0.0337						
Limited	0.0%	0.0%	0.5904	10.4%	6.1%*	0.0000	12.7%	7.6%*	0.0000
Unimproved	6.1%	6.7%	0.5197	1.8%	1.0%*	0.0186			
No service	2.0%	2.1%	0.7436	1.8%	2.1%	0.3918	1.9%	3.3%**	0.0061

*Statistically significant reduction comparing 2019 with 2016.
**Statistically significant increase comparing 2019 with 2016.
Source: INEC ENEMDU December 2016 and March 2019.

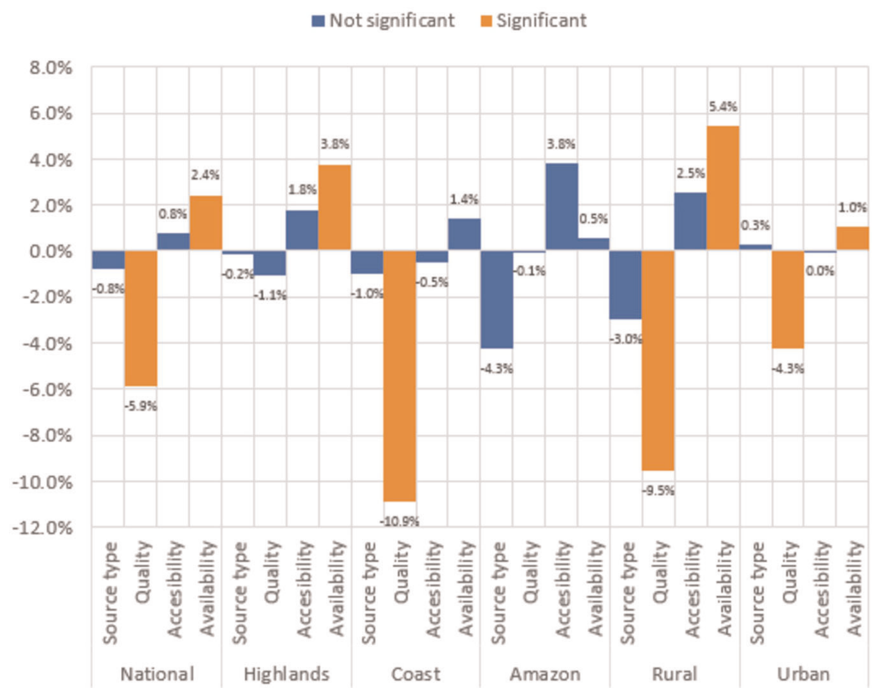

Fig. 1 Intertemporal change between December 2016 and March 2019 per component of the indicator safely managed water. Bar chart, which shows the percentage difference between 2016 and 2019. Orange bars show statistically significant difference for the analyzed period, blue bars show nonsignificant differences. The figure includes geographical disaggregation (Source: INEC ENEMDU December 2016 and March 2019).

of access to safely managed water would increase if we assume that each limiting factor was eliminated individually. The factor with the most important impact potential is water quality. If the issue of *E. coli* contamination in existing water services would be resolved nationwide and other factors remain unchanged, the percentage of population residing in Ecuador with access to a safely managed water service would increase with 20.6%, reaching 88.4%.

Drinking water contamination from service provision to the point of consumption

Administrative records, in combination with household survey data, including water-quality analysis at household source and point of consumption, enable an analysis of water quality along the chain from the service provision up to the point of consumption.

Figure 5 has been constructed with information from administrative records, linked with the ENEMDU 2019 survey data. Section "Statistical data analysis methods" contains the details on how the data were linked. Based on administrative records provided by municipal governments, 52.2% of the population is connected to the provision of water that complies with the INEN 1108 standard, 14.8% of the population is connected to a piped network that does not comply with national standards and the remaining 33.0% obtains water from another provider whose compliance with the standard cannot be established. Of the remaining 33.0%, 24.5% receive water from a source considered improved (source A: piped water, boreholes or tube wells, protected dug wells, protected springs, and packaged or delivered water—if the secondary source is piped water), 6.5% from an unimproved source (source B: unprotected wells or springs, rainwater and packaged or delivered water—if the secondary

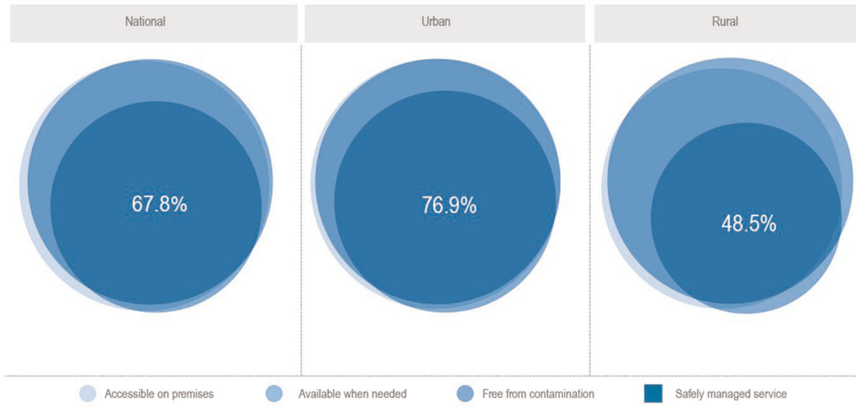

Fig. 2 Venn diagram for the components of the safely managed drinking water indicator with 2019 data. The three panels show national, urban, and rural information. Each circle in the Venn diagrams represent a component of the safe water indicator. The percentage represents the safe water composite indicator (Source: INEC ENEMDU 2019).

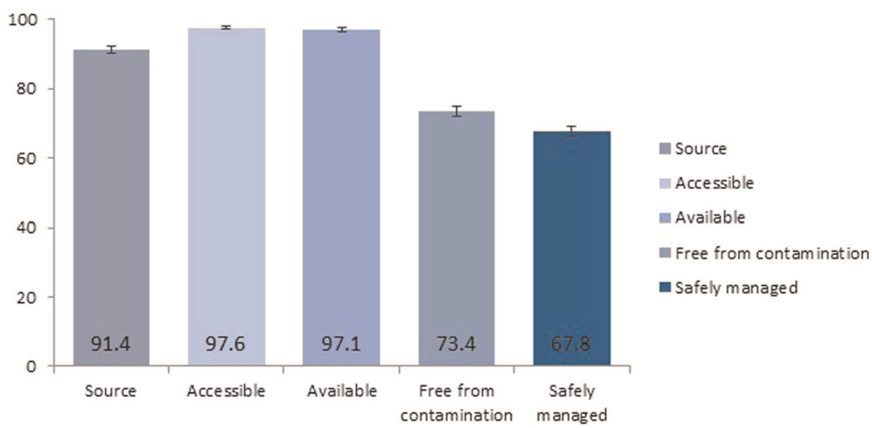

Fig. 3 Components of the safely managed drinking water indicator, Ecuador. All values in the bar chart are percentages for the components of the safe water indicator as well as for the indicator itself. Error bars indicate a 95% confidence interval (Source: INEC ENEMDU 2019).

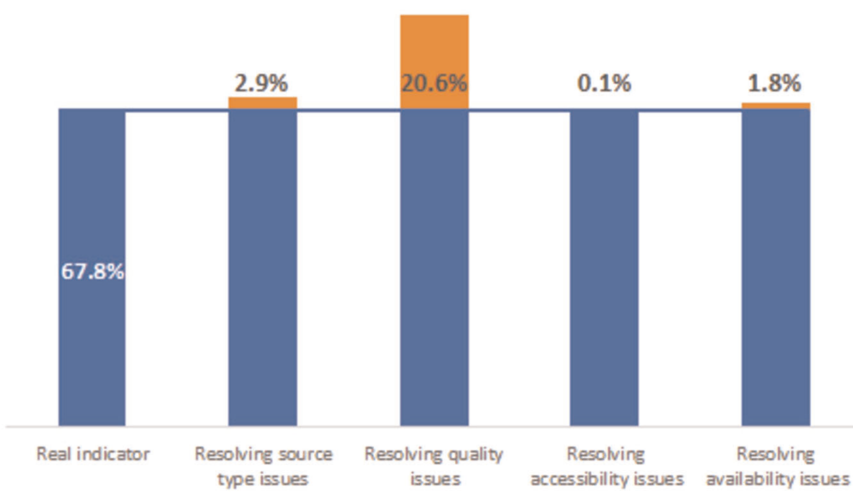

Fig. 4 Expected change in the indicator of access to safely managed drinking water services, Ecuador. The bar chart, going from left to the right, shows the real value of the safely managed water indicator, and several estimates on how much the indicator would increase if each limiting factor is individually resolved (Source: INEC ENEMDU 2019).

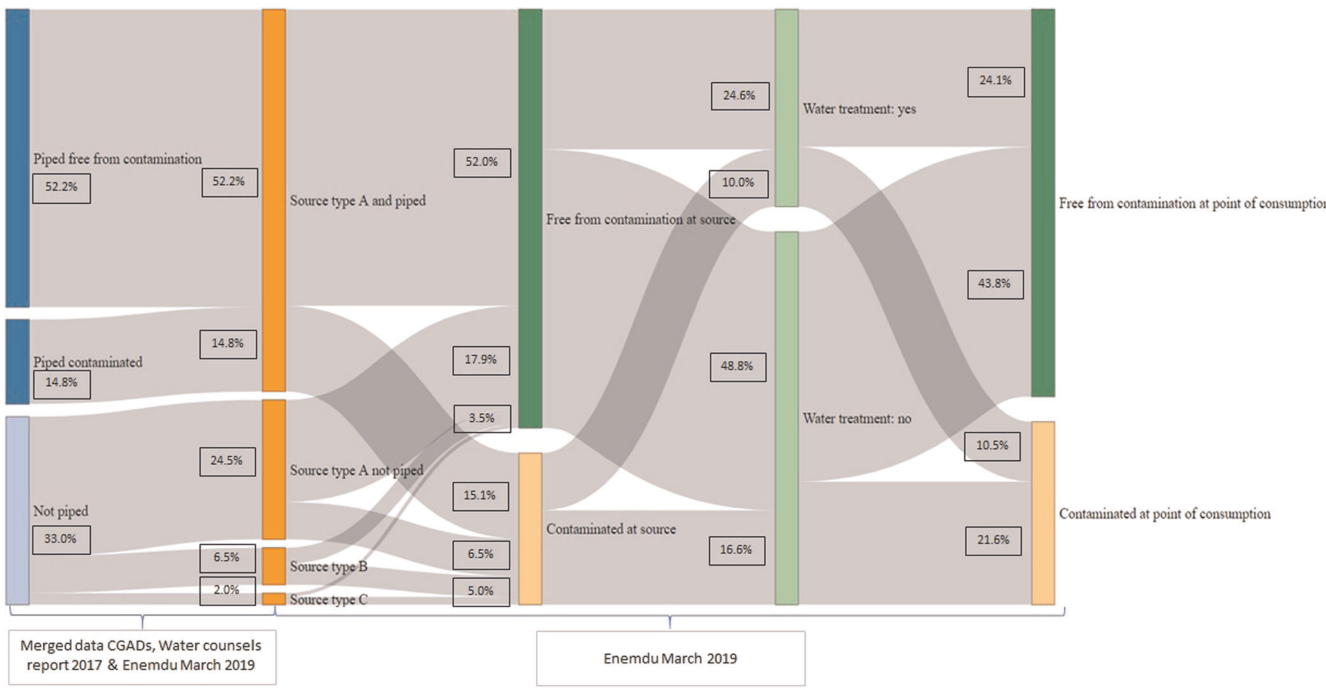

Fig. 5 Traceability of the source of water pollution that the household uses to drink in Ecuador. Sankey diagram that displays the flow of water contamination. There are five contamination stages: distribution, collection (source type), quality at source, treatment, and quality at consumption point. Section "Statistical data analysis methods" contains the details on how the data were linked (Source: INEC ENEMDU 2019; Census of Autonomous Decentralized Governments 2017 and Report from community providers 2017).

source is not piped water) and 2.0% from an unprotected surface source (source C: surface water, other).

The next step, based on the household survey data, shows that 73.5% of the population has access to water free from *E. coli* contamination at the household source level. Of this percentage, the majority (52.0%) receives their water mainly from a piped source. Although it is not possible to directly identify people who receive piped water under local regulations, the distribution of the population that have access or not to good quality water (INEN 1108 standard, self-reported administrative records) is very similar to the distribution of the population that receives piped water free from *E. coli* contamination (household water sample). Specifically, 52.2% of the population receives good quality water provided through a piped source according to most recent administrative records (2017), and 52.0% of the households use water to drink from a piped source that is not contaminated with the *E. coli* bacteria according to household water samples at the source level in the ENEMDU 2019 survey.

Among the households with access to an improved non-piped source, the majority (73.1% of the group equivalent to 17.9% of the total population) have water free from *E. coli* contamination at the primary drinking water source. On the other hand, among those with access to a source considered unimproved, 43.6% have water without *E. coli* contamination. Finally, among people who use surface sources, 67.4% do not have access to good quality water (free from *E. coli* contamination).

Although 26.6% of the population receives water with the presence of *E. coli*, 10.0% (37.8% of them) implement water treatment at home, such as boiling or filtering. Among people who have contaminated water at the source, but boil the water, 28.1% access *E. coli*-free water at the point of consumption, nevertheless 71.9% maintain water of poor quality. In the case of other water- treatment options, these proportions are 28.9% and 71.1%.

However, something that stands out is that 13.3% of households that have water free of *E. coli* contamination at the source level, *E. coli* contamination was detected at the point of consumption, despite reporting to apply an additional treatment before consumption. As a reference, among those who have good quality water at the source and do not implement an additional treatment at home, 11.7% have contaminated water at the point of consumption.

Associated factors with water quality at the point of consumption/glass of water

In this section, the marginal effects on the probability of accessing quality water in the consumption point are presented, associated with different types of factors (immediate factors, extended factors, and social factors). Immediate factors include those factors that are expected to have a direct relation with *E. coli* presence at the point of consumption, and include household water treatment, water quality at the source, hygiene practices (handwashing with soap), and sanitation practices. For the analysis on the extended factors, water quality at source level is substituted by those factors that determine water quality at the source level, such as sanitation, hygiene, source type, accessibility, etc. Social factors include specific social variables that might have a linkage with household practices or conditions that might influence water quality in the household; they include area (rural–urban), geographical region, per capita income, ethnicity or identity, household composition, and education level.

Table 2 presents the effect that immediate factors such as water quality at the source, household water treatment, hygiene (handwashing with soap), and sanitation have over water quality at the point of consumption. The factor that most strongly influences the probability of accessing quality water at the consumption point is having quality at the water source, with a marginal effect of around 0.8.

Table 3 shows the marginal effects of immediate factors influencing water quality at the point of consumption, conditional on poor or good quality at the source level. The effect of water treatment (boiling or other) increases the probability of having

Table 2. Marginal effects of immediate factors on the probability of accessing quality water at the point of consumption.

	Variable	Coefficient	Standard error
Water	Water quality at source	0.773***	(0.00425)
Hygiene	No water or soap	−0.0119	(0.0082)
	No facility	0.0177**	(0.00898)
Sanitation	Limited	0.0166*	(0.00851)
	Not improved	−0.0466***	(0.0178)
	Open defecation	−0.119***	(0.0177)

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
The number of observations: 24,544.
Sources: INEC ENEMDU 2019, Census of Autonomous Decentralized Governments (2017) and Report from community providers (2017).

good quality water at the consumption point when the source of water showed *E. coli* contamination in comparison with a negative effect when the water source was free from *E. coli* contamination; specifically, a mean effect of around 20%. A remarkable conclusion is that boiling water does not result in positive marginal effects when the water from the source is free from *E. coli* contamination; there exists even a small negative effect of 3%.

Table 4 shows the effect that extended factors have over the access to quality water in the consumption point. Here, the analysis focalizes on the components that conform the various indexes of water, hygiene, and sanitation. As expected, an unimproved water source (type B: unprotected wells or springs, rainwater, and packaged or delivered water (if the secondary source is not piped water) or type C: surface water, other) has negative effects on the probability of accessing quality water at the point of consumption. On the other hand, also as expected, factors of sufficiency and the percentage of water distributed compliant with the local norm on water quality, present positive marginal effects. An important fact is that sanitation, even limited, generates positive marginal effects over the probability of accessing quality water in the consumption point. Finally, open defecation has a strong negative correlation with water quality at the point of consumption (−16%).

Finally, Table 5 shows the marginal effects of social factors on the probability of accessing quality water in the point of consumption. Geographic location at the rural and regional level have negative effects of at least 15%, except for the insular region (Galápagos). The Amazon region presents the highest negative effect of all the social factors considered, with a negative 26%. Ethnicities as afro-Ecuadorian, *montubio*, and *mestizo* present smaller negative effects, contrary to the white people and other categories, where there exists a neutral effect on water quality at the point of consumption. As expected, if the level of education of the household head improves, the probability of accessing quality water at the consumption point increases.

DISCUSSION

Water-quality testing in national household surveys is one way to monitor SDG 6.1, and at the same time, it provides multiple opportunities to better understand the sector challenges both from the point of view of water sector policies, as well as from a public health perspective. The fact that water quality testing has been integrated in a national household survey in 2016 and again in 2019 present opportunities for discussion on the comparison between the 2016 and 2019 outcomes, the factors that are determinant in acceding to safely managed water services, the monitoring of water quality from service provider to point of consumption and the associated household factors that influence water quality at the point of consumption. A similar initiative has been documented by Cronin et al.[8,9], however, the scale at which water-quality monitoring integrated in household surveys in Ecuador is national, and comparable with the Multiple Indicator Cluster Surveys (MICS) supported by UNICEF in several countries.

National SDG 6.1 monitoring, survey design, and analysis

The inclusion of water-quality testing in household surveys is accelerating globally, principally because of the SDG global monitoring framework. The support from JMP at global level and multilateral cooperation at the country level is important in many countries. Often, the MICS survey coordinated by UNICEF is the household survey where water-quality analysis is included; in Ecuador, INEC included the presence/absence *E. coli* test in its own ENEMDU national survey, first in 2016 and second in 2019. Although external cooperation was important in 2016 in terms of technical assistance but also for the procurement of supplies, the 2019 survey relied on governmental funding for supplies and only technical assistance from UNICEF and JMP, showing progressive national ownership for SDG 6.1 monitoring. The mobilization of national resources for SDG 6.1 monitoring depend strongly on the alignment of national and sector plans and strategies with SDG 6.1 and 6.2; this is the case in Ecuador where the National Development Plan 2018–2021 includes indicators that require routine water-quality analysis in national household surveys.

The survey design in Ecuador is characterized by the following particularities which are important to consider for future initiatives in Ecuador but also in other countries:

1. **Scale: the national scale of the survey** presents opportunities and challenges. This study shows that national coverage of water-quality data permits a clear identification of gaps in terms of type of residence (urban-rural), region (Amazon, highland, coast, and insular). This allows for national SDG 6.1 monitoring, which would be different in case the survey would be limited to certain regions or provinces. On the other hand, logistical complexity increases with the scale, as well as the required funding for the purchase of supplies, training and in-country mobilization. Also, the representativeness levels are limited to the national and macro-subnational levels, and do not enable a local (municipal) representativeness; for the Ecuador case, this is a limitation because water service provision is a municipal competency, and as such the results cannot be used for a water provision performance analysis of the municipalities.
2. The **review and restructuring of the survey questionnaire** in 2016 (as described in "Introduction"), to allow for SDG 6.1 and 6.2 monitoring is a key process. Where the empowerment, commitment, and predisposition of INEC in combination with the consultation of the existing guidance and the support of the JMP has been substantial to enable structural changes that made a difference. The definitions of the service levels are strongly, but not completely aligned with the SDG monitoring framework; meeting an equilibrium between the national sector specificities, existing monitoring mechanism and the global monitoring framework was a crucial step in Ecuador to engage with routine SDG 6.1 and 6.2 monitoring. For example, one difference is that rainwater is not considered an improved source in Ecuador because it does not ask whether its storage is correct. Another difference is that the water packaged or supplied by tanker is not considered improved for Ecuador following the definition of the MDGs. Another important difference lies in the measurement of water quality. The United Nations is proposing a review of both chemicals and organic

Table 3. Marginal effects of immediate factors on the likelihood of improving or maintaining water quality conditional on poor or good quality at the source level.

Likelihood of improving or maintaining water quality conditional on poor quality at the source level				Likelihood of improving or maintaining water quality conditional on good quality at the source level			
(number of observations: 6,462)				(number of observations: 17,993)			
	Variable	Coefficient	Standard error		Variable	Coefficient	Standard error
Treatment	Boiling	0.235***	(0.00999)	Treatment	Boiling	−0.0270***	(0.00568)
	Other	0.275***	(0.0345)		Other	−0.00421	(0.015)
Hygiene	No water or soap	0.0122	(0.0129)	Hygiene	No water or soap	−0.0230**	(0.0103)
	No facility	−0.0248	(0.0151)		No facility	0.0476***	(0.0114)
Sanitation	Limited	0.0515***	(0.0169)	Sanitation	Limited	0.00364	(0.00973)
	Open Defecation	−0.0751***	(0.0128)		Not improved	−0.00105	(0.0256)
					Open defecation	−0.132***	(0.025)

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
Sources: INEC ENEMDU 2019, Census of Autonomous Decentralized Governments (2017) and Report from community providers (2017).

Table 4. Marginal effects of extended factors on the probability of accessing quality water in the point of consumption.

	Variable	Coefficient	Standard error
Treatment	Boiling	−0.0188***	(0.00674)
	Other	0.0296*	(0.017)
Hygiene	No water or soap	−0.0618***	(0.0116)
	No facility	−0.0430**	(0.0176)
Sanitation	Limited	0.0106	(0.0123)
	Not improved	−0.0269	(0.0302)
	Open defecation	−0.159***	(0.023)
Water	% water distributed under local norm	0.0837***	(0.00704)
	Type B[a]	−0.185***	(0.0136)
	Type C[b]	−0.130***	(0.0303)
Accessibility	<30 min	−0.136***	(0.0285)

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
Number of observations: 24,490.
Source: INEC ENEMDU 2019 and Census of Autonomous Decentralized Governments 2017.
[a]Type B: unprotected wells or springs, rainwater and packaged or delivered water (if the secondary source is not piped water).
[b]Type C: surface water, other.

Table 5. Marginal effects of social factors on the probability of accessing quality water in the point of consumption.

	Variable	Coefficient	Standard error
Area	Rural	−0.183***	(0.0069)
Region	Coast	−0.149***	(0.00624)
	Amazon	−0.257***	(0.0125)
	Insular	−0.0182	(0.0309)
Ethnicity	Afro-Ecuadorian	−0.0429**	(0.0193)
	Montubio	−0.0494***	(0.0163)
	Mestizo	−0.00981	(0.0105)
	White and other	−0.00434	(0.0264)
Household characteristics	Household size	−0.00129	(0.00147)
	Household with children <5 yrs old	−0.00124	(0.00671)
	ln (per capita income)	0.0373***	(0.00366)
Household head	Woman	−0.00838	(0.00656)
	Primary education	0.0135	(0.0134)
	Secondary education	0.0564***	(0.0141)
	Tertiary education	0.118***	(0.0155)

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
Number of observations: 25,236.

contamination. However, for the information sources used, it is only known if the water contains *E. coli* contamination and an analysis of the presence of other chemicals potentially harmful to humans is not performed due to the complexity of the analyzes required (Pozo, Serrano, & Castillo[9]).

3. A crucial difference between the 2016 ENEMDU survey and the 2019 ENEMDU survey is **the number of water-quality tests per household**. The inclusion of both a household source and point-of-consumption test, increases sensibly the cost of the survey, but provided valuable additional evidence, principally illustrated in this article through Fig. 5. The main advantages of the inclusion of a water test at the point of consumption are related to the possibilities to generate evidence of the importance of household practices, which can have a positive or negative impact on water quality, and the link with water quality as delivered by the service provider at the household source, as described in the sections "Drinking water contamination from service provision to the point of consumption" and "Associated factors with water quality at the point of consumption/glass of water".
4. The **timing and definition of the period of the year to organize water-quality testing** had consequences in the analysis of the results, for this study. Although the water-quality testing in 2019 was initially planned to take place in the same period of the year as previously done in 2016, external factors decided differently. As described in the section "Comparing 2016 versus 2019 water quality at the household's source level", water quality decreased significantly in 2019 compared with 2016. Also, meteorological data evidence strong differences in precipitation between the two periods where water-quality testing took place. Several studies have confirmed the strong link between

seasonal influences on *E. coli* presence in household drinking water, as systematized in the systematical review by Kostyla et al.[10]. This entails that the negative tendencies identified in Ecuador cannot be conclusively attributed to sector performance, as possible seasonal factors may have had an influence. On the other hand, the suggestive evidence that seasonal aspects might impact drinking water quality, strengthened with similar research in other countries, should raise sector awareness that water treatment, control and surveillance interventions, and strategies should consider possible seasonal dynamics. The cost of water-quality testing in household surveys at the national scale is a major limitation to enable water testing in different periods throughout the year, and future national surveys that include water testing will need a profound analysis on the definition of the adequate period to conduct the survey.

5. The analysis included the linking of administrative records of water service providers with survey data. Figure 5 and additional analysis evidenced that administrative records, in this case specifically related to compliance with the water-quality national norm INEN 1108, are a reliable information source, which shows important similarities with the results of water-quality testing at household source level. Important to mention is that the national norm INEN 1108 includes a wide range of water-quality parameters, and does not focus exclusively on bacteriological contamination or presence/absence of *E. coli* as is the case with water-quality testing within the ENEMDU survey. Considering the fact that administrative records in this case are the data which are auto-reported once each year by the service providers (whether they comply or not with the INEN 1108 norm), it does not provide conclusive evidence on compliance with all the parameters; the reporting mechanism and the similarities identified with the water-quality testing results in the household survey opens also the discussion on the possibility that service providers focus principally on bacteriological contamination or their performance in water treatment which targets bacteriological contamination (e.g., chlorination) when reporting on their INEN 1108 norm compliance. However, it seems that administrative records could be used partially as a substitute for water-quality testing at household source level in Ecuador, although the before mentioned limitations should be considered as well as the added value of comparing water quality at household source with the point of consumption.

Water sector learnings

The extended analysis on SDG 6.1 based on household surveys including water testing and linking administrative records from water service providers generates important sector learnings with important potential to influence sector policies and decision-making to accelerate progress towards the SDG goals. Three main findings illustrate this potential are:

1. Water quality is the main bottleneck in the water service ladder which impede households to advance from a basic to a safely managed service level. This is clearly illustrated by Fig. 4, and evidences the lack of a clear water-quality control and surveillance strategy and implementation. Although the INEN 1108 norm is well known in the sector, the number of water quality parameters included make it practically impossible to comply with regular control. However, a risk-based approach would enable water service providers to implement regular water quality control on those parameters that are more likely to outrange the national norm, and at the same time can have important consequences on public health, as for example residual chlorine. The sector regulator agency has also a fundamental role in compliance with minimum water quality control mechanisms for each service provider, which is an important challenge in a highly disperse sector as is the case in Ecuador. Finally, the Ministry of Health should be encouraged to design and implement a surveillance strategy, also based on a risk analysis, considering that there is not only the important cost to implement water-quality surveillance but also the monetary benefits for the health system of preventing morbidity related to poor water quality.
2. The analysis on marginal effects show that household water treatment as reported by households (principally boiling) has an important potential to improve water quality when the household water source is contaminated. Interestingly, boiling water seems to have a slightly negative marginal effect in the case that the water source is free from *E. coli* contamination. Several considerations can explain this effect; Rosa et al.[11] found in similar conditions in urban and rural households in Peru that household water treatment is often inconsistent and self-reporting in household surveys does not guarantee that household members practice water treatment consistently and correctly. Further, the ENEMDU household surveys does not report on safe storage of drinking water in the households, and unsafe storage can be a source of contamination even if water treatment is consistent. The results show as well that other hygiene practices such as handwashing with soap and open defecation have a negative marginal effect on water quality at the point of consumption and might cancel the positive effects of household water treatment practices. As such, the results suggest that household water treatment and specifically boiling should be promoted especially when the household water source is contaminated, but it should be consistent and focus on other hygiene practices, such as safe storage, handwashing with soap and use of hygienic sanitation facilities.
3. This study shows that the SDG 6.1 indicator estimations on safely managed water services would provide similar results through either water quality testing at the household source level or using administrative records from water service providers. On the other hand, water-quality testing at point of consumption shows the increased risk of contamination between source and point of consumption which is the final and decisive stage with direct consequences for public health, as argued in the systematic review by Wright et al.[12]. This dimension is currently not included in the SDG 6.1 monitoring framework, and the evidence presented in this study highlights the important gaps that can arise between water quality at the source and water quality at the point of consumption.

This study highlights the added value of aligning national monitoring systems to the SDG 6.1 monitoring framework in terms of evidence generation for the water sector. This requires important structural changes to household survey design and additional investment to include water-quality testing at the household level: the alignment of National Development Plans and sector strategy with SDG 6.1 is an important enabler to succeed.

At the national level, this initiative shows multiple opportunities to generate sector learnings beyond the national, rural, and urban estimation of service levels. In particular, this study focused on the possible seasonal influence on water-quality testing results, the importance of sector performance improvements related to water-quality control and surveillance, the effects of household hygiene practices on the deterioration or improvement of water quality between household source and point of consumption, especially household water treatment as reported through the household surveys.

The principal findings are, first, the significant decrease in water quality between 2016 and 2019, where seasonal factors should be considered as a possible influence, as precipitation data show important differences between the two periods where water testing took place. Second, the water sector has a strong potential to improve performance, specifically the proportion of the population acceding to safely managed water services, if the sector manages to strengthen water-quality policies, principally through the implementation of a water-quality control and surveillance strategy and regulation. Third, households reporting to implement household water treatment (principally boiling) are more likely to consume good quality water if the water source provides poor quality. However, other household hygiene practices such as handwashing with soap, use of hygienic sanitation facilities, and possible unsafe storage or inconsistent application of household water treatment can affect water quality even if the quality at the source is good and households report to implement water treatment before the point of consumption. Considering the difference between the potential effects of the other components, this analysis suggests that the most critical issue to resolve toward 2030 in Ecuador is water quality.

Finally, the inclusion of water sample *E. coli* analysis at the point of consumption opened opportunities to monitor household water treatment practices; after all, monitoring absence/presence of *E. coli* at the point of consumption is the critical stage to determine if fecal–oral contamination route exists and which barriers are most effective in breaking the contamination chain. The classification between improved or unimproved source type, which was the principal focus of the Millennium Development Goals monitoring for water and sanitation, shows in this study to be partially effective to use this classification as a proxy to estimate water quality, but the added value of SDG 6.1 monitoring is the possibility to contrast water quality at the source level with the point of consumption. Manipulation (including water treatment at household level) of water at household level between the source and the point of consumption evidences an overall negative impact on the water quality if compared with the source level, and a very limited effect if compared with the service provider's compliance with national drinking water standards or compared with the improved/unimproved classification. This evidence suggests that household water treatment efforts are practically cancelled by inappropriate water manipulation practices such as unsafe storage, other inadequate hygiene practices such as lack of handwashing with soap or possible well-intended, but inadequate water treatment practices or technologies. Further research is needed to be able to determine exactly the reasons for the limited impact of household water treatment practices.

METHODS

Data sources

The data sources used in the analysis are household surveys, administrative records, population and housing censuses, population projections, and meteorological data.

The information taken from household surveys comes from the national survey of employment, unemployment, and underemployment (ENEMDU) of December 2016 and March 2019. ENEMDU is a survey by probabilistic sampling, whose main purpose is the measurement and monitoring of employment, unemployment, and the characterization of the labor market (data sources available at https://www.ecuadorencifras.gob.ec/indicadores-ods-agua-saneamiento-e-higiene/). These surveys included the necessary questions to monitor the SDG indicators. The survey allows obtaining disaggregated information at the national, urban, and rural levels.

The administrative records used were the Census of municipalities (CGADs) 2016 and 2017 (data sources available at https://www.ecuadorencifras.gob.ec/informacion-2017-gad/) and information reported by the community providers to the Water Regulation and Control Agency (ARCA) in 2017 and systematized in the Administrative System of Water Regulation and Control (SARA). These data sources contain information on volume of distributed water, volume of drinking water, number of drinking water treatment plants, number of drinking water treatment plants that meet the quality standard of water INEN 1108, volume of sewage collected according to the type of sewage system (sanitary or combined), volume of wastewater that enters treatment and type of treatment, volume of discharge of treated wastewater, volume of water distributed, number of microbiological tests carried out on the quality of drinking water for distribution, number of microbiological tests on drinking water that meets the local standard, and wastewater treatment capacity.

The population projections of INEC were used to determine the theoretical provision of drinking water per capita. Isothermal maps of the Ministry of Agriculture (MAG) were also used.

Survey design and data collection

ENEMDU was selected as the most suitable instrument to include the questions that respond to the new conceptual requirements of SDGs. In the questionnaire, two questions were modified, 26 new questions (6 for sanitation, 14 for water, and 6 for hygiene) were added. Household questionnaires from MICS and DHS surveys were used as a reference to develop the new questions. In addition, INEC had the advice of government institutions related to water and sanitation to adapt the questions to the Ecuadorian reality. Finally, a water-quality test was included[6].

The SDG 6.1.1 indicator "Proportion of population using safely managed drinking water services" considers that water services should be from an improved source, located on-premises, available when needed and free from contamination (http://www.sdg6monitoring.org/). The national definition in Ecuador includes certain adjustments to respond to data limitations (Pozo, Serrano, & Castillo[6]) and national sector consensus. The major differences between the global definition of indicator 6.1.1 and the national definition are:

- Ecuador does not consider rainwater collection as an improved source, because correct storage is not verified (Molina-Vera et al.)[13];
- Availability, when needed, is defined as access to sufficient water for drinking during the last 2 weeks;
- Absence of *E. coli* is used as a proxy for free from contamination, while JMP includes additionally free from priority chemical contamination.

ENEMDU is a survey by probabilistic sampling, whose main purpose is the measurement and monitoring of employment, unemployment, and the characterization of the labor market. The new questions aiming at measuring the SDG indicators of water, sanitation, and hygiene were included in the survey's household module. December 2016 ENEMDU had a sample of 31,092 households, this guarantees national, urban, rural, provincial, and self-represented cities representativeness. March 2019 ENEMDU had a sample of 16,954 households, and is representative at the national, urban, and rural level.

The water-quality test measures the presence/absence of *E. coli* bacteria in a 100 ml of sample. Colitag™ water test was used. Once the sample is taken, it is incubated for a period between 24 and 48 h. Because of the cost and logistics required by the test, the test was performed only on a subsample (Pozo, Serrano, & Castillo, 2017[6]). This subsample included 4,442 households in 2016, and allowed a national, urban, and rural disaggregation. In each sampling unit, three households in the urban area and four in the rural area were chosen. It is important to note that the inclusion of the water test required important efforts in resources and training. In September 2016, a pilot test of the survey was carried out. With the results obtained, the necessary modifications were made in the questionnaire, and in December 2016 the data collection for the baseline of the water, sanitation, and hygiene indicators was completed.

In 2019, the data allowing the construction of the SDG indicators for water, sanitation, and hygiene were collected again. The data collection strategy was the same as in 2016: a subsample in ENEMDU, this time including 7,331 households (three households per cluster) (Table 6). This statistical operation allows estimating indicators with national, urban, and rural representativeness. INEC, with technical support from UNICEF and using the MICS survey design as a reference, included this time two samples of the water test in each household: the second sample was intended to measure the quality of water at the point of consumption (glass of water).

Table 6. Water-quality testing in ENEMDU surveys.

	December 2016	March 2019
ENEMDU sample size (households)	31,092	16,954
Subsample size water quality (households)	4,442	7,331
Representativity	National, urban, rural	National, urban, rural
Water test	Colitag	Colitag
Water samples per household	1 (source level)	2 (source and point of consumption)

Source: INEC ENEMDU December 2016 and March 2019.

Statistical data analysis methods

This section describes the statistical analysis methods applied for each topic discussed in "Results".

The comparison of the water quality at the household's source level between 2016 and 2019 focuses on the distribution of the national population according to the typology of access to water. Through a hypothesis test, one can compare two sets of information in two different periods to see if the variations are statistically significant or not. This is what has been done to obtain the results as presented in the first table of this paper. For a more detailed analysis, the safely managed drinking water indicator was divided in its four main components (water quality, sufficiency, type of water source, and closeness) evidencing through a temporal analysis between 2016 and 2019 that the component which drives mostly the variation in time is water quality, despite that the component of sufficiency has a positive variation, the negative evolution of the water-quality component has a more weighted influence over the aggregated index.

Because of the lack of comparability between 2016 and 2019 data, it is not possible to establish tendencies, however, a structural analysis for 2019 population can be made. First of all, through a Kernel regression, it was possible to evidence that the access to safely managed water is directly associated with population income level. It is also important to understand the participation of each component in the safely managed drinking water indicator. For this purpose, the Shapley value gives a percentage of participation as an average expected marginal contribution, between all possible combinations. For this exercise, there were 24 possible combinations between the four components of the index. It is important to notice that the percentages do not show how much the index would increase if each problem is solved, but they give a notion of the contribution that each component has.

For further analysis in water quality, analysis along the distribution chain has been done starting from the municipal level source. Only those households that receive water through a public network have been included because for the other source types water quality cannot be known at the initial point of distribution. The information obtained from two main data sources, the Association of Municipalities of Ecuador (AME) and the Water Regulation and Control Agency (ARCA), included information on the number of water treatment plants that meet the standard and the tests that prove compliance with the standard. This information is attached to the ENEMDU as the percentage of water treated at the municipal level, as the probability that a household in that municipality receives water under the INEN 1108 standard if its main source of drinking water is a public network, another channeled source or public tap. This pairing allows us to know if water quality is being lost or gained at different stages of collection, treatment, distribution, handling, and consumption. With the information of how the cantons are geographically distributed according to the care they have on the water source, the achievement of local standards on water quality and the data of water quality in the source and point of consumption, it is possible to trace the origin of the contamination of the water that households consume. Furthermore, the information of distributed water by a public network that achieves the standard INEN 1108 is compared at the subnational level with certain variables of the ENEMDU survey like type of water source; water quality and water treatment. This allows having a percentage of treated water as the probability of a household that receives water under the standard if its primary source is a public network, other piped source or public tap.

The estimations on the associated factors related to water quality at the point of consumption were achieved using a logistic regression model with Huber–White (robust) estimators of the standard errors. The information was used at the individual level. The households sample has 7,331 observations, while the sample of persons has 25,924 observations. The variables taken into account for this process were: water quality at the source, boiling or any other household water treatment; hygiene variables, such as lack of water and soap; lack of handwashing infrastructure; and complementing the WASH analysis, a sanitation variable shows the state of this dimension in two categories (limited and not improved). These factors were categorized as immediate factors. Some of these factors are categorized as extended factors too, like water quality by public network and the main components of the safe water index. There is a third categorization of associated factors that have to do with the social characteristics of the population. Social factors include variables such as geography, per capita income, ethnicity and education level of the household head. With this set of variables, for the three categories of associated factors, the marginal effects are calculated over the probability of having access to quality water at the consumption point.

DATA AVAILABILITY

Data referenced in this study to the surveys are available at https://www.ecuadorencifras.gob.ec/indicadores-ods-agua-saneamiento-e-higiene/, the data of the census of municipalities are available at https://www.ecuadorencifras.gob.ec/informacion-2017-gad/, and the data from community providers and municipal shape files can be accessed upon request. The scripts used in the analysis are available for download in the following link: https://github.com/ASHinec/WASHinec.

Received: 1 December 2019; Accepted: 3 April 2020;
Published online: 15 May 2020

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ACKNOWLEDGEMENTS
This study would not have been possible without the continuous support from Roberto Castillo, former Executive Director at INEC; it is evident that his decision to include water-quality sampling in household surveys has been determinative to generate the evidence generated through this study. The support from the World Bank Group and UNICEF since 2016 has been key to support INEC in the transition from monitoring MDGs to SDGs related to water, sanitation and hygiene.

AUTHOR CONTRIBUTIONS
F.J. and J.P. performed the calculations for the statistical analysis. M.P. and L.M. have been working since 2016 to adapt SDG methodology to Ecuadorian reality and they participated in the calculation of the indicators., K.V. and R.B. performed the interpretation of the results.

COMPETING INTERESTS
The authors declare no competing interests.

ADDITIONAL INFORMATION
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