39th IAHR WORLD CONGRESS GRANADA, SPAIN 2022 From Snow to Sea 19-24 June 2022

Proceedings of the 39th IAHR World Congress
19–24 June 2022, Granada, Spain
doi://10.3850/IAHR-39WC2521716X2022139

# Plan for the improvement of the water resources monitoring network in the Chillón, Rímac, Lurín and Alto Mantaro basins, Perú

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**Abstract**

The purpose of the research was to provide support to the Water Observatory of the Peruvian Water National Authority through a Plan for the Improvement of the Water Resources Monitoring Network in the Chillón, Rímac, Lurín and Alto Mantaro basins (PMRMRH –CHIRILU). The PMRMRH-CHIRILU methodology had as a vision a proposal that ensures data in sufficient quantity and quality to be used in studies such as future simulation of the behavior of water resources. In this sense, the PMRMRH-CHIRILU was validated and derived from the analysis of the lack of information and the specific proposals of the diagnosis of the situational state of the existing surface and underground water monitoring networks in the basins. The methodologies used to propose new monitoring stations were the Voronoi diagrams for climatological stations, the Karasiev method for hydrological stations, the geomorphology and geological fault location for piezometric monitoring wells and the water quality index for surface water quality monitoring stations. Three new climatological stations, four hydrological stations, eighty piezometric monitoring wells and four surface water quality monitoring stations were proposed. The PMRMRH-CHIRILU, was validated by the institutions related to the management of water resources in the basins of the Chillón, Rímac and Lurín and Alto Mantaro – CHIRILU. Likewise, it considered the accessibility conditions and the feasibility of financing the installation and maintenance costs of the proposed stations.

**Keywords**: Water resources; Monitoring network; Water Observatory

## 1. INTRODUCTION

Theproject ´Adaptation of Water Resources Management to Climate Change in Urban Areas with the Participation of the Private Sector' – PROACC (by acronyms in Spanish), promoted by the German Agency for International Cooperation - GIZ and the National Water Authority of Peru -ANA, had as purpose that the management of water resources in the hydrographic basins of the Chillón, Rímac and Lurín rivers, be oriented to include an adaptation approach to climate change with the cooperation of the private sector. For this purpose and among other activities of PROACC, it was to support the Water Observatory, in the development of a Plan for the Improvement of the Water Resources Monitoring Network in the Chillón, Rímac, Lurín and Alto Mantaro basins - PMRMRH -CHIRILU.

The scope of the study had an extension of 9689,7 km$^2$. It is worth mentioning that this extension represents 0,75% of the territory of Perú, however, it houses 27,5% of the total population of Perú. The detail of the partial areas is presented in the following Table 1. The Figure 1, shows the location map of the Chillón, Rímac, Lurín and Alto Mantaro -PMRMRH-CHIRILU basins. (Autoridad Nacional del Agua, GIZ. 2019).

**Table 1**. Areas of the basins and inter-basins of the CHIRILU and Alto Mantaro (km$^2$)

| Basins | Basin area | Inter-basins area | Area (km$^2$) |
|---|---|---|---|
| **Rímac** | 3459,9 | 49,2 | 3509,1 |
| **Chillón** | 2194,9 | 313,2 | 2508,1 |
| **Lurín** | 1633,8 | 132,1 | 1765,9 |
| **Chilca** | 779,3 | 777,1 | 1556,4 |
| **Alto Mantaro** | 350,2 | | 350,2 |
| **Total partial (km$^2$)** | 8418,1 | 1271,6 | |
| **Total (km$^2$)** | | 9689,7 | |

Source: INEI. Perú. Environmental statistics yearbook, 2017

 


**Figure 1**. Location map in the basins of the Chillón, Rímac, Lurín and Alto Mantaro -PMRMRH-CHIRILU

The PMRMRH-CHIRILU planning process began with meetings held with various institutions related to the management of water resources in the basins of the Chillón, Rímac and Lurín and Alto Mantaro - CHIRILU areas.

## 2. DIAGNOSIS OF THE SITUATIONAL STATUS OF SURFACE WATER MONITORING NETWORKS

The PMRMRH-CHIRILU methodology has the vision a proposal that ensures data in sufficient quantity and quality to be used in studies such as future simulation of the behavior of water resources. The calibrated and validated information would provide knowledge to society and allow decision makers greater capacity for analysis. In this sense, the PMRMRH constitutes a proposal that will be validated and agreed with the actors and institutions involved in the monitoring of water resources.

### 2.1 Climatic stations network

The Table 2, show the climatological stations of the Rímac, Chillón, Lurín and Alto Mantaro basins, used for the diagnosis of the climatic stations network.

**Table 2**. Climátic stations of the Rímac, Chillón, Lurín and Alto Mantaro basins

| |
|---|
| Milloc, Yuracmayo, Casapalca, San_Jose_Parac, Rio_Blanco, Carampoma, Sheque, San_Mateo_Huanchor, Canchacalla, Matucana, Autisha, Santa_Eulalia, Chosica, VonHumbolt, Campo_Marte, Torococha, Pariacancha, Lachaqui, Huaros, Huamantanga, Canta, Obrajillo, Pte_Magdalena, Arahuay, Obrajillo, San_Lazaro_Escomarca, Langa, Antioquia, Yantac, Marcapomacocha, Yauli. |

According Rau (2016), based on the application of the regional vector technique, the climatic stations were classified into five groups.

This made it possible to obtain five climatic zones, each with the same precipitation regime. Figure 2 shows the regional vector for groups 2 to 5. The group 1 is formed by the Von Humbolt and Campo Marte stations.

 

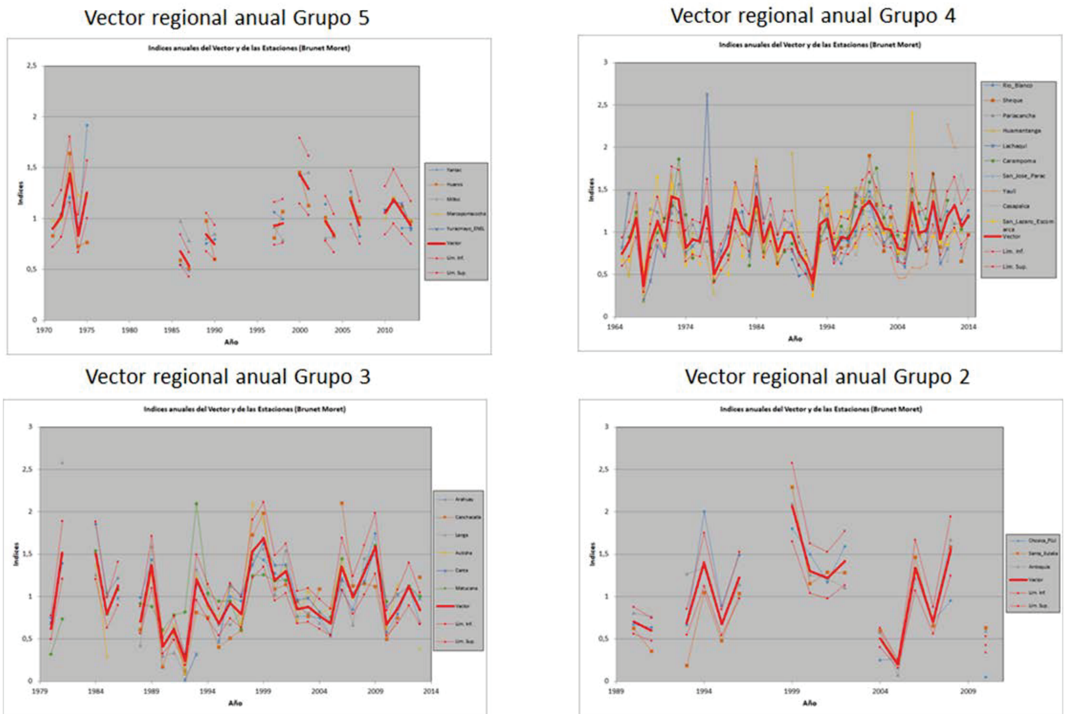


**Figure 2**. Regional anual vector analysis for the groups 2 to 5.

The following procedure consisted of making the Voronoi diagrams. Voronoi diagrams are one of the spatial interpolation methods, based on the Euclidean distance. They are created by joining the points together, drawing the perpendicular bisectors of the joining segment. The intersections of these perpendicular bisectors determine a series of polygons in a two-dimensional space around a set of control points, so that the perimeter of the generated polygons is equidistant from the neighboring points and designate their area of influence.

From the location points of the stations, circles of influence of the stations were drawn with diameters tangent to the farthest side within each polygon, as shown in figure 4. In the figure, the isolines of equal evapotranspiration déficit are presented, in order to corroborate the classification of the groups of stations, especially in the upper part of the Chillón, Rímac and Lurín basins and the sub-basins of the Alto Mantaro, during the wet months of the year.

Figure 3 shows, the Voronoi polygons generated for the rain gauge stations currently in operation and the circles of influence of the current and proposed rain gauge stations.

Based on the analysis of the information from the operational climatological stations (mainly pluviometric) and the proposals for the installation of climatological stations by the other institutions (PMGRH-ANA, the TRUST project, Servicio de Agua y Alcantarillado de Lima - SEDAPAL, Ente Nacional de EnergíaEléctrica - ENEL), the following climatological stations are proposed (Table 3).

**Table 3**. Proposal for climatological stations in the basins of the CHIRILU area

| Basins | Proposed climatological stations |
|---|---|
| Rímac | - New Station 1 (Lat.-11,468; Long.-76,479) |
| Alto Mantaro | - New Station 2 (Lat.-11,492; Long. -76,196) |
| | - New Station 3 (Lat.-11,19; Long. -76,411) |

 

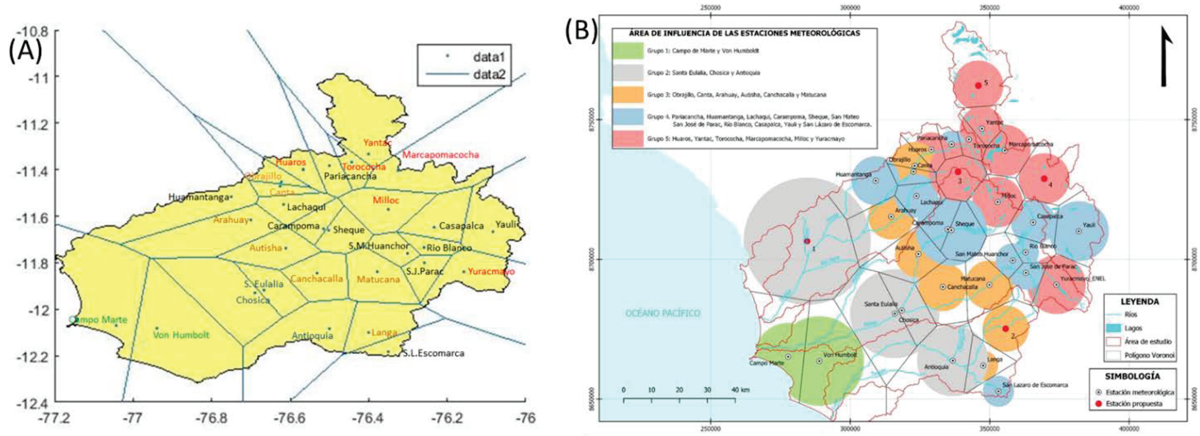


**Figure 3**. Area of influence of climatological stations in the CHIRILU basins. (A) Voronoi polygons for current operating rainfall stations, (B) Circles of influence of current operating stations and proposals

Figure 4 shows, the network of rain gauge in the CHIRILU basins, in operation, proposed and planned.

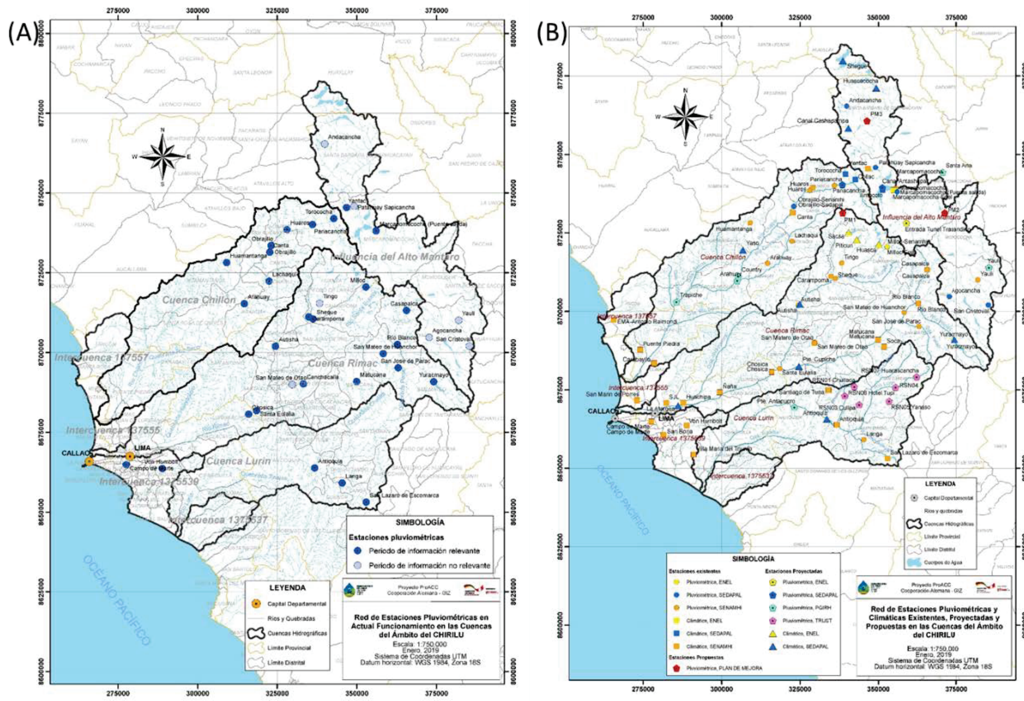


**Figure 4**. Network of rain gauge in the CHIRILU basins. (A) In operation, (B) In operation, proposed and planned

## 2.2Hydrological stations network

To carry out the analysis of the monitoring network of the hydrological stations, the percentage of surplus or deficit of runoff between a hydrological station and the corresponding one located downstream was calculated for each of the Chillón, Rímac and Lurín basins.

The proposed methodology is related to the methodology that the Servicio Nacional de Meteorología e Hidrología - SENAMHI has been developing for the design of hydrological networks (SENAMHI, 2013). The methodology is based on the Karasiev equation and starts by defining the units of the rivers and then calculates the difference between the flow of said stretch of river with another of the following order. If the difference is minimal, there is no need for a new station.

The following Table 4 indicates the hydrological or hydrological stations currently in operation located in the Rímac, Chillón, Lurín and Alto Mantaro basins.

**Table 4.** Hydrological stations located in the Rímac, Chillón, Lurín and Alto Mantaro basins

| |
|---|
| Agua Azul, Pte.Huarabi, Pte. Magdalena, Larancocha, Yipata CH-2, Obrajillo, Pariacancha, Pte.Huachipa, Pte. Los Angeles, Chacrasana, Huampaní, Yanacoto, Chosica, Santa Eulalia, Tamboraque, San Mateo, Río Blanco, Milloc, Sheque, Desembocadura L-1, Manchay, Pte. Antapucro, Cruz de Laya, San Damian, Río Pallanga |

Table 5 shows the multiannual mean flow of each station, the percentage of the difference in runoff volume and the comparison period given by the common period of information between stations.

**Table 5.** Multi-annual average flow of each station, the percentage of the difference in runoff volume and the comparison period given by the common period of information between stations (SENAMHI, 2015)

| Basins | Hydrological station | Mean flow. ($m^3$/s) | Difference runoff volume. (%) | Period |
|---|---|---|---|---|
| Chillón | Pariacancha | 2,458 | +50,8 | 01/01/1969 - 31/12/1977 |
| | Obrajillo | 5,000 | | |
| | Obrajillo | 2,983 | +23,1 | 01/10/1968 - 31/12/1969 |
| | Yipata | 3,882 | | |
| | Yipata | 3,882 | +20,5 | 01/10/1968 - 31/12/1969 |
| | Pte. Magdalena | 4,881 | | |
| | Pte. Magdalena (De enero a mayo) | 15,173 | -9,8 | 01/01/2014 - 31/12/2017 |
| | Agua Azul (De enero a mayo) | 13,688 | | |
| Rímac | Milloc | 7,028 | +53,6 | 01/01/2005 - 31/12/2017 |
| | Sheque | 14,348 | | |
| | Sheque | 15,641 | -91,8 | 01/01/2014 - 31/12/2017 |
| | Sta. Eulalia | 8,155 | | |
| | Rio Blanco | 2,895 | +78,5 | 01/01/1969 - 31/12/2017 |
| | San Mateo | 13,472 | | |
| | San Mateo | 15,034 | +5,2 | 01/01/2009 - 31/12/2017 |
| | Tamboraque | 15,853 | | |
| | Tamboraque | 14,652 | +54,5 | 01/01/2014 - 31/12/2017 |
| | Chosica | 32,204 | | |
| | Sta. Eulalia | 8,155 | +74,7 | 01/01/2014 - 31/12/2017 |
| | Chosica | 32,204 | | |
| | Chosica | 32,313 | -10,1 | 01/01/2012 - 31/12/2017 |
| | Huampani | 29,040 | | |
| Lurín | Antapucro | 2,303 | +65,6 | 01/10/1968 - 31/12/1969 |
| | Desembocadura | 6,690 | | |

Figure 5 shows, the river sections with the percentages of the difference in runoff volume.

As in the network of climatological stations, the Programa de Modernización de la Gestión de RecursosHídricos de la ANA - PMGRH, Autoridad Local del Agua CHIRILU - ALA CHIRILU, SENAMHI, SEDAPAL and ENEL, have proposed stations for the Chillón, Rímac, Lurín and Alto Mantaro basins, respectively.

Based on the analysis of the information from the operational hydrometric stations and the proposals for the installation of hydrometric stations by other institutions, the hydrological stations proposed by the Improvement Plan are shown in Table 6. Figure 6 shows the network of existing hydrological stations, projected and proposed in the basins of the CHIRILU and Alto Mantaro area.

 

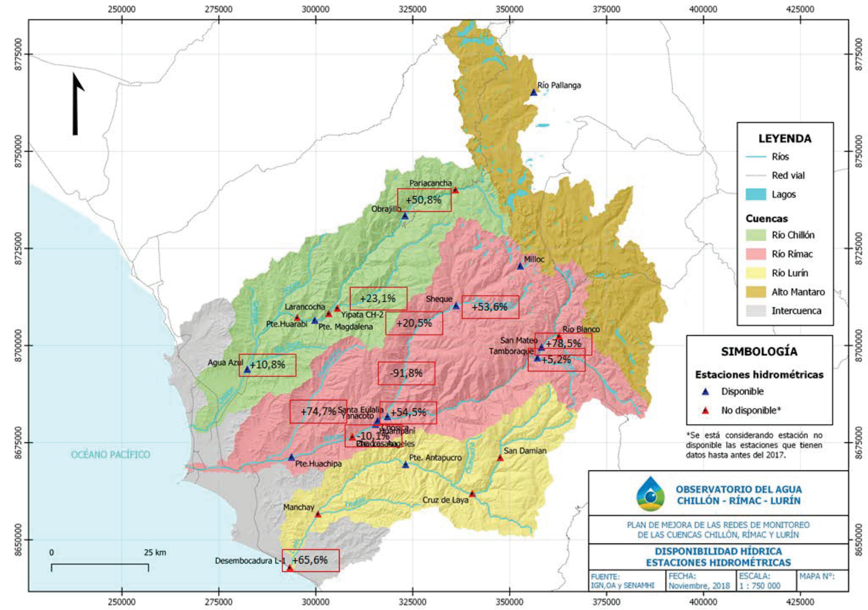


**Figure 5.** Reach of the Chillón, Rímac and Lurín rivers with the percentages of the difference in runoff volume.

**Table 6**. Proposal for hydrological stations in the basins of the CHIRILU area

| Basins | Proposed hydrological stations |
|---|---|
| Chillón | - New station at the mouth of the river (Lat. 11,96; Long. -77,13) |
| Rímac | - New station High Rímac (Lat.-11,73;Long.-76,27) |
| Lurín | - New station at the mouth of the river (Lat. 12,27; Long. -76,9) |
| | - New station Canchahuara (Lat.-12,10;Long.-76,46) |

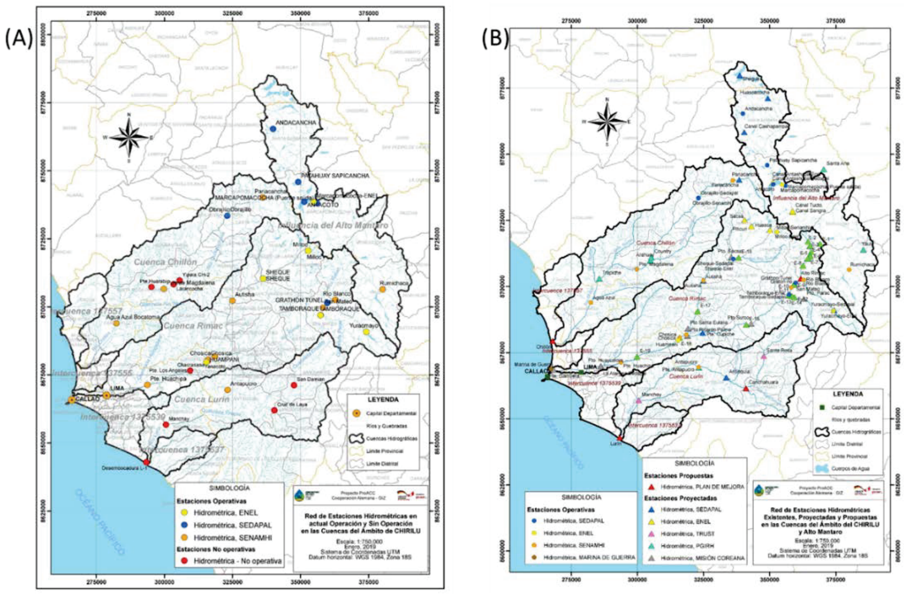


**Figure 6.** Network of flow gauge in the CHIRILU basins. (A) In operation and no operation, (B) In operation, proposed and planned

## 3. DIAGNOSIS OF THE PHYSICAL ASPECTS OF THE GROUNDWATER MONITORING NETWORK

According Díaz (2015), The aquifer reservoir of the Chillón and Rímac valleys is made up of alluvial deposits from the Quaternary (represented by boulders, gravel, sand and clay, interspersed in intermingled strata).
It has an approximate area of 390 $km^2$ and a usable saturated thickness of between 100 m. at 300 m The Chillón and Rímac aquifers are predominantly free, with the exception of the La Punta sector, which contains confinement containing good quality water.

The aquifer has a variable width, whose narrowest sectors correspond to the upper parts of the valleys, upstream from Vitarte (Rímac) and Punchauca (Chillón). In these locations, the alluvial deposits are approximately 1,5 km wide. The largest sector is found at the junction of the alluvial deposits of Rímac and Chillón, reaching 27 km (at the outlet of the underground flow to the sea).
The aquifer reservoir of the Lurín valley is represented by the Quaternary alluvial deposits of fluvio-alluvial origin, which are found in the eroded channel of the consolidated pre-quaternary rocks, which constitute the basement of the aquifer.
According to reports from the Water Observatory CHIRILU (OA-CHIRILU), the water table reaches 600 m in the highlands and less than 20 m along the coastal zone, whose flow is in the direction of the sea (Autoridad Nacional del Agua, 2018). The supply was estimated considering the entire area of the Chillón-Rímac and Lurín aquifers, with a minimum thickness of 10 m and the conservative assumption that the storage coefficient is 5% (SEDAPAL, 2014), obtaining a minimum reserve of 330,2 $hm^3$ (Chillón-Rímac) and 103,1 $hm^3$ (Lurín).
The exploitation of groundwater in the Chillón – Rímac and Lurín aquifers as of December 2017, is shown in the following Table 7. (Autoridad Nacional del Agua, 2016).

**Table 7**. Exploitation of groundwater with SEDAPAL and private wells in the Rímac, Chillón and Lurín aquifers in m3/s, as of December-2017

| Sources | Rímac - Chillón | Lurín | Total |
|---|---|---|---|
| SEDAPAL wellsandChilllón project | 3,78 | 0,38 | 4,16 |
| SEDAPAL filtration galleries | 0 | 0 | 0 |
| Private wells | 3,32 | 0,69 | 4,01 |
| TOTAL | 7,1 | 1,07 | 8,17 |

To carry out the analysis of the groundwater monitoring network, the actual inventory of wells was superimposed with the wells monitored during the year 2018. This superimposition was made on the coverage of geomorphology and geological faults.
It is worth mentioning that the groundwater monitoring network is carried out by SEDAPAL in the Chillón - Rímac and Lurín aquifers and by the AAA Cañete Fortaleza, only in the Lurín and Chillón aquifers.
Table 8 shows, the number of wells monitored during 2018. In said table, 'With data' is indicated: to wells monitored in 2018. 'Without data': to wells not monitored in 2018 but monitored in previous years.
During 2018, the Chillón aquifer was monitored between July and September (a single measurement per well). The Lurín aquifer was monitored in October (a single measurement per well) and the Rímac aquifer was monitored from January to October 2018.

**Table 8**. Wells in the network (Monitoring 2018)

| Institutions | Chillón | | | Rímac | | | Lurín | | | Total wells |
|---|---|---|---|---|---|---|---|---|---|---|
| | With data | Without data | SubTotal | With data | Without data | SubTotal | With data | Without data | SubTotal | |
| SEDAPAL | 84 | 14 | 98 | 19 | 218 | 237 | 22 | 2 | 24 | 359 |
| AAA* | 161 | 33 | 194 | | | | 154 | 63 | 217 | 411 |
| Total Chillón | | | 292 | Total Rímac | | 237 | Total Lurín | | 241 | 770 |

The methodology to propose the monitoring of additional wells was based on considering new monitoring points where the geomorphology changes and where there are geological faults that interrupt the continuity of the flow between wells.
As a result, it is proposed that Water Administrative Authority Cañete – Fortaleza (AAA Cañete – Fortaleza) and SEDAPAL monitor an additional 80 wells, in the following amounts (Table 9).

**Table 9**. Number of piezometric monitoring wells proposed for the AAA Cañete-Fortaleza and SEDAPAL by aquifer

| Aquifer | AAA Cañete - Fortaleza | SEDAPAL | Total |
|---|---|---|---|
| **Chillón** | 19 | 5 | 24 |
| **Rímac** | 27 | 12 | 39 |
| **Lurín** | 17 | | 17 |
| **Total** | 63 | 17 | 80 |

 

## 4. DIAGNOSIS OF THE PHYSICAL ASPECTS OF THE WATER QUALITY MONITORING NETWORK

### 4.1. Surface water quality

The evaluation of water quality was carried out based on the calculation of the water quality index (ICA-PE), a methodology approved by the National Water Authority - ANA. In this way, the status of the water quality of the Chillón, Rímac and Lurín rivers is evaluated based on 11 parameters measured by SEDAPAL and ANA.
The results of the ICA-PE for the three rivers are associated with the percentages of exceedance with respect to the Environmental Quality Standard (ECA) (MINAM, 2017).
The evaluation was carried out based on the results of 65 points obtained during the surface water quality monitoring campaigns carried out by SEDAPAL and ANA, from 2014 to 2018 and during the dry season and wet season.
As reported by the OA-CHIRILU, during 2016, the upper basin of the Rímac River presents regular quality with high levels of metals, mainly: arsenic, manganese, iron and lead. The Huaycoloro river has poor quality, due to high levels of BOD, phosphorus, arsenic, iron and thermotolerant coliforms.
Regarding the lower part of the Chillón river basin, the quality is poor, especially due to high levels of BOD, copper, lead and thermotolerant coliforms.
Finally, in the lower part of the Lurín river basin, the quality is poor since there is a high presence of thermotolerant coliforms; however, in the upper part the water quality is excellent.
The proposed stations and monitoring points for surface water quality are shown in Table 10.

**Table 10**. Proposal for stations and monitoring points for surface water quality

| Monitoring station | Monitoring point | Basin | East | Nort | Elevation (m) |
|---|---|---|---|---|---|
| CH_1_Est | | Chillón | 304952,0 | 8709788,7 | 1165,0 |
| CH_2_Est | | Chillón | 321729,7 | 8731020,7 | 2507,0 |
| CH_3_Est | | Chillón | 267968,3 | 8679532,9 | 14,0 |
| | RI1 | Rímac | 335775,0 | 8713623,0 | 3473,0 |
| | RI2 | Rímac | 324931,9 | 8702229,0 | 2144,0 |
| | RI3 | Rímac | 372067,0 | 8693719,0 | 4267,0 |
| | RI4 | Rímac | 328844,2 | 8682822,0 | 1275,0 |
| | RI5 | Rímac | 311943,4 | 8677995,0 | 759,0 |
| LU_1_Est | | Lurín | 293321,0 | 8642907,7 | 9,0 |
| | LU1 | Lurín | 345219,5 | 8664728,0 | 2283,0 |
| | LU2 | Lurín | 335636,7 | 8664191,0 | 1560,0 |

### 4.2.Groundwater quality

AccordingJousma (2004), the analysis of the groundwater quality monitoring network was carried out by superimposing the hydrogeochemical network monitored during 2018, the hydrogeochemical network monitored in 2015 with the piezometric monitoring network carried out in 2018.
Figure 7 shows, the network of proposed monitoring points for water quality. (A) Surface water and (B) Groundwater.

 

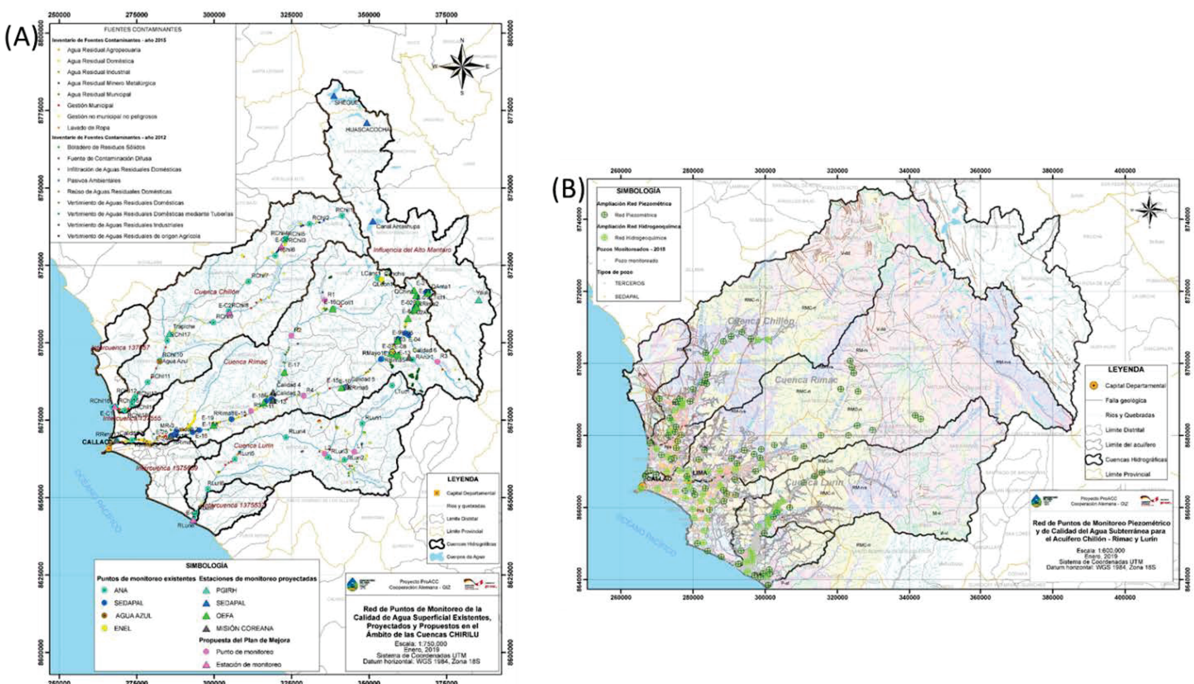


**Figure 7**. Network of water quality in the CHIRILU basins. (A) Surface water, (B) Groundwater

## 5. CONCLUSIONS

- It was proposed for the Peruvian Water National Authoruty a plan for the improvement of the water resources monitoring network in the Chillón, Rímac, Lurín and Alto Mantaro basins - PMRMRH-CHIRILU, validated and derived from the analysis of the lack of information and the specific proposals of the diagnosis of the situational state of the existing surface and underground water monitoring networks in the basins.
- Three new climatological stations, four hydrological stations, eighty piezometric monitoring wells and four surface water quality monitoring stations were proposed.
- The PMRMRH-CHIRILU, was validated by the institutions related to the management of water resources in the basins of the Chillón, Rímac and Lurín and Alto Mantaro – CHIRILU. Likewise, it considers the accessibility conditions and the feasibility of financing the installation and maintenance costs of the proposed stations.

## 6. RECOMMENDATIONS

- Overcome the limitations of the public institutions for the use of the GOES satellite transmission system in order to allow the exchange of information between public and private institutions.
- Prevent vandalism and theft of hydrological, climatological or water quality stations. Provide protection and carry out work to raise awareness among the population about the importance of having said information.
- Prevent the increase of marine intrusion in the lower parts of the Lurín and Chilca basins.
- Use the viewer of the Water Observatory (OA-CHIRILU), to show the critical situation of some aspects in order to inform decision makers at the level of the Central Government and Regional Governments.
- Involve in the PMRMRH – CHIRILU reuse waters and desalinated waters.
- Involve the academic sector for the generation of adaptation studies of the Water Resources Management of the CHIRILU basins to climate variability and change.
- Use isotopic analysis techniques such as the determination of 18O (Oxygen 18) and 2H (Deuterium), to specify the origin of the waters at any point in the basins.
- Involve the concept of citizen observatories in the monitoring network of the water resources of the CHIRILU basins.

## 7. ACKNOWLEDGEMENTS

Thank to the project ´Adaptation of Water Resources Management to Climate Change in Urban Areas with the Participation of the Private Sector' – PROACC (by acronyms in Spanish), promoted by the German Agency for International Cooperation - GIZ and the Peruvian National Water Authority –ANA.

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