IMPLEMENTATION OF SDG INDICATOR 6.3.2 IN CHILE

Proportion of bodies of water with good ambient water quality

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1. SUMMARY

This document outlines the implementation of the Sustainable Development Goal (SDG) indicator 6.3.2, "Proportion of bodies of water with good ambient water quality" in Chile. The Dirección General de Aguas (DGA, the Chilean water agency) operates and maintains a water quality monitoring network comprised currently of 989 active stations monitoring surface water (excluding lakes and reservoirs) and groundwater resources. A set of parameters are monitored depending on the type of water body, including basic parameters (pH, electrical conductivity, dissolved oxygen, temperature), ions (e.g. Ca, Mg, Na, K, SO_4, Cl), total metals (e.g. As, Al, Cu, Fe, Mn, Pb), nutrients (nitrogen and phosphorus) and organic compounds (BOD_5[1] and COD[2]) (Dirección General de Aguas, 2014, Dirección General de Aguas, 2017).

The monitoring activity has resulted in over 1 million records of water quality data. Considering the time span and the dynamic multi-step nature of monitoring, these records may contain spurious entries due to human or analytical mistakes. Thus, it is important to define and implement a variety of well-defined criteria to maximize the likelihood that correct data are used for the calculation of SDG indicator 6.3.2. The data cleansing process consisted of (1) the removal of records deemed as erroneous, dubious or above a reporting limit, (2) the removal of records with a zero or negative value, as concentrations cannot be reported below an analytical limit of detection, (3) the revision of consistent reporting according to the analytical method used (information provided by the DGA), and (4) identification of outliers.

Calculation of the SDG indicator 6.3.2 used the "Step-by-step monitoring methodology for indicator 6.3.2." document by UN-Water (2018), albeit adapted to the relevant local conditions. The first two steps in the methodology are the definition of watersheds and the definition of water bodies, respectively. The DGA has identified basins, sub-basins and sub-sub-basins, as well as different types of water bodies (surface streams, lakes, reservoirs, groundwater aquifers). The DGA decided that the indicator would be calculated using basins as the reporting unit (i.e. all stations within a basin would be aggregated) and that only active stations monitoring surface streams would be considered in the analysis. The shape of Chile is long and narrow, with rivers going from the Andes to the Pacific Ocean, flowing across a short length compared with major rivers in the Northern Hemisphere, defining 101 basins, which supports the decision to use basins as the reporting unit. A further disaggregation in sub-basins and sub-sub-basins may also be possible, but not implemented here.

The third step was the definition of monitoring stations, which was ultimately decided as all surface stream stations that (1) are currently active, (2) have data in the 2015 – 2018 analysis period for at least one parameter, and (3) have data regarding target values for at least one parameter.

The fourth step is the collection of water quality data. The option of using the existing monitoring programme was made. The DGA makes data publicly available through its Banco Nacional de Aguas (BNA). According to parameters used for calculation of the indi-

[1] BOD_5: biochemical oxygen demand 5 days.

[2] COD: chemical oxygen demand.

cator, it was decided that pH, electrical conductivity, dissolved oxygen, orthophosphate and two species of nitrogen would be used (nitrate nitrogen and total oxidized nitrogen). In the latter case, it was also decided that nitrate nitrogen would precede total oxidized nitrogen if a single sample presented records for both parameters.

The fifth step was the assessment of water quality, which involves 3 sub-steps: (1) definition of water quality targets, (2) classification of water quality and (3) calculation of the indicator. Water quality targets were defined for each station based on the following prioritized alternatives, according to the DGA protocol: (1) values defined by an ambient water quality standard, (2) values derived from historical data (2000 – 2014), and (3) values defined in standards of water quality for a variety of uses. Classification of water quality was performed by calculating the percentage of compliance for each parameter at a station level by comparing monitoring values with target values by year, as suggested by UN-Water (2018). Compliance was then aggregated for each station (average of all parameters measured each year), and aggregated (averaged) at a basin level, which serves as the reporting unit. A basin was defined as having "good" ambient water quality if the compliance was 80% or over, as indicated by UN-Water (2018). Finally, the indicator was calculated as the proportion of basins that have good ambient water quality and the total number of monitored basins. The results of indicator 6.3.2 are presented in the following table:

Year	Number of basins with good ambient water quality	Total number of monitored basins	Indicator 6.3.2
2015	25	49	51
2016	36	50	72
2017	36	50	72
2018	38	50	76

The SDG indicator 6.3.2 was calculated on an annual basis for 2015 through 2018 as an example in this document. A three-year basis could also be used (2017 to 2019) producing smoother variations and reduced impact of missing data.

The calculation of SDG indicator 6.3.2 for Chile reveals an important number of challenges and opportunities to improve the process in future reporting cycles. These include: (1) the disaggregation of results by using a smaller reporting unit (e.g. sub-basins, or sub-sub-basins), which would benefit a focused management of water resources, (2) the inclusion of lakes and groundwater resources, which are sensitive to anthropic activities and are relevant to the provision of groundwater, respectively, (3) the strengthening of the monitoring network so stations can be calculated with all five core parameters, and (4) the inclusion of metal and metalloids in the indicator, as part of Level 2 monitoring (UN-Water, 2018), as these are particularly relevant in basins in the northern and central zones of Chile due to natural enrichment and mobilization by mining activities.

2. INTRODUCTION

This document outlines the implementation of the Sustainable Development Goal (SDG) indicator 6.3.2, "Proportion of bodies of water with good ambient water quality" in Chile. Firstly, it presents a brief introduction to the Chilean context and the status of water quality monitoring in the country. Secondly, it presents a brief explanation on the preparation of data generated by the local water agency (Dirección General de Aguas, DGA). It then focuses on the determination of SDG indicator 6.3.2, including the adaptation of the methodology to overcome several challenges resulting from restrictions and limitations in data availability. Finally, it presents future opportunities and additional challenges to improve the robustness of the indicator and its national relevance.

2.1. The Chilean context

According to the Atlas del Agua 2016 (Dirección General de Aguas, 2016), the DGA has identified 101 basins throughout the Chilean territory, which are divided into 467 sub-basins and 1,496 sub-sub-basins. Hydrological and water quality conditions in these watersheds are highly variable. While northern watersheds are characterized by low runoff and natural enrichment by dissolved salts, metals and metalloids, the southern watersheds are characterized by low concentrations of these constituents resulting from a lower frequency of their sources and a greater dilution due to higher rainfall and runoff (Pastén et al., 2019, Vega et al., 2018). This implies a challenge in the definition of an indicator of water quality for the country.

2.2. Water quality monitoring in Chile

The DGA maintains and operates a water quality monitoring network that has recorded data since the 1960s in Chile. This network has continually grown over time by incorporating or removing stations – as of October 2019, it is comprised of 1,472 stations monitoring surface water (excluding lakes and reservoirs) and groundwater (Figure 1), of which 989 are currently active. Depending on the water body being monitored, they can include several basic parameters (pH, electrical conductivity, dissolved oxygen, temperature), ions (e.g. Ca, Mg, Na, K, SO_4, Cl), total metals (e.g. As, Al, Cu, Fe, Mn, Pb), nutrients (nitrogen and phosphorus) and organic compounds (BOD_5 and COD) (Dirección General de Aguas, 2014, Dirección General de Aguas, 2017). Nevertheless, not all parameters, including basic ones, are measured regularly in every single station.

Generally, monitoring frequency depends on the type of body of water. For most of the monitoring network, surface water resources are monitored 4 times per year (once each season), whereas groundwater resources are monitored 2 times per year (autumn and spring) (Gobierno de Chile, 2017).

Nevertheless, the monitored parameters and the frequency of monitoring can be modified if the station is considered within an ambient water quality standard (Norma

Secundaria de Calidad de Agua, NSCA). Currently, 5 watersheds have a NSCA in force: Serrano River, Maipo River, Bio-Bio River, Llanquihue Lake and Villarica Lake. The Valdivia River had a NSCA in force, but was withdrawn after litigation at an environmental court.

Figure 1. Distribution of surface water and groundwater monitoring stations (active and suspended). Source: Own elaboration based on data from DGA.

3. CALCULATION OF SDG INDICATOR 6.3.2

In this document, the SDG indicator 6.3.2 will be calculated for rivers. In later stages, groundwater and lakes should be included in the calculation of the indicator. The lessons learned with this exercise can be applied in this new stage.

3.1. Steps 1 & 2: Definition of watersheds and water bodies

As indicated in section 2.1, the Chilean territory is divided in 101 basins, 467 sub-basins and 1,496 sub-sub-basins. It has been defined by the DGA that basins are the reporting unit for SDG indicator 6.3.2, implying that all stations within the basin will be considered and aggregated for analysis.

Regarding water bodies, it has been established that the calculation will be performed on monitoring stations that are associated to surface streams, excluding groundwater and lakes from the indicator in this stage, according to the DGA.

3.2. Step 3: Definition of monitoring stations

It was established that all stations that (1) are active, (2) had data in the 2015 – 2018 assessment period and (3) had information regarding target values (section 3.4.1), for at least one core parameter, would be considered in the analysis.

3.3. Step 4: Collection of water quality data

3.3.1. Monitoring parameters

Indicator 6.3.2 considers five core monitoring parameter groups, each with its own recommended and alternative core parameters (Table 1). Specific fractions of nitrogen and phosphorus should be included according to the national context (UN-Water, 2018).

Parameter group	Recommended parameter	Alternative parameter
Oxygen	Dissolved oxygen	Biological oxygen demand Chemical oxygen demand
Salinity	Electrical conductivity	Salinity Total dissolved solids
Nitrogen	Total oxidized nitrogen	Total nitrogen Nitrite Ammoniacal nitrogen
Phosphorus	Orthophosphate	Total phosphorus
Acidification	pH	N/A

Table 1. Recommended and alternative core monitoring parameters for rivers. Source: UN-Water (2018)

Measurements of pH, electrical conductivity and dissolved oxygen are available for most stations, whereas phosphorus and nitrogen are measured less frequently. Orthophosphate and nitrate – and, to a lesser extent, nitrate + nitrite (hereinafter referred to as total oxidized nitrogen) – are the most commonly measured species for these elements, respectively. Therefore, it was decided by the DGA that orthophosphate would be used as core parameter for the phosphorus group. In the case of nitrogen, both nitrate and total oxidized nitrogen measurements were used. If a measurement contained data for both parameters, the former was considered in the analysis. This situation is explored in Example 1 in section 3.4.2.

3.3.2. Quality assurance of data

Water quality data can present mistakes resulting from human (e.g. typing) and analytical errors (e.g. errors during sampling or measurement). Therefore, it is important that such records are identified and removed from further analyses. Considering criteria from other studies (e.g. CADE-IDEPE (2003), Oelsner et al. (2017)), the data from the DGA network was validated under the following criteria:

a) Quality of record

The database from the DGA includes a variable that can contain several observations regarding each record. These can indicate whether the observation is questionable, erroneous, or below or above a reporting limit. Therefore, data that was deemed questionable, erroneous or above a reporting limit were removed from analysis.

b) Compliance with physical and analytical limits

The majority of water quality data, particularly concentrations of elements and substances, must be positive, as zero or negative values are not analytically possible (excluding temperature and alkalinity). Therefore, records with a reported value of 0 were removed.

c) Correct reporting of records in accordance to the analytical method

As analytical techniques evolve, limits of detection or quantification change, as may do the units in which the results are reported. Therefore, it was verified by the DGA whether the records were reported under the correct parameter and that the units are consistent.

d) Identification of outliers

Outliers are extreme values arising from errors during sampling or analysis (including sample contamination and typographic mistakes), anthropic influence (e.g. accidental wastewater spill) or even natural variation. These values must be identified and their inclusion in the analysis must be evaluated, according to the objectives.

3.4. Step 5: Assessment of water quality

3.4.1. Definition of water quality targets

Water quality data should be compared with ambient water quality targets for the calculation of SDG indicator 6.3.2. Target values may fall under one of the following situations: (1) ambient water quality standards are in place; (2) data are available, while national standards are not; or (3) data are insufficient to set target values (UN-Water, 2018). In the Chilean case, these three situations can be found and have been applied according to the criteria described in Table 2, according to the DGA protocol. Target values are defined on a per-station basis.

Situation	Implementation in Chile
(1) National ambient water quality standards are in place	Ambient water quality standards (NSCA) defining requirements for select parameters in select stations in 6 basins[3]. These were used whenever available. Details on the NSCAs are presented in Appendix 8.1.
(2) Data are available, while national standards are not	Targets will be set using data from 2000-2014 (both years included), considering a minimum of 20 records[4] and excluding outliers. They 5th percentile will be set as lower limit, whereas the 95th percentile will be set as upper limit.
(3) Data are insufficient to set target values	Water quality standards for specific uses are available in Chile (e.g. drinking water, irrigation, recreational with direct contact). The following standards were considered (in that order): • NCh1333/78: Irrigation • D.S. 143/2009: Recreational use with direct contact • NCh1333/78: Aquatic life Details on these standards are presented in Appendix 8.2.

Table 2. Definition of ambient water quality targets used in the calculations.

It is important to note that, while the 5th and 95th percentiles may be calculated for all parameters, only one threshold could be important for each parameter. Specifically, dissolved oxygen is expected to be above a lower limit only; nitrogen, phosphorus and electrical conductivity are expected to be below an upper limit only; whereas pH is expected to be within a range defined by both thresholds. Statistical descriptors for targets for core parameters in all stations, calculated with these criteria (Table 2), are presented in Appendix 8.3. The high variability of the values shows that a country value cannot be used, and the best target must be evaluated for each case.

[3] Although the NSCA for the Valdivia River basin was withdrawn after reclamation at an environmental court, it has been used in the calculation of the indicator.

[4] The UN-Water methodology suggests at least 1 year of data and a minimum of 20 data points. The original DGA methodology requires 20 data points over a 5-year period (2010 – 2014, considering 4 samples should be taken each year); however, the reference period was extended to 2000 – 2014 since few stations would have enough data points for the 2010 – 2014 period.

Example 1. Identification of water quality targets at the Mapocho en Los Almendros station

The Mapocho en Los Almendros station has target values established in the NSCA for the Maipo River basin, which are presented in Table E1-1. Nevertheless, this example considers the calculation of target values based on the water quality data for the 2000 – 2014 period (second criterion).

Parameter	Unit	Lower Limit	Upper Limit
Dissolved oxygen	mg/l O_2	8	ND
Electrical conductivity at 25˚ C	µS/cm	ND	400
Nitrate nitrogen	mg/l N-NO_3	ND	1.5
Orthophosphate phosphorus	mg/l P-PO_4	ND	0.08
pH	pH unit	6.5	8.5

Table E1-1. Ambient water quality targets (NSCA) for the Mapocho en Los Almendros station. Note: Limits not defined in the NSCA are shown as ND (Not Defined).

Table E1-2 presents an excerpt of the measured values of nitrate nitrogen (parameter code 6240) and total oxidized nitrogen (nitrite + nitrate nitrogen, parameter code 6250) at the Mapocho en Los Almendros station. Since these parameters present more than 20 records in the reference period (2000 – 2014), target values can be calculated using this criterion. The calculation of targets using this criterion (5th and 95th percentiles) was done excluding outliers, so these are identified (blue rows) and eliminated from the values to be used (Calculation Value column).

Station ID	Parameter ID	Date	Time	Value	Outlier	Calculation Value
5722002	6240	18-01-2000	13:30:00	0.466		0.466
5722002	6240	16-03-2000	11:08:00	0.41		0.41
5722002	6240	17-04-2000	12:45:00	0.503		0.503
5722002	6240	18-07-2000	11:30:00	1.158		1.158
5722002	6240	23-10-2000	11:05:00	0.532		0.532
⋮	⋮	⋮	⋮	⋮	⋮	⋮
5722002	6240	26-09-2008	11:56:00	5	Outlier	
⋮	⋮	⋮	⋮	⋮	⋮	⋮
5722002	6250	06-11-2012	14:50:00	0.568		0.568
5722002	6250	30-05-2013	11:55:00	1.068		1.068
5722002	6250	14-10-2014	10:50:00	0.615		0.615

Table E1-2. Extract of records associated with nitrogen in Mapocho en Los Almendros station.

Example 1 (continued). Identification of water quality targets at the Mapocho en Los Almendros station

Once the values that will be used for the calculation of targets have been identified, percentiles 5th and 95th can be calculated. Nitrogen only considers an upper limit, so only the 95th percentile should be calculated. Nevertheless, both limits (lower and upper) are presented in Table E1-3.

Parameter	Unit	Lower Limit	Upper Limit
Nitrate nitrogen	mg/l N-NO_3	0.326*	1.222

Table E1-3. Lower and upper limits for nitrogen at the Mapocho en Los Almendros station, based on historical data (2000 – 2014).

** Although this value is presented, it is not used in the calculation of the indicator.*

3.4.2. Classification of water quality

The classification of water quality was calculated through a simple index based on the comparison of monitoring data (including outliers, as a conservative approach was adopted) with target values. For each parameter, at each station, this index is the percentage compliance with the target values, namely:

$$C_{wq} = \frac{n_c}{n_m} \text{x}100$$

where:

C_{wq} is the percentage compliance (%)
n_c is the number of monitoring values in compliance with target values
n_m is the total number of monitoring values

The index at a level station was calculated as the arithmetic average between the percentage compliance for all available core parameters. It is important to note that a station may not have data for each of the five core parameters. It was decided that these stations would still be included in the calculation, despite the missing data.

Finally, the compliance at a basin level (reporting unit) was calculated by averaging the percentage compliance of all stations within that basin and later assessed as "good" if the compliance is equal to or exceeds 80%.

Example 2. Classification of water quality at the Mapocho en Los Almendros station and the Maipo River watershed

Table E2-1 presents an excerpt of the nitrate nitrogen and total oxidized nitrogen records at the Mapocho en Los Almendros station during the calculation period (2015 – 2018). According to the definition of parameters presented in section 3.3, in the case that both parameters were measured on the same day, nitrate nitrogen takes preference. Therefore, records marked in blue are not considered in the calculation (Calculation Value column).

Station ID	Parameter ID	Date	Time	Value	Calculation Value
5722002	6240	14-01-2015	11:50:00	0.267	0.267
⋮	⋮	⋮	⋮	⋮	⋮
5722002	6240	12-10-2016	10:00:00	0.562	0.562
5722002	6250	12-10-2016	10:00:00	0.573	
⋮	⋮	⋮	⋮	⋮	⋮
5722002	6240	16-01-2017	11:20:00	0.492	0.492
5722002	6250	16-01-2017	11:20:00	0.535	
⋮	⋮	⋮	⋮	⋮	⋮
5722002	6240	06-11-2018	10:18:00	0.393	0.393

Table E2-1. Excerpt of nitrate nitrogen and total oxidized nitrogen at the Mapocho en Los Almendros station, 2015 – 2018.

Compliance is later calculated by comparing all values with the previously identified limits. In this particular case, records comply with the target values if their value is less than 1.5 mg/l N-NO_3 threshold, as indicated in the NSCA. A "1" value will be assigned if the record complies with the target value (Compliance column). Table E2-2 presents the compliance assessment for nitrate nitrogen and total oxidized nitrogen in 2016.

Station ID	Parameter ID	Date	Time	Calculation Value	Compliance
5722002	6240	26-01-2016	10:15:00	0.453	1
5722002	6240	10-02-2016	12:05:00	0.336	1
5722002	6250	12-04-2016	10:10:00	0.207	1
5722002	6240	18-05-2016	9:51:00	0.649	1
5722002	6250	13-06-2016	11:07:00	1.199	1
5722002	6250	11-07-2016	11:00:00	0.9	1
5722002	6240	23-08-2016	11:01:00	0.819	1
5722002	6240	12-09-2016	11:40:00	0.76	1
5722002	6240	12-10-2016	10:00:00	0.562	1
5722002	6240	02-11-2016	9:50:00	0.628	1
5722002	6240	14-12-2016	11:10:00	0.614	1

Table E2-2. Compliance assessment for nitrate nitrogen and nitrite + nitrate nitrogen at the Mapocho en Los Almendros station, 2016.

Example 2 (continued). Classification of water quality at the Mapocho en Los Almendros station and the Maipo River watershed

The calculation of compliance per parameter is determined by the division between compliant records and the total number of records. In this case, the percentage compliance for nitrogen would be:

$$C_{wq} = \frac{n_c}{n_m} \text{x}100 = \frac{11}{11} \text{x}100 = 100\%$$

Table E2-3 presents the percentage compliance for all five core parameters.

Parameter	Compliant records	Total records	Compliance (%)
pH	9	11	81.8
Electrical conductivity	11	11	100.0
Dissolved oxygen	11	11	100.0
Nitrate nitrogen	11	11	100.0
Orthophosphate phosphorus	9	10	90.0

Table E2-3. Percentage compliance per parameter at the Mapocho en Los Almendros station, 2016.

The percentage compliance at a station level is calculated as the arithmetic average of the compliance of each parameter, namely:

$$C_{wq.station} = \frac{81.8 + 100 + 100 + 100 + 90}{5} = 94.4\%$$

The percentage compliance at a watershed level is calculated as the arithmetic average of the compliance per station. Table E2-4 presents an excerpt of the compliance levels for some stations at the Maipo basin in 2016.

Station ID	Compliance (%)
05701002-9	92.7
05702006-7	93.8
05703003-8	93.8
⋮	⋮
05746001-6	94.5
05748001-7	98.0

Table E2-4. Compliance by station at the Maipo basin, 2016.

Example 2 (continued). Classification of water quality at the Mapocho en Los Almendros station and the Maipo River watershed

This way, the percentage compliance at a watershed level is:

$$C_{wq.watershed} = \frac{92.7 + 93.8 + 93.8 + \dots + 94.5 + 98.0}{5} = 92.8\%$$

The compliance at the Maipo River watershed is larger than the 80% threshold; therefore, this basin is classified as a body of water with "good" quality.

Calculation of the indicator

The indicator is calculated as the proportion of basins classified as water bodies with good quality, expressed in percentage:

$$WBGQ = \frac{n_g}{n_t} \text{ x}100$$

where:

$WBGQ$ is the percentage of water bodies (basins) classified as having a good quality status
n_g is the number of water bodies (basins) classified as having a good quality status
n_t is the total number of monitored and classified water bodies (basins)

Example 3. Calculation of indicator 6.3.2 "Proportion of water bodies with good ambient water quality"

Table E3-1 presents an excerpt of the percentage compliances at a basin level in 2016, along with the classification of the result as "good" or "not good".

Basin ID	Compliance (%)	Clasification
10	87.9	Good
12	73.3	Not good
13	91.7	Good
⋮	⋮	⋮
128	91.1	Good
129	100.0	Good

Table E3-1. Assessment of the water quality per basin, 2016.

Example 3 (continued). Calculation of indicator 6.3.2 "Proportion of water bodies with good ambient water quality"

The number of basins with good ambient water quality in 2016 is 36, out of 50 analyzed watersheds. This way, indicator 6.3.2 is the following, according to the formula:

$$WBGQ = \frac{n_g}{n_t} \text{ x}100 = \frac{36}{50} \text{ x}100 = 72.0\%$$

Table 3 presents the results for SDG indicator 6.3.2. It shows the number of water bodies classified as having good quality (n_g), the total number of water bodies analyzed (n_t) and the indicator itself (WBGQ).

Year	n_g	n_t	WBGQ (%)
2015	25	49	51
2016	36	50	72
2017	36	50	72
2018	38	50	76

Table 3. Calculation of indicator 6.3.2, percentage of water bodies with a good ambient water quality (WBGQ), at a national level. Source: Own elaboration.

4. FUTURE CHALLENGES AND OPPORTUNITIES

The current status of the water quality monitoring network and the data it generates led to different decisions being made during the calculation of the indicator, such as the decision to include stations that do not have sufficient information for all five core parameters. This implies both challenges and opportunities to improve the calculation of SDG indicator 6.3.2 in Chile, some of which are outlined below.

4.1. Steps 1 & 2: Definition of watersheds and water bodies

As indicated in section 3.1, the calculation of the indicator was performed considering basins as water bodies. Furthermore, the indicator was limited to data from streams, excluding lakes and groundwater resources. This leads to the followings opportunities to improve the calculation of the indicator:

4.1.1. Disaggregation of results

Since basins are the largest hydrological units the country is divided into, the decision to define water bodies as basins limits the ability to discern spatial patterns in water quality at a finer scale. Therefore, it should be discussed whether the classification of water quality should be performed at a finer scale (i.e. considering sub-basins, or sub-sub-basins as water bodies) in order to illustrate intra-basin patterns, an approach that would be beneficial for the management of water resources (UN-Water, 2018).

4.1.2. Inclusion of lakes and groundwater

Groundwater is an important source of water for drinking water production, accounting for 53% of the national capacity (Superintendencia de Servicios Sanitarios, 2018). On the other hand, lakes can be heavily sensitive to inputs of nutrients deriving from anthropogenic activities, affecting their trophic status. Therefore, the monitoring and assessment of the quality of groundwater and lakes is similarly relevant to that of streams, and their inclusion in the calculation of SDG indicator 6.3.2 should be considered and discussed. This will be done in a next stage using this learning. In fact, both of these types of water bodies are considered in the methodology established by UN-Water (2018). In the case of groundwater, careful consideration must be taken in assigning aquifers to a reporting unit (basin or sub-basin).

4.2. Step 3: Definition of monitoring stations

As indicated in section 3.2, the indicator was calculated for stations that had data in the 2015 – 2018 assessment period and information regarding target values for at least one core parameter. In consequence, for some stations the compliance of the monitoring data with the defined targets was calculated with less than the 5 core parameters, according to a DGA decision. For example, one station in particular only had data for two core parameters (pH and EC) during the calculation period (2015-2018). Furthermore, standards defining water quality requirements for different uses (third situation while setting targets) do not specify threshold for nitrates and orthophosphate. Therefore, it may be the case that certain stations that have only recently started acquiring data for nutrients (i.e. there are measurements during the calculation period, but not enough records during the 2000-2014 baseline period) won't have thresholds values defined, leading to the indicator being calculated with fewer core parameters.

It should be discussed whether to include or exclude stations that do not have sufficient data for all five core parameters from the calculation. However, it is important to note that placing this restriction can heavily change the results of the indicator, as shown in Table 4. This restriction will limit the use of valid data, that was obtained in the field with public resources and effort.

Year	WBGQ considering all stations			WBGQ considering stations witch sufficient data for all 5 core parameters		
	n_g	n_t	WBGQ (%)	n_g	n_t	WBGQ (%)
2015	25	49	51	1	1	100
2016	36	50	72	2	3	67
2017	36	50	72	2	3	67
2018	38	50	76	1	3	33

Table 4. Comparison of the calculation of the WBGQ indicator considering all stations and stations with sufficient data for all 5 core parameters

4.3. Step 4: Collection of water quality data

4.3.1. Strengthening and improvement of the monitoring network

As previously discussed, some stations did not have data for all parameters during the assessment period, which led to the calculation of the indicator to be performed without some core parameters. Therefore, it is important that the monitoring network is strengthened so that stations in future reporting cycles can be calculated with all 5 core parameters.

It was also noted during the calculation of SDG indicator 6.3.2 that the number of measurements for each parameter can be different throughout a single year and between years. For example, Table 5 shows the number of data points by parameter at the Mapocho en Los Almendros station. It can be seen that in 2015 pH, electrical conductivity and dissolved oxygen presented more measurements compared to total oxidized nitrogen and orthophosphate. It can also be observed that the database has fewer entries on 2017 (one for each parameter). These situations imply that each individual measurement can hold a different weight in the calculation of SDG indicator 6.3.2, and it should be discussed whether this is acceptable or not. In any case, more consistency in the frequency of monitoring should be a goal in order to improve the monitoring network.

Year	Number of records				
	pH	Electrical conductivity	Dissolved oxygen	Total oxidized nitrogen	Orthophosphate
2015	16	16	16	12	11
2016	11	11	11	11	10
2017	1	1	1	1	1
2018	11	11	11	11	11

Table 5. Number of records by parameter at the Mapocho en Los Almendros station, 2015 - 2018

4.3.2. Inclusion of metals and metalloids

Waters in Northern and Central Chile tend to present higher concentrations of dissolved salts, metals and metalloids due to mineral enrichments in the Andes mountain range and pressures from the mining industry (Pastén et al., 2019, Vega et al., 2018). These contributions are partly attenuated by more favorable hydrological conditions in Central Chile as well as geological substrate as we move to the south. Therefore, the inclusion of metals and metalloids as parameters in level 2 monitoring (i.e. not mandatory) is relevant in creating an indicator of national relevance (UN-Water, 2018).

Nevertheless, consideration of the natural enrichment in rivers from Northern and Central Chile must be discussed. It should be disused whether target values should consider natural enrichment (i.e. the indicator would aim to prevent the degradation resulting from anthropogenic activities) or should consider water quality standards for several uses (i.e. the indicator would aim to improve water quality to a degree that is suitable for certain uses).

5. METHOD IMPLEMENTATION IN A DATA ANALYSIS SPREADSHEET AND R SCRIPT

An Excel workbook was prepared implementing the Step-by-step methodology that yields the results shown on the previous tables. The workbook contains an explanation to walk the reader through the application of the step-by-step methodology, starting from the raw data and finishing with the indicator calculation.

Since historic water quality databases may involve a massive number of records, an R script was developed, and it is also available upon request to the authors. The reader may adapt this script to suit the format and content of each dataset.

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8. APPENDIXES

The following section contains additional information on:

- 8.1 Chilean ambient water quality standards (NSCAs)
- 8.2 Chilean water quality standards for different uses
- 8.3 Target for core parameters

Nº	Parameter	Unit	LL-O Puerto Octay	LL-F Frutillar	LL-E Ensenada	LL-V Puerto Varas
1	Conductivity	µS/cm	110	110	110	110
2	pH	pH unit	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5
3	Dissolved oxygen	mg O_2/L	≥8.5	≥8.5	≥8.5	≥8.5
4	Dissolved oxygen	% O_2	≥85	≥85	≥85	≥85
5	Turbidity	NTU	2.1	2.1	2.4	2.5
6	Silica	mg/L	1.83	1.84	1.77	1.80
7	COD	mg/L	4.8	4.9	6.0	5.0
8	Transparency	M	≥13.5	≥14.0	≥16.0	≥12.5
9	Total nitrogen	mg N/L	0.12	0.14	0.13	0.13
10	Total phosphorus	mg P/L	0.01	0.01	0.01	0.01
11	Chlorophyll "a"	mg/L	1.4	1.4	1.4	1.4

Table 6. Ambient water quality requirements at the Llanquihue Lake watershed by station.

Nº	Parameter	Unit	Criterion	PEL	LIT-Poza	LIT-Pucon	LIT-Norte	LIT-Villarrica	LIT-Sur
1	Desired trophic status	-	-	Oligotrophic	Oligomeso-trophic	Oligomeso-trophic	Oligomeso-trophic	Oligomeso-trophic	Oligomeso-trophic
2	Transparency	m	Annual average	≥ 9	≥ 7	≥ 7	≥ 7	≥ 7	≥ 7
			Minimum	≥ 5	≥ 4	≥ 4	≥ 4	≥ 4	≥ 4
3	Dissolved phosphorus	mg P-PO_4/L	Annual average	≤ 0.010	≤ 0.015	≤ 0.015	≤ 0.015	≤ 0.015	≤ 0.015
			Maximum	≤ 0.015	≤ 0.025	≤ 0.025	≤ 0.025	≤ 0.025	≤ 0.025
4	Total phosphorus	mg P/L	Annual average	≤ 0.010	≤ 0.015	≤ 0.015	≤ 0.015	≤ 0.015	≤ 0.015
			Maximum	≤ 0.015	≤ 0.025	≤ 0.025	≤ 0.025	≤ 0.025	≤ 0.025
5	Oxygen saturation	% O_2	Minimum	≥ 80	≥ 70	≥ 70	≥ 70	≥ 70	≥ 70
			Annual average	< 0.10	≤ 0.15	≤ 0.15	≤ 0.15	≤ 0.15	≤ 0.15
6	Dissolved nitrogen	mg N/L	Maximum	≤ 0.15	≤ 0.30	≤ 0.30	≤ 0.30	≤ 0.30	≤ 0.30
			Annual average	≤ 0.15	≤ 0.15	≤ 0.15	≤ 0.15	≤ 0.15	≤ 0.15
7	Total nitrogen	mg N/L	Maximum	≤ 0.20	≤ 0.30	≤ 0.30	≤ 0.30	≤ 0.30	≤ 0.30
			Annual average	≤ 3	≤ 5	≤ 5	≤ 5	≤ 5	≤ 5
8	Chlorophyll "a"	µg/L	Maximum	≤ 6	≤ 10	≤ 10	≤ 10	≤ 10	≤ 10

Table 7. Ambient water quality requirements at the Villarica Lake basin by station.

Nº	Parameter	Unit	Río Maipo					Río Mapocho		Río Angostura	Estero Lampa	Estero Puangue	
			MA-1	MA-2	MA-3	MA-4	MA-5	MP-1	MP-2	AN-1	LA-1	PU-1*	PU-2
1	Dissolved oxygen	mg/L	8	8	8	8	6	8	6	6	5	8	5
2	Electrical conductivity	µS/cm	1900	1900	1900	1600	1600	400	1600	1600	1900	400	1750
3	pH	-	6.5 - 8.7	6.5 - 8.7	6.5 - 8.7	6.5 - 8.7	6.5 - 8.7	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5
4	Chloride	mg/L	300	240	240	180	180	30	240	180	240	30	240
5	Sulphate	mg/L	430	380	380	380	380	150	380	380	480	150	380
6	BOD_5	mg/L	8	8	8	8	8	5	10	10	10	5	10
7	Nitrate	mg/L $N\text{-}NO_3$	0.5	0.5	0.5	4	8	1.5	10	4	4	1.5	10
8	Orthophosphate	mg/L $P\text{-}PO_4$	0.08	0.08	0.08	0.15	1	0.08	2.5	0.15	0.6	0.6	25
9	Dissolved Pb	mg/L	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
10	Dissolved Ni	mg/L	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
11	Dissolved Zn	mg/L	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
12	Total Cr	mg/L	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table 8. Ambient water quality requirements at the Maipo River basin by station.

Nº	Parameter	Unit	PA-10	SE-10	SE-20	GR-10	CH-10	BA-10	VI-10	DG-10	TP-10
1	Aluminum	mg/L	9	1	3	3	10	7	6	1	1
2	Cadmium	mg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
3	Chloride	mg/L	8	10	8	8.5	8	10	11	26	15
4	Copper	mg/L	0.05	0.08	0.01	0.07	0.05	0.09	0.06	0.06	0.04
5	Fecal coliforms	NMP/100 ml	-	10	-	-	-	-	-	-	-
6	Electrical conductivity	µS/cm	80	180	80	340	300	370	360	550	370
7	Chromium	mg/L	0.06	0.06	0.01	0.06	0.05	0.06	0.08	0.07	0.06
8	Iron	mg/L	16	1	3	5	12.7	35	28	5	4
9	Manganese	mg/L	0.3	0.1	0.2	0.08	2	0.7	0.6	0.1	0.05
10	Mercury	mg/L	0.001	0.001	0.001	0.001	0.001	0.01	0.001	0.001	0.001
11	Molybdenum	mg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
12	Nickel	mg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
13	Dissolved oxygen	mg O_2/L	9.8	9.5	7.9	8.6	7	9.2	7.3	9.3	9.7
14	pH	pH Unit	7 - 8	7 - 8	7 - 8	7 - 8	7 - 8	7 - 8	7 - 8	7 - 8	7 - 8
15	Lead	mg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
16	SAR	-	0.2	0.5	0.4	0.7	1	0.8	0.8	-	0.7
17	Selenium	mg/L	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
18	Sulphate	mg SO_4/L	5	13	5	5	56	30	28	58	29
19	Zinc	mg/L	0.04	0.02	0.04	0.02	0.09	0.04	0.09	0.05	0.05

Table 9. Ambient water quality requirements at the Serrano River basin by station.

			Río Biobío						Bureo	Duqueco	Río Laja			Río Malleco	Río Renaico	Río Vergara
Nº	Parameter	Unit	BI-10	BI-20	BI-30	BI-40	BI-50	BI-60	BU-10	DU-10	LA-10	LA-20	LA-30	MA-10	RE-10	VE-10
1	Total Al	mg Al/L	0.4	0.4	0.4	0.5	0.7	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
2	Ammonium	mg $N\text{-}NH_4$/L	0.02	0.02	0.02	0.02	0.03	0.06	0.02	0.03	0.02	0.03	0.02	0.02	0.02	0.03
3	Organohalogen compounds	mg/L	0.002	0.01	0.03	0.03	0.02	0.03	0.01	0.02	0.002	0.006	0.01	0.002	0.002	0.03
4	Chloride	mg /L	3	7	7	8	9	-	4	4	3	3	3	4	5	6
5	Fecal coliforms	NMP/100ml	50	50	500	500	1000	1000	1000	1000	50	50	500	50	50	500
6	Electrical conductivity	µS/cm	80	90	150	150	150	-	80	120	80	95	150	60	60	80
7	BOD_5	mg/L	2	2	2	2	2	2	2	2	2	2	2	2	2	2
8	COD	mg/L	5	5	8	8	5	7	9	6	3	3	8	6	7	10
9	Total phosphorus	mg P/L	0.03	0.02	0.04	0.05	0.05	0.07	0.05	0.05	0.02	0.02	0.1	0.03	0.02	0.04
10	Total Fe	mg/L	0.3	0.3	0.3	0.5	0.7	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.4	0.4
11	Phenol index	mg/L	0.003	0.004	0.005	0.004	0.004	0.004	0.003	0.003	0.002	0.003	0.003	0.002	0.002	0.004
12	Nitrate	mg $N\text{-}NO_3$/L	0.03	0.03	0.15	0.15	0.15	0.2	0.2	0.2	0.04	0.03	0.15	0.04	0.03	0.2
13	Nitrite	mg $N\text{-}NO_2$/L	0.002	0.002	0.003	0.002	0.002	0.01	0.006	0.003	0.002	0.002	0.002	0.002	0.002	0.01
14	Total nitrogen	mg N/L	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.6	0.1	0.1	0.3	0.2	0.1	0.4
15	Orthophosphate	mg PO_4/L	0.01	0.01	0.01	0.02	0.02	0.1	0.02	0.01	0.01	0.02	0.02	0.01	0.01	0.05
16	Dissolved oxygen	mg O_2/L	10	10	9	9	8.7	8.7	9	9	9	8.7	8.7	10	9	9
17	pH	-	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	6.5 - 8.5
18	Total suspended solids	mg/L	8	4	7	8	9	8	10	5	2	2	5	5	5	6
19	Sulphate	mg SO_4/L	5	6	6	14	14	-	5	5	7	6	6	5	5	10

Table 10. Ambient water quality requirements at the Biobío River basin by station.

Nº	Parameter	Unit	Río San Pedro	Río Calle Calle			Río Valdivia	Río Cruces				
			RSP	RCCI	RCCII	RCCIII	RV	RCI	RCII	RCIII	RCIV	SNCA
1	pH	-	6.3 - 8.0	6.3 - 8.0	6.3 - 8.5	6.3 - 8.5	6.3 - 8.5	6.3 - 8.0	6.3 - 8.0	6.3 - 8.0	6.3 - 8.0	6.3 - 8.5
2	Dissolved oxygen	mg O_2/L	>9	>9	>9	>8	>8	>9	>9	>9	>9	>8
3	Electric conductivity	µS/cm	70	70	*	*	*	70	70	70	70	*
4	Sulphate	mg SO_4/L	3	3	*	*	*	3	7	7	7.8	*
5	Sodium	mg /L	4.6	4.6	*	*	*	4.4	8.3	8.3	7.9	*
6	Choride	mg Cl/L	5.3	7.1	*	*	*	6.4	7.6	7.6	8.1	*
7	DBO5	mg/L	2	2	2	2	3	2.5	2.5	2.5	2.5	3
8	Aluminum (total)	mg/L	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.22	0.22
9	Aluminum (dissolved)	mg/L	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
10	Copper (total)	mg/L	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03
11	Copper (dissolved)	mg/L	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003
12	Chromium (total)	mg/L	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
13	Iron (total)	mg/L	0.1	0.2	0.2	0.2	0.39	0.39	0.39	0.39	0.39	0.39
14	Iron (dissolved)	mg/L	0.06	0.06	0.06	0.06	0.06	0.1	0.1	0.1	0.1	0.1
15	Manganese (total)	mg/L	0.02	0.02	0.02	0.02	0.04	0.04	0.04	0.04	0.02	0.14
16	Manganese (dissolved)	mg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
17	Zinc (total)	mg/L	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.01	0.01
18	Zinc (dissolved)	mg/L	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
19	Nitrate	mg N-NO_3/L	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
20	Phosphate	mg PO_4/L	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
21	AOX*	mg/L	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006

Table 11. Ambient water quality requirement at the Valdivia River basin by station (withdrawn standard).
**AOX halogenated organic compounds, not perfomed.*

8.2. Chilean water quality standards for different uses

The requirements for the core parameters defined in water standards for irrigation and aquatic life (NCh1333/78) and recreational use with direct contact (Decreto 143/2008 del Ministerio Secretaría General de la Presidencia) are shown in the following table:

	Irrigation		Recreational water whit direct contact		Aquatic life	
Parameter	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit
Dissolved oxygen	ND	ND	ND	ND	5	ND
Electrical conductivity at 25°C	ND	1500*	ND	ND	ND	ND
Nitrate nitrogen	ND	ND	ND	ND	ND	ND
Orthophosphate phosphorus	ND	ND	ND	ND	ND	ND
pH	5.5	9.0	6.0	8.5	6.0	9.0

Table 12. Target values based on water quality standards for different uses.

** The standard presents an indicative table with several ranges for electrical conductivity, based on the sensitivity of crops. A value of 1500 µS/cm was adopted, as only sensitive crops would be affected at this level.*

ND: Not Defined.

8.3. Target for core parameters

The minimum, maximum, and mean of the target for the core parameters in all stations, calculated with criteria presented in Table 2, are shown in the following table:

Parameter	Unit	Target					
		Maximun		Minimun		Mean	
		Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit
Dissolved oxygen	mg/L	11.1	ND	1.7[5]	ND	7.2	ND
Electrical conductivity at 25°C	µS/cm	ND	24,320[6]	ND	29	ND	867
Nitrate nitrogen	mg/L $N\text{-}NO_3$	ND	10.2	ND	0.03[7]	ND	1.5
Orthophosphate phosphorus	mg/L $P\text{-}PO_4$	ND	25	ND	0.003[8]	ND	1.8
pH	-	8.0	9.6	2.7[9]	4.9	6.7	8.5

Table 13. Target values.

[5] *The lowest target-value for DO correspond to Baños del Toro station (North Chile), this low value can be explained by the geology of the zone and the presence of mining activity. This value was set as 5th percentile using data from 2000-2014 (both years included).*

[6] *The highest target-value for EC correspond to Río Loa en Desembocadura (North Chile), a river that born in Tatio geysers, and in their outfall to the sea has low flow. This value was set as the 95th percentile same period.*

[7] *National ambient water quality standards in Biobío River basin for some stations (South Chile).*

[8] *National ambient water quality standards in Biobío River basin for some stations (South Chile).*

[9] *The lowest target-value for lower limit of pH correspond to Río Caracarani en Alcerreca, a river which tributary is Río Azufre (their name is sulfur, pH <2). This value was set as 5th percentile.*