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Articles

Municipal model evaluation for providing drinking water and sanitation services in a developing country

Evaluación de modelo municipal para la provisión de servicios de agua potable y saneamiento en un país en desarrollo

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Abstract

In this study, models for the provision of drinking water and sanitation services, were evaluated for the San Joaquin Municipality, Carabobo State, Venezuela, represented in the Municipal Autonomous Institute of Water of San Joaquin (IAGUASANJO, in Spanish) through three management indexes proposed in an integrated manner for drinking water and sanitation, a model index for the provision of drinking water services and model index for the provision of sanitation services. IAGUASANJO has oriented 65 % of the activities towards the provision of sanitation services and 35 % of the actions for the provision of the drinking water service in the period 2019-2023.

Keywords: Model index for the provision of sanitation services, model index for the provision of drinking water services, San Joaquin Municipal Autonomous Institute, drinking water and sanitation services, public services, public service management models.

Resumen

En este estudio se evaluaron modelos de prestación de servicios de agua potable y saneamiento para el municipio San Joaquín, estado Carabobo, Venezuela, representado en el Instituto Municipal Autónomo del Agua de San Joaquín (IAGUASANJO) a través de tres índices de gestión propuestos de manera integrada para agua potable y saneamiento, un índice modelo para la prestación de servicios de agua potable y un índice modelo para la prestación de servicios de saneamiento. IAGUASANJO ha orientado el 65 % de las actividades hacia la prestación de servicios de saneamiento y el 35 % de las acciones para la prestación del servicio de agua potable en el periodo 2019-2023.

Palabras clave: modelo de índice de prestación de servicios de saneamiento, modelo de índice de prestación de servicios de agua potable, Instituto Autónomo Municipal de San Joaquín, servicios de agua potable y saneamiento, servicios públicos, modelos de gestión de servicios público.

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Introduction

Since 1990, one of the main water sources used as a component within the drinking water supply systems to satisfy the needs of drinking water services (DWS) represented by the rivers in global regions such as Latin America, Asia and Africa have significantly increased their pollution (Tortajada, 2020). According to United Nations (UN, 2023), an important aspect is that for at least 3 billion people, the quality of the water they depend upon is indefinite due to an absence of monitoring, being one of the fundamentals of the construction base of the Sustainable Development Goals (SDGs), specifically in that related to the availability and sustainable management of DWSS for all (SDG 6) (UN, 2023).

In Venezuela, the contemporary advance of the DWSS initiated in in the 1940s with the creation of the National Institute of Sanitary Works (INOS, by its acronym in Spanish), when the Venezuelan government recognized the need to improve the supply of drinking water and the collection of wastewater as a transformation mechanism to overcome the serious technical and social impacts that its lack had on the health of the population (Peraza-Barreto *et al*, 2022). During the 1960s and 1970s, the DWSS had substantial financial funds that permitted INOS to construct most of the large water production, transportation, purification, and distribution systems in the country's main cities (Corrales, 2004). During the 1970s and 1980s, INOS concentrated its efforts on the construction of large works (mainly reservoirs), giving lower priority to the maintenance and rehabilitation of the DWSS networks and to the efficiency in the operation and commercialization of the DWSS (Corrales, 2004; Peraza *et al*., 2021; Peraza-Barreto *et al*., 2022; Lugo *et al*., 2023). At the beginning of 1990, the government proceeded to create a new institutional arrangement for the DWSS operation, which consisted of the creation of a central company (HIDROVEN) and ten regional hydrological companies on a temporary basis until such time as the transfer to municipal authorities (Huguet-Sierra, Márquez-Romance, Guevara-Pérez, Pérez-Pacheco, & Buroz-Castillo, 2023a; Huguet-Sierra, Márquez-Romance, Guevara-Pérez, Pérez-Pacheco, & Buroz-Castillo, 2023b). In the period between 2000 and 2010, the new government approved a new legal framework that would provide stability and security to the transfer process from regional companies to the municipal governments, as well as to the community participation (Corrales, 2004; Corrales, 2008).

In this study, the experiences of DWSS management model in the San Joaquin Municipality (SJM), Carabobo State (CS), which is made up of direct-complex public management represented by the San Joaquin Water Autonomous Municipal Institute (IAGUASANJO, in Spanish) affiliated to the SJM-CS mayor's office, and the Central Hydrological Company (HIDROCENTRO) belonging to Hydrological Company of Venezuela (HIDROVEN, in Spanish). The institutional reform is based on the horizontal structure of the DWSS industry, where the processes of capture, storage in artificial water reservoirs, treatment and distribution of the drinking water obtained from the water surface source as well as the collection and treatment of the wastewaters are performed by the regional company (HIDROCENTRO) and IAGUASANJO is complying a type of joint work to rehabilitate, maintain, extend the DWSS, with a special emphasis in a sustainable use of the SJM-CS aquifer as a water source to satisfy the need of an important fraction of the inhabitants within the SJM-CS, all these actions within the frame of the municipal transferring process from regional company to the municipal institution in compliance with the

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national DWSS regulation (Peraza *et al*., 2021; Peraza-Barreto *et al*., 2022; Lugo *et al*., 2023).

Based on the foregoing, the objectives of this research are: i) to identify the institutional arrangement of the companies providing DWSS in the SJM-CS ii) to analyze the DWSS provision models in the SJM-CS, iii) to establish the management model of the DWSS in SJM-CS, iv) to create the DWSS provision model indexes in the SJM-CS. The creation of new DWSS provision indexes in the SJM-CS will involve to estimate to three management indexes, including an integrated index for drinking water and sanitation services, a model index for the provision of drinking water services and a model index for the provision of sanitation services.

Methods

Study area

Study area comprises San Joaquin municipality within the Carabobo state (SJM-CS), located at the central-northern region of the Bolivarian Republic of Venezuela, whose geographic coordinates involve, latitude between N 10º14’00” and N 10º21’30”, longitude between W 67º43’00” and W 67º52’00”, which encompasses a total area of 130.75 km^2 (Figure A1). The land use and land cover (LULC) distribution are the followings (Figure A1): 1) vegetation: 49.16 km^2 (37.6 %), 2) urban: 13.21 km^2 (10.11 %), 3) natural soil: 62.41 km^2 (47.73 %), agricultural: 1.94 km^2 (1.49 %) and water bodies 4.01 km^2 (3.07 %). LULCs were obtained using the supervised classification technique from the software ENVI V 4.7 (license: 9F3GP-B8TB6-9F7MT-FP8P4-94W92) and the software ArcGIS V

10.0 (license: 37105865) (Márquez, Guevara, & Rey, 2019a; Márquez-Romance, Farías-de-Márquez, & Guevara-Pérez, 2022a).

Phases of the investigation

Identification of the institutional arrangement of the companies providing DWSS in the SJM-CS

The institutional arrangement for the provision of DWSS in the SJM-CS has legal fundamentals mainly in three laws: 1) Organic law for the Provision of the Drinking Water and Sanitation Services (OLPDWSS) (National Assembly of the Bolivarian Republic of Venezuela, 2001); 2) Law of Partial Reform of the Organic Law for the Provision of Drinking Water and Sanitation Services (National Assembly of the Bolivarian Republic of Venezuela, 2007b), and 3) Ordinance of the San Joaquin Water Municipal Autonomous Institute (Municipal Gazette No. 4664, 2020), created by Municipal Council according to the extraordinary edition Nº 4664.

Analysis of DWSS provision models in the SJM-CS

The depth of the changes carried out in the San Joaquin Municipality due to the creation of the IAGUASANJO incorporates aspects such as the technical and organizational restructuring of the DWSS, the development of markets, the creation of a new legal framework, the elimination of some public organizations and the creation of new decision-making bodies, the redistribution of power centers and the reduction and retraining of personnel.

Establishment of the management models of the DWSS in SJM-CS

Establishment of the DWSS management model in the SJM-CS is a combination of a mixed public administration (direct and delegate) with the participation of private organizations, which will be analyzed in its components, reflecting advantages and disadvantages. The selection has sought to guarantee collective well-being in terms of universal access to the service, at low cost and of the quality necessary to preserve and maintain public health.

The evaluation of the DWSS provision models involved the description of the performance of two providers, one at the municipal level represented by IAGUASANJO and the comparison with other providers in terms of regulation, coverage and quality, as well as the activities of DWSS management in the SJM-CS. two variables were considered within the management model in the SJM-CS (Peraza *et al.*, 2021):

1. Comparison of the institutional regulation of the DWSS in the SJM-CS: which was based on the Partial Reform Law of the Organic Law for the Provision of Drinking Water and Sanitation Services (National Assembly of the Bolivarian Republic of Venezuela, 2007a) and the ordinance for the creation of the San Joaquín Municipal Water Institute (IAGUASANJO) by the Municipal Council of San Joaquín in the extraordinary edition No. 4664 dated July 14, 2020 (Municipal Gazette No. 4664, 2020).

2. Comparison of DWSS coverage in the SJM-CS, which was based on the graphical representation of the following five DWSS management variables:

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a) Comparison of the social and operational variables of the DWSS in the SJM-CS: recorded by the National Institute of Statistics (INE) of Venezuela (INE, 2011), obtained from the census carried out in 2011 in the SJM-CS, and represented using the MATLAB software, whose license is associated with the Hydrological and Environmental Research Center of the University of Carabobo (CIHAM –UC).

b) Comparison of the records of water production from underground sources in the SJM-CS: the information on the production of underground sources in the SJM-CS was obtained from IAGUASANJO, HIDROCENTRO, the Ministry of Environment and Natural Resources (MARN), as well as the undergraduate and master's theses of the UC assisted by CIHAM - UC such as Márquez, Guevara and Rey (2019b); Márquez and Carrillo (2015), and Márquez and Peraza (2018).

c) Comparison of the hydrogeochemical variables of the underground sources in the SJM-CS, which was extracted from the databases used in Márquez, Guevara, Pérez and Rey (2020); Márquez *et al*. (2019a); Márquez *et al*. (2019b); Márquez, Guevara, and Rey (2018), and from a study of six wells of communal councils and the Mayor's Office managed by IAGUASANJO, whose sampling and analysis was carried out by the laboratory accredited by the Ministry of Ecosocialism and Water (MINEA), HIDROLAB-TORO in the present year 2021 (HIDROLABTORO &IAGUASANJO, 2021.

d) Comparison of evolutionary records of the provision of SAPS from 1950 to the present. It was obtained from reports from the Central Office of Statistics and Informatics (OCEI, 1996), INE (2001), HIDROVEN-CAF (2002) and Corrales (2004).

e) Comparison of the management variables of the Public Works Directorate of the SJM-CS and IAGUASANJO: it was obtained from the presidency of IAGUASANJO (IAGUASANJO, 2021). These variables have been requested based on those observed from the international courses on commercial management for water, drainage and sanitation operating organizations (Water Center for Latin America and the Caribbean-Tecnológico de Monterrey (Centro del Agua para América Latina y el Caribe, 2012), hydrogeology (CODIA & AECID, 2012) and policies on the sustainable use of water and the efficient provision of related public services (CEPAL, 2009).

Creation of DWSS provision model indexes in the SJM-CS

For the model for the provision of drinking water and sanitation services (MPDWSS): the estimation of three indexes of the model for the provision of drinking water and sanitation services (IMPSAPS) is proposed, discriminated by the activities provided in water services drinking water (IMPSAP) and sanitation service delivery model index (IMPSS) at the municipal scale based on the activities carried out by the Public Works Department of the San Joaquín Municipality and the San Joaquín Municipal Water Institute (IAGUASANJO) during the period 2019-2021. The index is formulated according to the procedure applied by López, Márquez-Romance, and Guevara-Pérez (2020); López-Calatayud, Márquez-Romance, and Guevara-Pérez (2022c); López-Calatayud, Márquez-Romance, Guevara-Pérez, Pérez-Pacheco and Buroz-Castillo (2023) for the design of the tropical wetland management model.

The method consists of the definition, formulation and elaboration of an integrated multi-criteria matrix (MCM), which characterizes a group of procedures hypothetically capable of refining the transparency, auditability and systematic consistency of these decisions (Dunning, Ross, & Merkhofer, 2000). MCM can be defined as a decision model which contains (Hajkowicz & Collins, 2007; López-Calatayud *et al*., 2023; López *et al*., 2020; López-Calatayud, Márquez-Romance, & Guevara-Pérez, 2021; López-Calatayud, Márquez-Romance, & Guevara-Pérez 2022a; López-Calatayud, Márquez-Romance, Guevara-Pérez, & Buroz-Castillo, 2022b; Márquez-Romance, & Guevara-Pérez 2022a): 1) a set of decision options which need to be categorized or scored by the decision maker; 2) a set of criteria, typically measured in different units; and 3) a set of performance measures, which are the raw scores for each decision option against each criterion. The MCM model is represented by an evaluation matrix X of n decision options and m criteria or variables. The raw performance score for decision option *i* with respect to criterion j is denoted by $x(i,j)$. A minimum requirement for the MCM is to contain at least two criteria and two decision options (n ≥ 2 and m ≥ 2). The importance of each criterion is generally given in the vector of dimensional weights W containing m weights, where *wj* denotes the weight assigned to the *jth* criterion (Hajkowicz & Collins, 2007). The MCM is defined with two (2) components associated with the activities carried out in drinking water and sanitation services, respectively; and it is composed of two commonly applied value functions (Hajkowicz & Collins, 2007), which are weighted addition and weighted multiplication. The weighted sum model is often expressed as (López-Calatayud *et al*., 2022a):

$$u_i = f(X, W) = \sum_{j=1}^{m} x_{i,j} w_j \qquad (1)$$

The weights (w_j) are non-negative and add to 1, and $x\,(i,j)$ is a performance score transformed to a scale from 0 to 1 where 1 represents the best performance. The general performance score for each option is given by u_i, according to the management model of each country and criteria or variables that are measured by the attributes j.

Results and discussion

Identification of the institutional arrangement of the companies providing DWSS in the SJM-CS

Institutional arrangement for the provision of services during the period 1950-1990

The current institutional arrangement of the DWSS sector began in Venezuela in the 1940s, with the creation of the National Institute of Sanitary Works (INOS, by its acronym in Spanish) for the year 1943. Venezuelan government recognized the need to improve the supply of drinking water and the collection of wastewater as a vehicle to overcome the serious impacts that its lack had on the population's health. The effort made by the country in this matter was particularly notorious during the fifties, sixties and seventies, and achieved greater success in the supply of drinking water than in the collection of effluents. The process was characterized by two fundamental factors. The first factor involved a planning and service management model predominantly centralized in INOS, financed from the national budget, which allowed to rise the coverage by extending drinking water networks to almost the entire national territory. The second factor was associated with a sectorial

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strategy that gave priority to health and social solidarity purposes, minimizing the quality of the DWSS and the economic efficiency of the provision (Corrales, 2000).

The evolution in the DWSS coverage for Venezuela during the period from 1950 to 1990, can be observed in Figure A2, the first quartile is representing the augmentation in the DWSS provision close to 20 %. Total drinking water services (Aqueduct, Public Fountain, and Truck) climbed from 49.2 to 71.7 % from 1950 to 1961, having changed the DWS coverage associated only to the aqueduct from 25.4 % to 46.1 %. In the same manner, the total sanitary services (TSS) coverage (sewer, septic tank, and latrine) rose from 40.5 to 62.4 % (Figure A2), corresponding to those only associated to the sewer, to a change from 16.5 % to 27.4 %. During the fifties, the largest historical percentage of the gross domestic product (GDP) was dedicated to investment in infrastructure. For the years 1956-1958, the economy's effort amounts to 10 % and per capita investment is at levels close to US$ 90 per inhabitant, at constant 1957 prices (Corrales, 2008).

For the years 1961 and 1971, the census showed increases mostly focused in the construction of the aqueduct and sewerage network, reaching coverage for DWS of 46 and 72.4 %, as well as for SS of 27.43 % and 40.3 %, respectively. For the last two decades in the period 1950-1990, the investment in the creation of the DWSS was decreased and the results indicated lower growth progression of approximately, for DWS (aqueduct) of 6 and 4 %, respectively; while for SS (sewer), of 16 % and 8 %, respectively (Figure A2). The results obtained were also similar to those of other countries in the region. Starting in the 1980s, the impossibility of supporting the sector using public budgets became evident, a process of constant deterioration of quality and coverage indicators began, and the development and centralized model of service delivery collapsed, product of the low efficiency and prevalence of individual interests in generalized corruption of the operating institutions.

Institutional arrangement for the provision of services during the period 1990-current time

Starting in 1989, a restructuring process of the Venezuelan public sector began, which included the comprehensive restructuring of the DWSS. The basic principles of this process were: 1) to recover and improve the quality of services, b) to decentralize services and return powers to municipal governments, c) to progressively achieve operational and financial autonomy of the service, d) to promote a modern regulatory framework that would give it stability and encourage the participation of private agents. In 1991, the INOS liquidation process began, which was legally consolidated with the Law to abolish the Institute approved in 1994. For the DWSS provision, a transitory scheme was installed until the process of transferring powers to municipal authorities. This scheme was made up of ten regional hydrological companies (RHC) (Figure 1), responsible for the operation of the systems and the DWSS provision throughout the country. The Hydrological Company of Venezuela (HIDROVEN, by its acronym in Spanish) was established as a parent company without operational functions (Figure 1), responsible for sectorial planning, coordination of the decentralization program, regulation and control of the RHC, as well as the promotion and search for resources for sectorial investments.

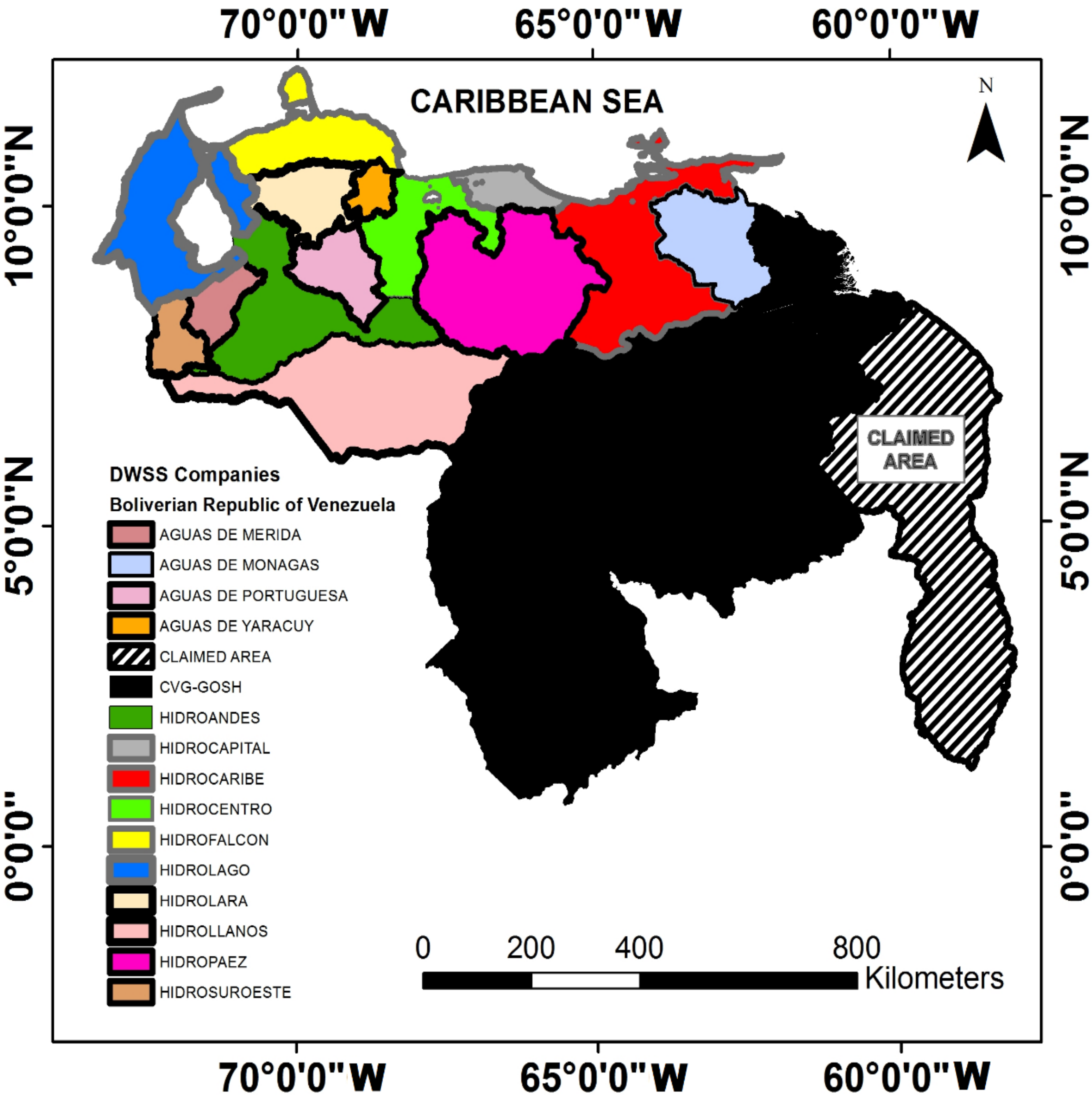

Figure 1. Spatial distribution of the hydrological companies for drinking water and sanitary services (DWSS) affiliated to Hydrological Company for Venezuela (HIDROVEN by its acronym in Spanish) and decentralized companies in the Bolivarian Republic of Venezuela founded in the period 1990-1991. Adapted from Corrales (2004).

During the period 1991-1998, within the framework of the consolidation of transitory structures, five decentralized companies (Aguas de Mérida, Aguas de Monagas, HIDROLARA, Aguas de Portuguesa, and Aguas de Yaracuy) were created (Figure 1), with the participation of the respective governments and municipalities, to which DWSS were transferred The incorporation of private operators was carried out under the creation of contracts under the modality of integral management, which promoted the consolidation of the companies HIDROLARA and Aguas de Monagas in the period 1991-1998 and of the Company HIDROLAGO in the subsequent period 1999-2002 (Corrales, 2008). The integral management, it is a type of public indirect management, in which the integral management of the service is contracted to a private operator. The remuneration of the company, in general, is associated with improvements in operating efficiency. Contract terms are generally set at five years. Due to contracting terms, there is a risk that short-term solutions are preferred over long-term ones (Corrales, 2000).

Starting in 1999 with the arrival of the new government, the importance was placed on the approval of a new legal framework that would sanction the process to be convened stability and security. On December 31, 2001, the Organic Law for the Provision of Drinking Water and Sanitation Services (OLPDWSS) (National Assembly of the Bolivarian Republic of Venezuela, 2001) was approved, which constituted the legal framework that ordered the DWSS provision in the country.

According to the OLPDWSS's article 134, it was established that the Venezuelan Hydrological Limited Company (HIDROVEN) would be the responsible body, throughout the national territory, for the transfer of DWSS provided by the National Executive Power to the metropolitan

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districts or municipalities, whose action might not last more than five (5) years from the OLPDWSS publication. As it is indicated in the National Assembly of The Bolivarian Republic of Venezuela (2001), until the transfer occurs, the entities that currently provide the DWSS would continue to do so under the supervision of the HIDROVEN.

At the present, the national map that shows the DWSS operators for the end of 1998 and the beginning of 1999 (Figure 1), has remained without significant changes. Despite this transfer effort, approximately 80 % of the national population continues being served by HIDROVEN and its affiliated companies, due to the fact that the reversion process has not been focused on the regions that concentrated the large cities from the country.

According to the population census for the year 1990, the DWSS coverage in Venezuela was categorized related to the social stratum (Figure A3). For DWS using aqueduct network, the formal area of the city (FAC) included to those types of housing infrastructures associated to country houses, houses, apartments, and tenement houses, in which the coverage reached 87.1 %, whose informal settlements —ranches— within the city (ICS) were supplied until 48 %, while those placed in the rural areas as features of peasant ranches (RIS), were attended in approximately 28.3 %. The industrial states of the country resulted with high DWS coverage (FAC, ICS, RIS), being FAC from medium to high levels including (Figure A3a), Capital District (92.1, 64.9, and 41.8 %), Carabobo (86.3, 42.5 and 28.3 %), Aragua (89.8, 44.4 and 36.2 %) and Miranda (90.8, 52.4 and 41.8 %), while the situation seemed to be suitable in Delta Amacuro (80.3, 5.9 and 10.9 %). The situation of greatest demand of DWS coverage might be associated to the states located at the south of the country with a DWS coverage between low and

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medium levels such as Apure (69, 34 and 6 %) and Amazonas (76, 38.2, and 20.6 %). With regard to SS for 1990, a similar pattern was found with coverage values in the industrial states that corresponded to high for FAC and low to medium for ICS and RIS, reaching low to medium values in the states mostly placed at the south of the country and also traditionally poorest (Figure A3b). For the year 2001, the industrial states rose in a significant way their DWSS coverage, especially in the ICS obtaining around 20 %, at the same time, a slower process was developing in the states at the south of the country (Figures A3c- A3d).

The differences found in the percentage of the DWSS coverage in Venezuela between the decade of the 1980s and the starting of the decade of the 2000s, consolidates a tendency to reduce investment in infrastructure. The average effort in the eighties does not exceed 2.5 % of annual GDP, while in the nineties it barely exceeds 1.5 %, a figure that does not even assure the amounts necessary for the maintenance and adaptation of the existing infrastructure. For the years 2000 and 2001, according to estimates based on the Central Bank of Venezuela (BCV, 2002), the percentage of GDP assigned to investment in infrastructure remained close to these same levels (1.4 % for 2000 and 1.7 % for the 2001). The irregular evolution of the effort made only magnifies the deviations that occur in economic development, which deteriorates at levels that are close to stagnation (Corrales, 2008). Despite the reduction in the infrastructure investment and GDP experienced during the period 1990-2001 discussed above, the transformation in the institutional arrangement had a positive effect over the DWSS coverage maintaining a permanent increase influenced mainly by the socio-economic status of the involved states at national scale, concentrating the greatest increase

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to those states located in the central-northern region of Venezuela (Figure A3).

The population assisted by the hydrological companies for DWSS affiliated to HIDROVEN and decentralized companies in the Bolivarian Republic of Venezuela recorded in the XIII population census of 2001 (INE, 2001) is shown in Figure A4, where it is observed that the highest concentration of population has corresponded with the absolute frequency related to the amount of inhabitants (2 382 560-4 465 267) linked to the industrial states located mainly at the central-northern region of the country (Miranda, Aragua, Carabobo, Cojedes, Zulia). This scenario is due to the fact that Caracas, Valencia, Maracay and the other cities and municipalities connected by highways of the first order and the main seaports of the Capital and Central regions (Federal District and the States of Miranda, Aragua and Carabobo), where precisely the 70 % of the municipalities is located with more than 2 500 employees. The location of these establishments depends on the existence of population centers, hence the location of the industry is closely related to the presence of large urban centers (Gómez, 1997; Lucena & Álvarez, 2011). According to the values of the Central Office of Statistics and Information (OCEI) and dates from the year 1994 (OCEI, 1996), the largest number of jobs and production matched with the capital region (155 572; 3619 million USD) and central region (141 692; 6447 million USD), closely followed by Central-Western, Zulia and Guayana regions.

At national scale, the evolution of the DWS and SS coverage during the period 1994-2002 can be seen in Figure A5 and Figure A6, and Figure A7 and Figure A8, respectively. With respect to the affiliated companies to HIDROVEN and decentralized companies, it is observed that there was permanent and consistent spatial distribution pattern being the highest

DWSS coverage associated to the companies of the central-northern region of the country (HIDROCAPITAL, HIDROCENTRO), and in sequence with the level of the coverage supplied to the state of the country, the order would involve to the north-western companies (HIDROFALCON, HIDROLAGO, Hidrosuroeste Aguas de Yaracuy), the north-eastern companies (HIDROCARIBE, HIDROPAEZ) and the southern companies (HIDROLLANOS). Mostly, the decentralized companies were created and their functions executed at the end of the period 1993-1994 (Figures A5h-A5f, Figures A7f-A7h), which include Aguas de Mérida, Aguas de Portuguesa, Hidrolara. Figure A6 shows that the decentralized companies (HIDROLARA, Aguas de Yaracuy, Aguas de Portuguesa, Aguas de Monagas) arose in the analyzed period and promptly achieved DWS coverage levels equivalent to those of the affiliated companies of HIDROVEN in the central-northern region of Venezuela, which represented occurrence frequencies to more than 80-90 % in the provision of DWS. The lowest coverage in DWS is associated to the HIDROLLANOS performance, however an increase was observed from 40 to 70 %, finding the fraction of the values linked to the DWS coverage that occurred between the 25 to the 50 % of time positioned from 55 to 65 % of coverage for those regions of the country (Figure A8) With respect to the SS. Figure A8 shows that with high frequency the SS coverage values occurred between 25 and 50 % of time in the interval from 50 to 65 % for the companies north-western, north-eastern and south region of the country, the highest and the lowest coverage in SS is attributed to central-northern region (HIDROCENTRO, HIDROCAPITAl, HIDROCARIBE) and the south region (HIDROLLANOS), respectively.

The results obtained in the adaptation period related to the years 1994-2002 associated to the transformation in the institutional arrangement, transiting from INOS, as a centralized body for the management of the DWSS provision in the country, to the companies affiliated with HIDROVEN and the decentralized companies, were effective and brought relatively rapid increases in the DWSS coverage that could be observed in the period 1994-2002 (Figures A7-A10), at least in the formal area in the cities using mainly pipe network systems for aqueduct and sewer in both, the complex direct public management model (HIDROVEN) and indirect public management model (decentralized companies). According to Corrales (2000), experience has shown that the transition from one model to another is slow and complex. It is possible that some of the changes proposed in the property regime or in the legal framework can be brought forward rapidly, while the changes associated with behavior or institutional development processes present serious lags.

The operating expenses coverage (Figure A10), by HIDROVEN and its ten affiliated companies achieved to reach values from 40 to 90 %, which show a significant effort to overcome the pattern of dependence on transfers from the Central Government to cover the operating expenses of the service. However, there is still an absolute dependence on the sector to meet its investment needs for rehabilitation and expansion of the systems (Corrales, 2004).

Institutional arrangement for the DWSS provision for the municipal government since 2020, with emphasis in the experience of the creation and operation of the San Joaquin Water Autonomous Municipal Institute, Carabobo state, Venezuela

In Venezuela, at municipal scale, currently there are only two municipalities corresponding to Guacara and San Joaquin, located in the Carabobo state, that have created and implemented water autonomous municipal institutes of public property, named as Guacara Water Municipal Autonomus Institute (IMAGUA, by its acronym in Spanish) (Figure 2) operating since 2019 (Reyes & Márquez, 2019) and San Joaquin Water Autonomus Municipal Institute (IAGUASANJO) (Figure 2), belonging to San Joaquin Municipality (Peraza *et al*., 2021; Peraza-Barreto *et al*., 2022; Lugo *et al*., 2023). These two municipal institutes have been performing functions of DWSS provision within the region covered by one of the ten affiliated companies of HIDROVEN company, known as Central Hydrological Company (HIDROCENTRO) (Figure 2), in compliance with what is established in Article 2 of the Partial Reform Law of the Organic Law for the Provision of Potable Water and Sanitation Services (National Assembly of the Bolivarian Republic of Venezuela, 2007a).

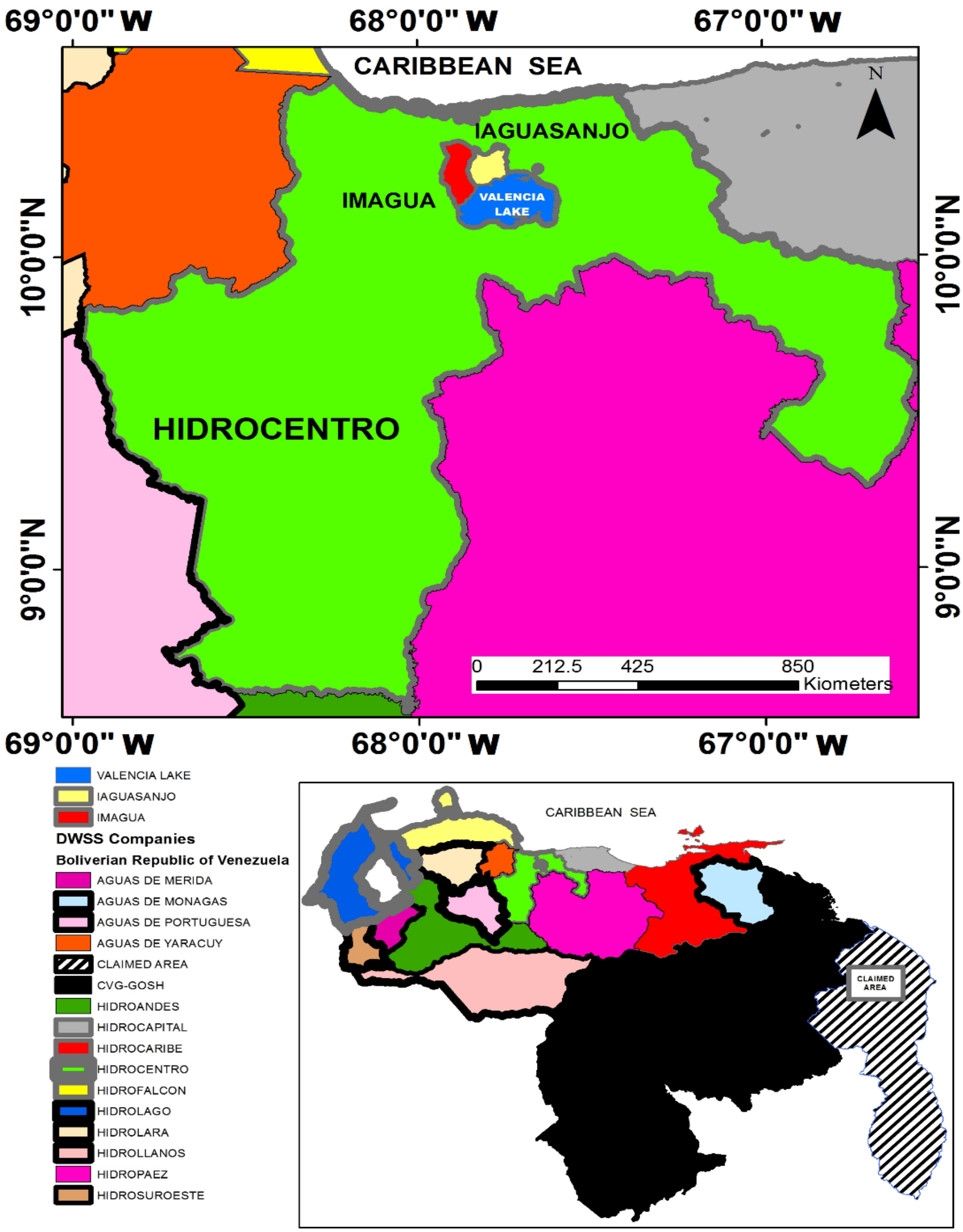

Figure 2. Water Municipal Autonomous Institutes located in the Carabobo state, Bolivarian Republic of Venezuela.

IAGUASANJO (Figures A1, 2), was created according to the Ordinance, published in the Municipal Gazette, Year XXXI, San Joaquin, July 14th, 2020, Extraordinary Edition No. 4664, whose powers encompasses the construction, rehabilitation and maintenance of sewage collectors; construction and rehabilitation of aqueduct networks, predictive, preventive and corrective maintenance of deep wells for drinking water, registration of deep wells for drinking water, treatment plants and pumping stations of wastewater, registry of users of deep wells administered by the municipality, as well as, the comprehensive management of water resources in the SJM-CS (Peraza *et al*., 2021; Peraza-Barreto *et al*., 2022; Lugo *et al*., 2023).

In Figure 3 it is observed the management model for the drinking water and sanitation services in SJM-CS, which has been configured according to that established in the OLPDWSS, the municipal management model for the DWSS provision in SJM-CS is a direct-complex public management model by two public institutions, in which the actions of two public institutions coexist represented by the municipal government (IAGUASANJO) and the regional company (HIDROCENTRO) (Peraza *et al*., 2021; Peraza-Barreto *et al*., 2022; Lugo *et al*., 2023). According to Corrales (2000), under direct-complex public management, the DWSS is provided through a publicly owned autonomous company or institute, in which the investments are partially or totally financed by the company, and there is a strong tendency to resort to financing from public funds. In agreement with EUREAU (2020), within the European countries, only England and Wales, United Kingdom, implemented a modernization program that led to privatization with the transfer of ownership of all previously public water companies.

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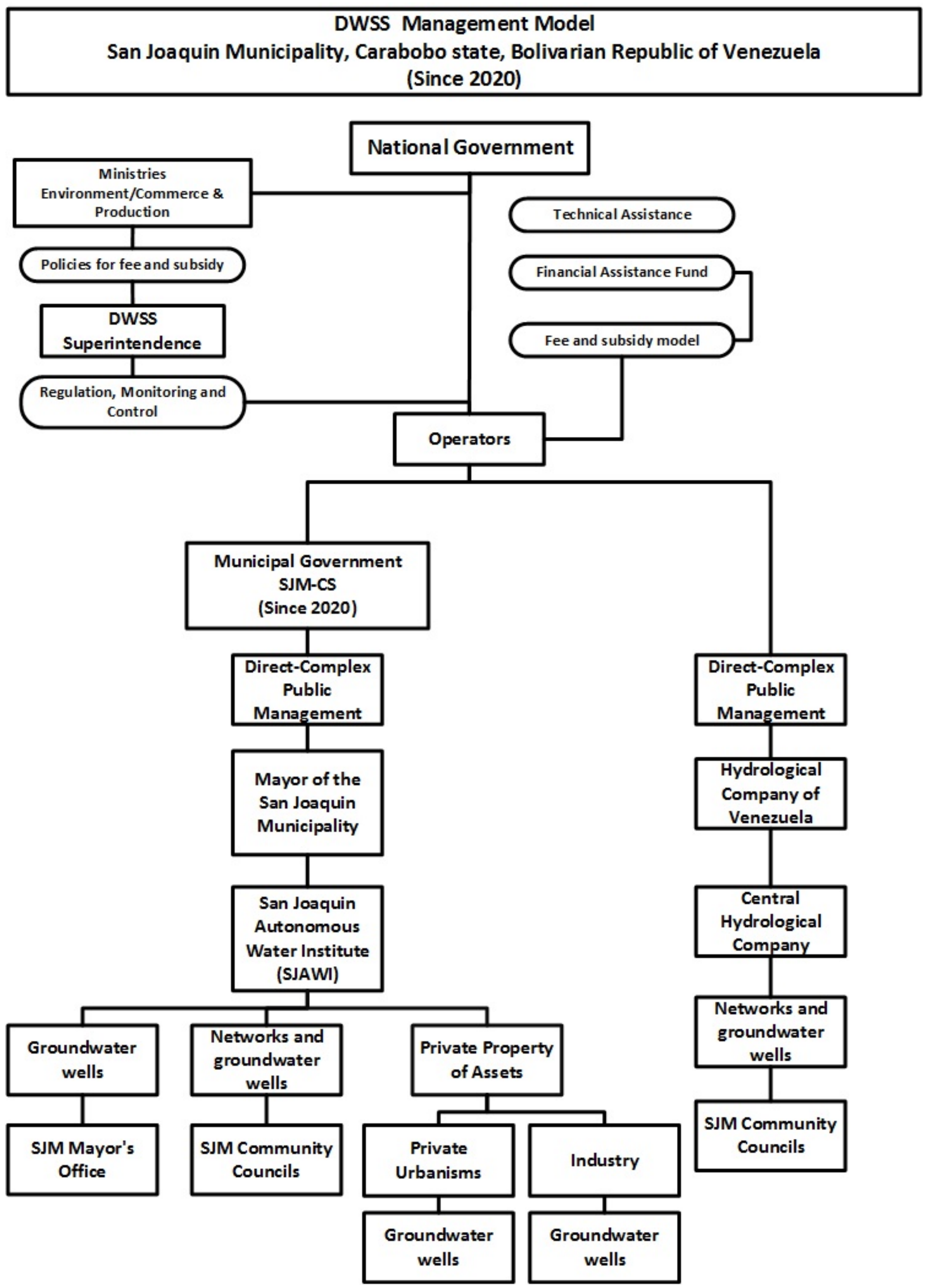

Figure 3. Model for management of the drinking and sanitation services (DWSS) in San Joaquin Municipality, Carabobo state (SJM-CS), Bolivarian Republic of Venezuela according to the Organic Law for the Provision of Drinking and Sanitation Services (National Assembly of the Bolivarian Republic of Venezuela, 2001).

Analysis of DWSS provision models in the SJM-CS

According to the Ordinance (article 11) (Municipal Gazette No. 4664, 2020), IAGUASANJO has powers in the control, supervision, inspection of the use of drinking water and private systems, either individuals or groups, of collection, treatment and disposal of wastewater, in those areas where the Central Hydrological Company (HIDROCENTRO) has not developed any type of system in relation to the DWSS provision. From its creation, IAGUASANJO is carrying out its DWSS management characterized in assuring efficient levels of DWSS coverage, with special emphasis to guarantee for the DWS, a high performance in terms of continuity, pressure and water quality. In addition, IAGUASANJO is part of work team within pilot projects for applying in situ an ex situ bioremediation techniques in an aquifer contaminated with hydrocarbons (Márquez *et al*., 2023; Márquez-Romance, López-Calatayud, Farías-De-Márquez, & Guevara-Pérez, 2022b; Márquez-Romance, Freytez-Boggio, Cárdenas-Izaguirre, Maldonado-Maldonado, 2022c), as well as for the water quality restoration in rivers the Carabobo and Aragua states, in which Ereigüe river, one of the main surface streams in the SJM-CS is included, using ex situ and in situ bioremediation techniques in order to contribute to protect the water sources within the municipality (Márquez-Romance *et al*., 2023). These criteria are in agreement with the fundamentals of SDGs (UN, 2023), which by being compared with MDGs, the SDGs are more ambitious, exceeding the goal of increasing coverage with "improved water sources" and "improved sanitation solutions", adding considerations of service quality and affordability, ensuring (surface or underground) sources of water, which implies advancing in the protection of ecosystems.

Water quality from the groundwater in the SJM-CS aquifer

Water quality of the groundwater in the aquifer of SJM-CS used for human consumption and agricultural activities, has been evaluated by the Ministry of Ecosocialism (MINEC & IAGU&SANJO, 2020) and the records from 1970 to 2020 were joined with the results of the monitoring wells carried out by IAGUASANJO for 2021 whose evaluation was conducted by the HIDROLAB-TORO Laboratory, which is a laboratory certified by the Ministry of Waters (HIDROLAB, TORO, & IAGUASANJO, 2021) as well as the work on water sampling by IAGUASANJO during the year 2022 and its processing in the Territorial Unit of Water Attention affiliated to the Laboratory of the Ministry of Waters for 2022 (UTAA & IAGUASANJO, 2022). Figure 4 and Figure A11 show the depictions of water quality variables of the groundwater being pumped from the SJM-CS aquifer for human consumption trough box-whisker diagrams and maps of the spatial-distribution of the physicochemical parameters determined in the period 1971-2022. In the urban area of SJM-CS (Figures 4-A11), all physicochemical variables have took values below the acceptable maximum limits reported for the organoleptic quality (turbidity, total dissolved solids, total hardness, pH, chloride, sulfate, sodium) and inorganic compounds (nitrite, nitrate) in the article 14 of the Sanitary Standards for Drinking Water Quality (Sanitary Standards for Drinking Water Quality, 1998). The total coliforms and fecal coliforms have frequently resulted less than 1.8 MPN/100 ml, whose value is lower than 2000 MPN/100 ml indicated in the Official Gazette Nº 5 (Regulations for the classification and quality control of the waters of the Lake Valencia Basin, 1999), being considered as safe water (Guevara & Cartaya, 2004). In addition, a groundwater quality index (GWQI) was estimated following the Equation (1) (Table 1), giving as a result a value of 36.70, which is lower than 50 being categorized as an excellent groundwater quality (López-Calatayud *et al*., 2022c).

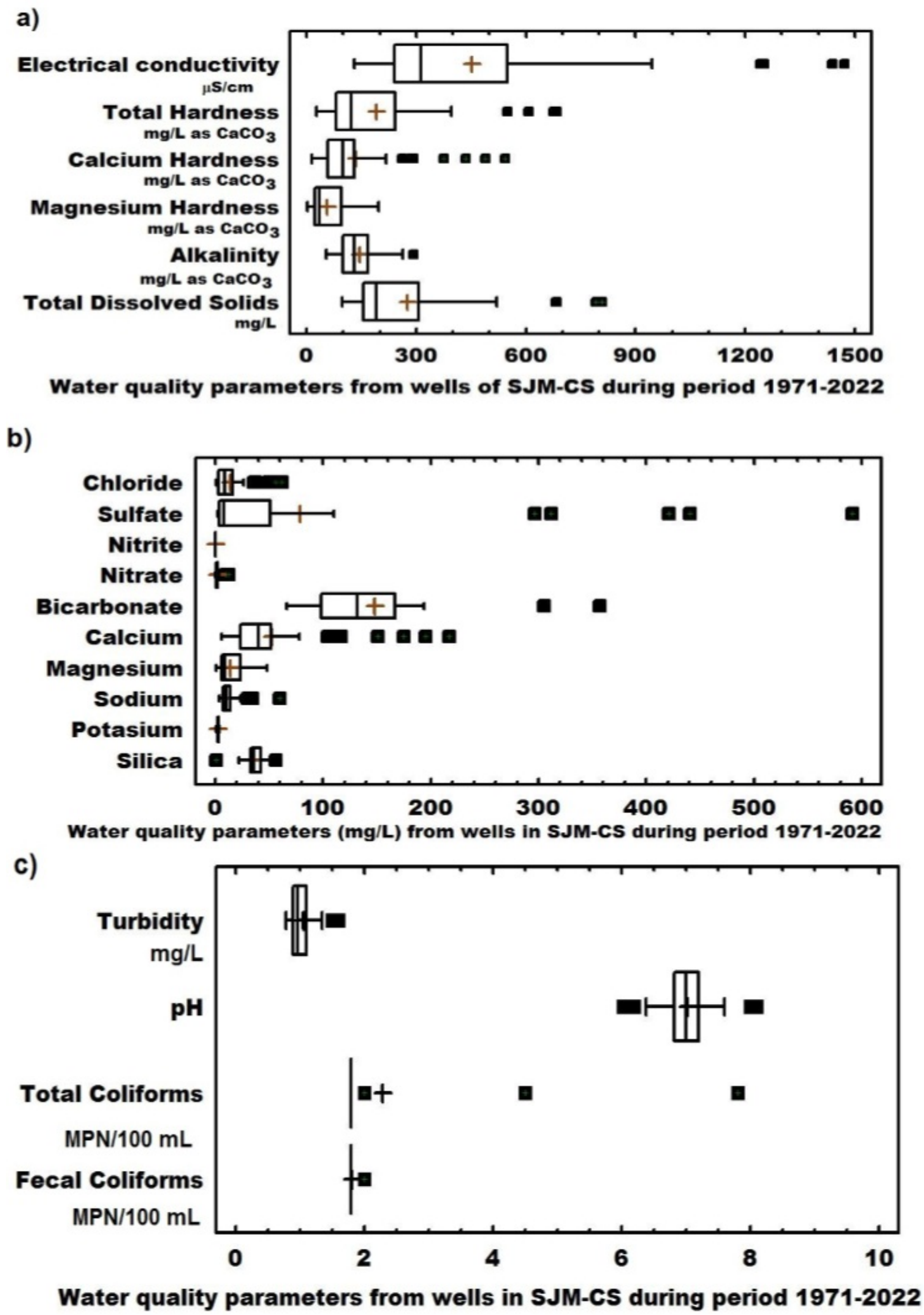

Figure 4. Water quality parameters in groundwaters of wells in SJM-CS during period 1971-2022. Adapted from MINEC and IAGUASANJO (2020), Peraza-Barreto *et al*. (2022), UTAA and IAGUASANJO (2022).

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Table 1. Groundwater quality index for the SJM-CS aquifer based on mean values of physicochemical parameters represented in Figure 4.

Parameter	Unit	Sanitary Standards for Drinking Water Quality (1998)	wi	Wi	C_i	qi	GWQI
pH	-	6.5-8.5	3	0.10	7.02	100.29	9.71
Turbidity	NTU	1	5	0.16	1.05	105	16.94
Total hardness	mg/l as $CaCO_3$	500	2	0.06	190.02	38	2.45
Total dissolved Solids	mg/l	1 000	4	0.13	274.61	27.4	3.54
Sulfate	mg/l	500	4	0.13	63.71	12.7	1.64
Chloride	mg/l	300	3	0.10	13.58	4.5	0.44
Nitrate	mg/l	10	5	0.16	1.22	12.2	1.98
Total coliforms	MPN/100 ml	0	5	0.16	< 1.8	-	-
Total			31	1			36.70

In the agricultural area (Figure A1, Figure 4), located commonly at the southern area of the SJM-CS, the analysis of the water quality for the irrigation is an important factor to prevent the salinization of the soils. Related to the electrical conductivity (EC) (Figure 4a), 50 % of values were found in a magnitude less than 300 μS/cm, what suggests that these waters has low salinity, aside the human consumption, they also might be used to irrigate most crops, in almost any type of soil with very little chance of salinity developing (Guevara, 2019; Guevara & Cartaya, 2004). By calculating the sodium absorption ratio (SAR) based on mean values of concentrations (meq/l) associated to ions including calcium (2.64 meq/l), sodium (0.61 meq/l), and magnesium (1.15 meq/l), it was obtained a SAR of 0.44, whose result can be combined with a mean value of EC of 300 μS/cm (< 700 μS/cm), giving as a result that there is no restrictions for its use for irrigation of soils employed in the agricultural activity (Guevara & Cartaya, 2004). The third calculated index was the Mg index, taking into account the calcium and magnesium concentrations, to obtain a Mg index of 30.34, when this value is upper to 50, the water is considered hazardous for irrigation purposes. An excessive Mg absorption affects the soil unfavorably and can induce calcium deficiencies in crops (Guevara, 1990; Guevara & Cartaya, 2004). The fourth calculated index was the proportion of carbonates and sulfates, assuming the maximum values in the sample, it is compliment that the sum of the concentrations of calcium ion (Ca^{+2}) (10.64 meq/l) and magnesium ion (Mg^{+2}) (4 meq/l) for a total of 14.64 meq/l, are upper than the sum of the concentrations of bicarbonate ion (HCO_3^-) (2.42 meq/l) and carbonate ion (CO_3^{-2}) (3.79 meq/l) for a total of 6.21 meq/l, expressed as the Equation (2):

$$\mathrm{Mg}^{+2} + \mathrm{Ca}^{+2} > \mathrm{HCO}_3^- + \mathrm{CO}_3^{-2} \qquad (2)$$

As it was expressed by the result of the application associated to Equation (1), water can be classified under type II (Guevara, 2019; Guevara & Cartaya, 2004), this classification corresponds to when concentrating the water, part of the Mg^{+2} and Ca^{+2} precipitate in the form of carbonates. All the remaining Mg^{+2} remains in the solution. The remaining calcium precipitates in part, in the form of sulfate, but since calcium sulfate (gypsum) has a certain solubility (30 meq/l), part of the Ca^{+2} remains dissolved, therefore the SAR does not rise as much as class 1 (Guevara, 2019; Guevara & Cartaya, 2004). This result is consistent with the fact that sulfate ion was slightly exceeding the acceptable maximum limit (400 mg/l) for waters in the subtypes 1A and 1B (Sanitary Standards for Drinking Water Quality, 1998), occurring as outside points in a proportion of close to more than 1.5 times the interquartile range (box width) above the box (Figure 4) and geographically positioned in the agricultural area at the southern region of the SJM-CS (Figure A11).

The pumped flow of the SJM-CS aquifer in the period 1971-2023 is shown in Figure A12 and Figure A13, represented by a sample of 72 wells registered in the IAGUASANJO cadaster (IAGUASANJO, 2021), whose flow rate has been distributed in 782 l/s for the urban use and 559 l/s employed in the agricultural uses, totalizing an approximated flow of 1 341 l/s extracted from the SJM-CS aquifer, being a component within the plans of integral management of the water resources of the hydrographic region of the Valencia Lake (National Assembly of the Bolivarian Republic of Venezuela, 2007b). The highest flow rate pumped from wells varied between 40 and 60 l/s, which corresponded to wells located in areas owned by the Ministry of Agriculture and Land, and associated with the development of agricultural activity.

DWSS Provision in SJM-CS by municipal government

In general, with respect to the DWS coverage in the SJM-CS, 56 % coverage is carried out through the networks of the Central Regional Aqueduct, Stage II (Peraza *et al*., 2021; Peraza-Barreto *et al*., 2022; Lugo *et al*., 2023), whose system has been administered from 1990 to the present by the HIDROCENTRO. From 2020 to the present, IAGUASANJO has executed a total of 331 actions of rehabilitation of pipe network stretches, with a maximum of 30 monthly rehabilitation actions (Figure

5a). Another purpose has consisted of 1 995 m involved in the installation of extended stretches of the drinking water pipe network (Figure 5a), including a monthly maximum value of 906 m, occurred for 2021.

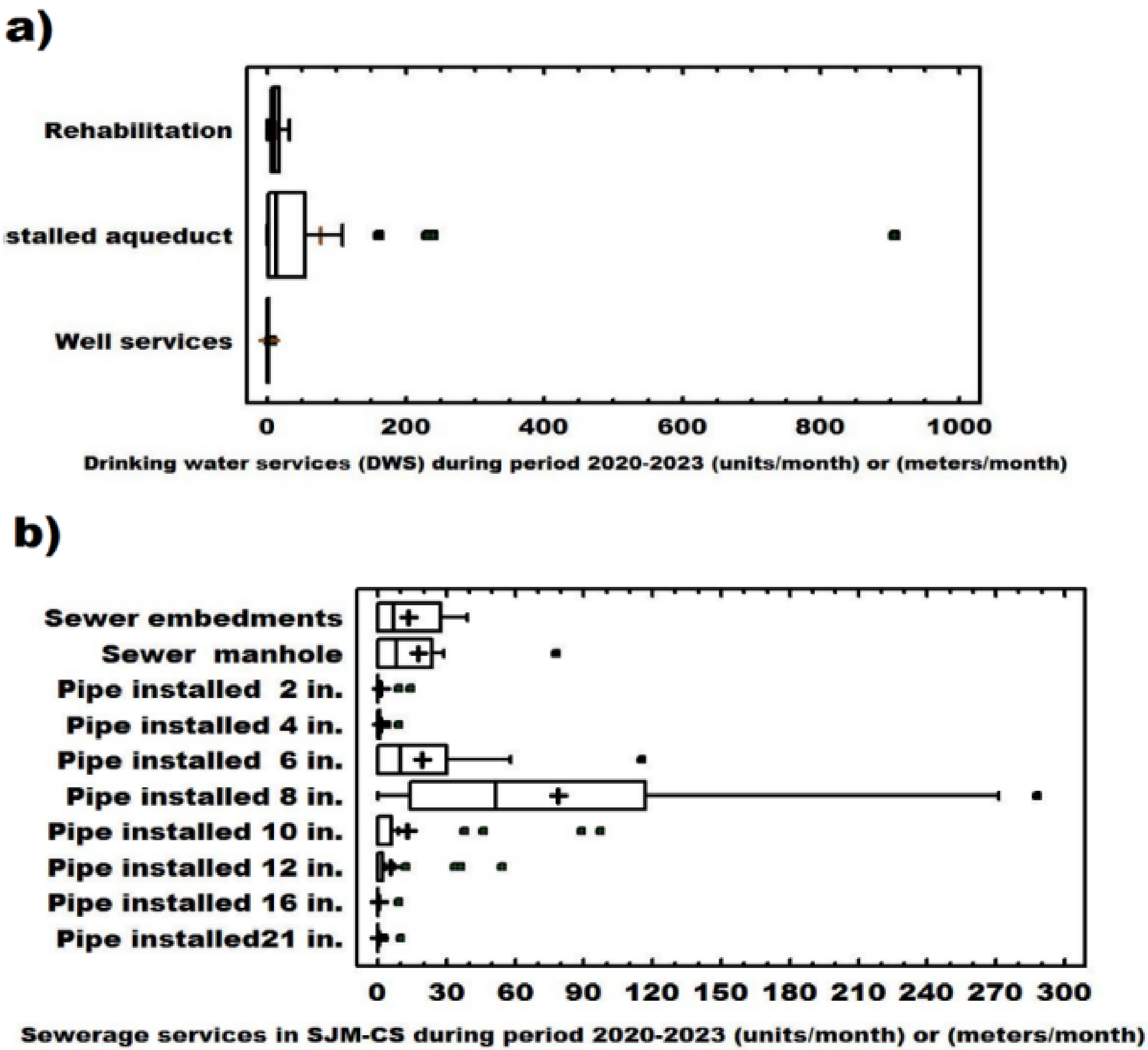

Figure 5. DWSS implemented by IAGUASANJO, SJM-CS, Venezuela, expressed as units/month or meters/month (aqueduct installed), during period 2020-2023.

The sewerage network has complied more than 30 years of service, it was designed considering the transport of wastewater flow rate of until 5.03 m^3/s for 2020 (López & González, 2003). From 2020 to the present, the total of provisions of sanitation services by IAGUASANJO has covered the following six activities (Figure 5b) (Peraza *et al.*, 2021; Peraza-Barreto *et al.*, 2022; Lugo *et al.*, 2023): 1) 108 cleaning, inspection and reconstruction of embedments to the wastewater collector networks; 2) 166 cleaning and inspection of manholes; 3) 32 meters of rehabilitation of 2-inch collectors: 4) 29 meters of rehabilitation of 4-inch collectors; 5) 502 meters of rehabilitation of 6-inch collectors; 6) 2 046 meters of rehabilitation of 8-inch collectors; 7) 334 meters of rehabilitation of 10-inch collectors; 7) 147 meters of rehabilitation of 12-inch collectors; 8) nine meters of rehabilitation of 12-inch collectors, and 9) 45 meters of rehabilitation of 21-inch collectors.

Establishment of DWSS provision models in the SJM-CS

The establishment of the new model for the DWSS provision for the SJM-CS, is focused to guarantee the supply, management and conservation of drinking water (Table 2). Table 2 presents a summary of the characteristics of the components of the DWSS provision model in the San Joaquin Municipality, Carabobo State, which includes the type of operator, the service model, the regulatory framework, the source of financing, tariff policies and subsidy systems, as well as functions. In the DWSS management model, HIDROCENTRO manages the drinking water networks and 7 % of the groundwater sources, while IAGUASANJO manages 94 % of the underground sources including those groundwater sources that are managed by the privatized management units. Regarding

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sanitation services, HIDROCENTRO and IGUASANJO carry out projects, execution of works and maintenance of wastewater collection joined networks, as well as wastewater treatment plants such as "Los Guayos".

Table 2. Characteristics of the components of the model for the provision of drinking water and sanitation services in the San Joaquin Municipality, Carabobo Stat.

DWSS Service Providers, San Joaquin Municipality	Operator	Management Model	Financing	Regulatory framework	Tariff policies and subsidy systems
Central Hydrological Company (HiDROCENTRO)	Regional Company (Limited)	Direct-Complex Public Management Subsidiary of HIDROVEN	Republic budget. Fee collection system	Organic Law for the Provision of Drinking Water and Sanitation Services. Rate adjustments anchored to the petro, the Ministry of People's Power for Light Industries and Commerce sets the maximum permissible rates for the sector	Subsidy policy and rate design, to be applied by municipalities
Directorate of water and public works (Nov. 2018-July 2020)	Municipal Institution (Limited)	Direct-Simple Public Management	Budget of the Republic assigned to the Mayor's Office	Organic Law for the Provision of Drinking Water and Sanitation Services (LOPSAPS)	not established
Communal Council	Municipal Community Association (Limited)	Controlled by IAGUASANJO	Budget of the Republic assigned to the mayor's office	LOPSAPS, Law of communal councils,	

DWSS Service Providers, San Joaquin Municipality	Operator	Management Model	Financing	Regulatory framework	Tariff policies and subsidy systems
Urbanisms Private Associations	Municipal Associations (interference of provider of service)	Controlled by IAGUASANJO	Own resources, extra condominium fees, mayor's office, government	Internal regulations	Fees paid to the condominium
IAGUASANJO (July 2020)	Company Municipal	Direct-Complex Public Management	Budget of the Republic assigned to the mayor's office	Organic Law for the Provision of Drinking Water and Sanitation Services. Municipal ordinance of creation of the Institute of July 20, 2020.	Adjustments anchored to the petro, the Ministry of People's Power for Light Industries and Commerce sets the maximum permissible rates for the sector

Creation of DWSS provision indexes in the SJM-CS

Table 3 presents the method for creating the three indexes associated with the provision of drinking water and sanitation services by IAGUASANJO in the SJM-CS derived from the application of Equation (1). The values of the matrix of the Table 3 have been separated into two components, which include the activities for the provision of drinking water and sanitation services.

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Table 3. Multi-criteria matrix of Drinking Water and Sanitation Services Provision Indexes (IPSAPS) at the IAGUASANJO municipal level during 2019-2021 (I) in the four communes of the San Joaquin Municipality, Carabobo State.

Comp.	**variables**	**Year**	**IAGUA-SANJO**	**Relative frequency of DWSS activities in the communes**			
				Oro del Pueblo	**Centro-Oeste Lago Los Tacariguas**	**Tacarigua Sur**	**Carabalí Socialist**
DWS provision	1.1 Rehabilitation/inspection of aqueducts	2019	1	0.2	0.4	0.2	0.1
		2020	1	0.21	0.5	0.2	0.1
		2021	1	0.4	0.4	0	0.1
	Subtotal 1.1		3	0.9	1.3	0.4	0.3
	1.2 Installation of aqueducts	2019	1	0.09	0.6	0.2	0.1
		2020	1	0.4	0.2	0.2	0.2
		2021	1	0.7	0.2	0	0.1
	Subtotal 1.2		3	1.2	1.0	0.4	0.3
	1.3 Deep well services	2019	1	0.2	0.4	0.2	0.2
		2020	1	0.5	0.1	0	0.4
		2021	1	0.31	0.5	0.1	0.1
	Subtotal 1.3		3	1.0	0.9	0.2	0.7
Subtotal 1			9	3.1	3.3	1.2	1.3
SS Provision	2.1 Cleaning, inspection and reconstruction of embedments	2019	1	0.21	0.23	0.4	0.16
		2020	1	0.53	0.18	0.28	0.01
		2021	1	0.57	0.43	0	0
	Subtotal 2.1		3	1.31	0.84	0.68	0.17

Comp.	variables	Year	IAGUA-SANJO	Relative frequency of DWSS activities in the communes			
				Oro del Pueblo	Centro-Oeste Lago Los Tacariguas	Tacarigua Sur	Carabalí Socialist
	2.2 Cleaning and inspection of manholes	2019	1	0.34	0.20	0.32	0.14
		2020	1	0.59	0.23	0.13	0.05
		2021	1	0.43	0.51	0	0.06
	Subtotal 2.2		3	1.36	0.94	0.45	0.25
	2.3 Rehabilitation of sewage pipes for pipes with a diameter of 6 inches	2019	1	0	0	1	0
		2020	1	1	0	0	0
		2021	1	1	0	0	0
	Subtotal 2.3		3	1	2	3	4
	2.4 Rehabilitation of sewage pipes for pipes with a diameter of 8 inches	2019	1	0.22	0.48	0.17	0.13
		2020	1	0.71	0.06	0.21	0.02
		2021	1	0.87	0.13	0	0
	Subtotal 2.4		3	1.8	0.67	0.38	0.15
	2.5 Rehabilitation of sewage pipes for 12-inch diameter pipes	2019	1	0	0	1	0
		2020	1	0	0	1	0
		2021	1	0	1	0	0
	Subtotal 2.5		3	0	1	2	0
	2.6 Rehabilitation of sewage pipes for pipes with a diameter of 21 inches	2019	0	0	0	0	0
		2020	1	1	0	0	0
		2021	1	0	1	0	0
	Subtotal 2.6		2	1	1	0	0
Subtotal 2			17	7.5	4.5	4.5	0.6

Comp.	variables	Year	IAGUA-SANJO	Relative frequency of DWSS activities in the communes			
				Oro del Pueblo	Centro-Oeste Lago Los Tacariguas	Tacarigua Sur	Carabalí Socialist
Total 1+2			26	11	7.8	5.7	1.9
IMPSA			0.35	0.12	0.13	0.04	0.05
IMSS			0.65	0.29	0.17	0.17	0.02
IMPSAS			1	0.4	0.3	0.2	0.1

Source: Own elaboration. Adaptation of López-Calatayud *et al*. (2022c).

In Table 3, it can be seen that the component associated with the provision of drinking water services encompasses three variables representing the actions carried out by IAGUASANJO in the period 2019-2021, the results of which were presented in Figure 5. The three variables involve the activities of a) rehabilitation/inspection of aqueducts, b) installation of aqueducts and c) services of deep wells. The weights were obtained as the number of actions carried out within each commune divided by the total actions for the four communes of the municipality. The valuation of the subtotal of the actions in provision of drinking water services developed by IAGUASANJO during three years resulted in 9 (Subtotal 1), whose value includes the values for each of the four communes within the San Joaquin Municipality, resulting in a score for commune 1 (Oro del Pueblo) of 3.19, commune 2 (Centro-Oeste Lago Los Tacariguas) of 3.33, commune 3 (Tacarigua Sur) of 1.15 and the Carabalí Socialist commune of 1.33.

Regarding the component associated with the provision of sanitation services, it encompasses six variables representing the actions carried out

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by IAGUASANJO in the period 2018-2021 (Table 3), whose results were presented in Figure 5. The six variables involve the activities of a) cleaning, inspection and reconstruction of embedments, b) cleaning and inspection of manholes, c) rehabilitation of wastewater pipes for 6-inch diameter pipes, d) rehabilitation of wastewater pipes for pipes with a diameter of 8 inches, e) rehabilitation of sewage pipes for pipes with a diameter of 12 inches, and f) rehabilitation of wastewater pipes for pipes with a diameter of 21 inches. The valuation of the subtotal of the actions in provision of sanitation services developed by IAGUASANJO during three years resulted in 17 (Subtotal 2), whose value includes the values for each of the four communes within the Municipality of San Joaquin, resulting in a score for commune 1 (Oro del Pueblo) of 7.47; commune 2 (Centro-Oeste Lago Los Tacariguas) of 4.45; commune 3 (Tacarigua Sur) of 4.51, and the Carabalí Socialist commune of 0.57. The results of the three indexes found for the four communes are shown in Table 3, where it is observed with respect to the drinking water service delivery model index (IMPSAP) that presented the highest score for the Oro del Pueblo commune (0.35) and a lower proportion for the rest of the communes. Regarding the sanitation service delivery model index (IMPSS), it was found that the highest score was obtained for the Oro del Pueblo commune (0.65) and a lower proportion for the rest of the communes. Regarding the global index of the model for the provision of drinking water and sanitation services (IMPSAPS), it was found that it covered a weighting of 0.41 in the Oro del Pueblo commune followed by the index of the Centro-Oeste Lago Los Tacariguas commune (0.30), as well as this for the communes of Tacarigua Sur (0.22) and Socialista Carabalí (0.07). The classification of DWSS indexes on the scales is considered as follows (López-Calatayud *et al.*, 2022c): Very low (0-20 %), low (20-40 %), medium (40-60 %), high (60-80 %), and very high (80-100 %). In this study, a high value was found for the IMPSS (65 %), and a low value for the IMPSAP (low: 35 %). Figures 6a-6b show the graphical representation of the three indexes, IMPSAP, IMPSS and IMPSAPS, calculated on the basis of a 3-year period (2019-2021) and discriminated for the four communes of the San Joaquin Municipality. Carabobo State, where it is observed that the IMPSAP was lower than the IMPPSS, and the complement of both indexes justify the values obtained for the IMPSAPS index. With respect to the global indexes by the SJM-CS, it is observed that 65 % of the activities developed by the IAGUASANJO in the SJM-CS were oriented towards covering the needs of sanitation services, while 35 % of the actions were carried out in drinking water services (Figure 6). At global scale, the most approximated indexes to the IMPSAP, IMPSS and IMPSAPS, are related to the coverage of the drinking water and sanitation services in terms of population supplied. For Europe EUREAU (2020), in the United Kingdom, the public delegated management has achieved an index of coverage of drinking water and sanitation services in the order of 100 % of the population supplied, while in countries such as Austria, Denmark, Italy, Portugal, Spain, France, Germany, the direct public management has achieved coverage of drinking water and sanitation services between high (100 %) for the first four and medium to low (10-60 %) for the rest of the countries. For Latin America, Ferro (2017) reported that 67 % of the companies cover over 60 % of the DWSS.

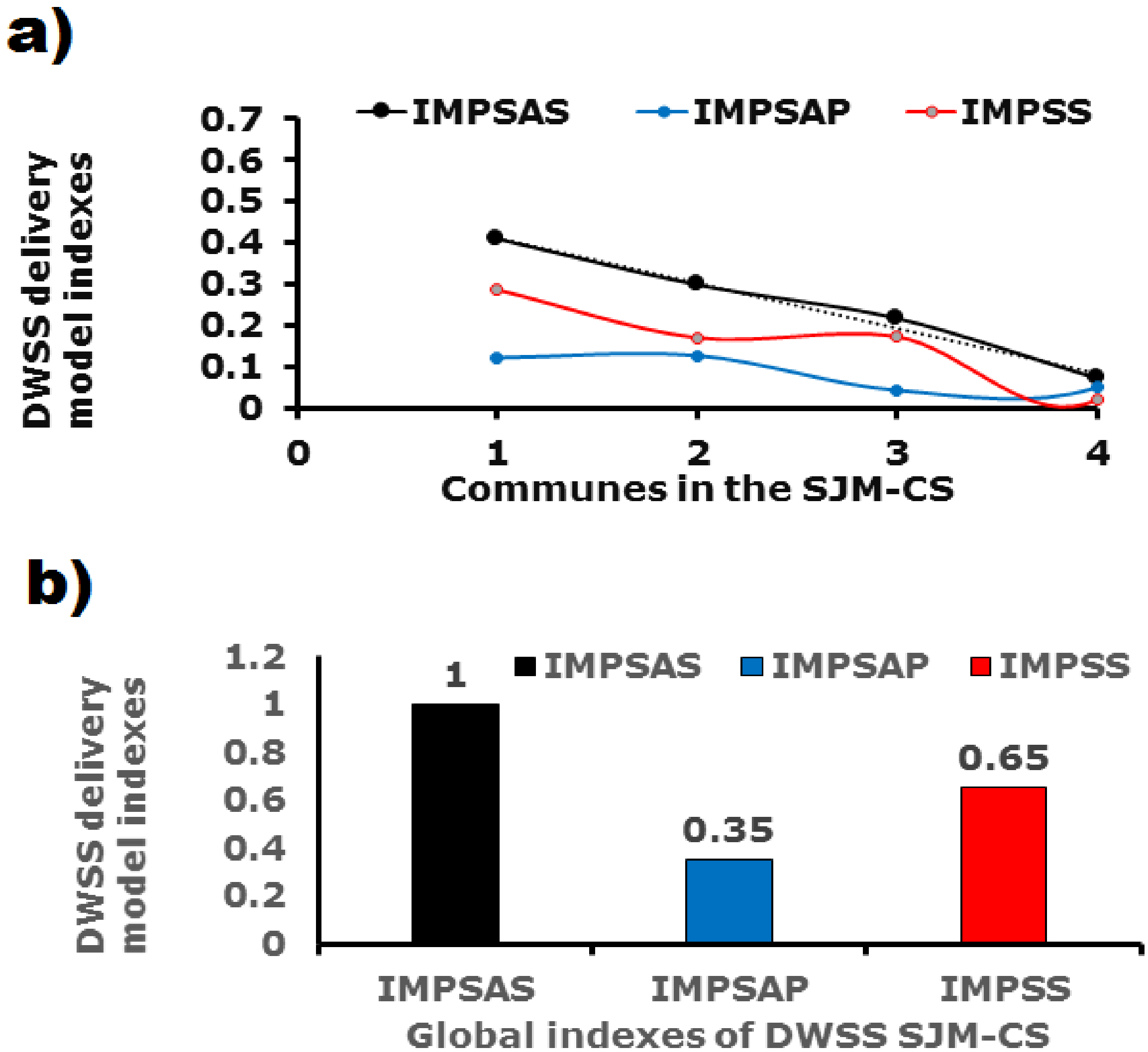

Figure 6. Model indexes for the provision of drinking water and sanitation services in communes of the San Joaquín Municipality by IAGUASANJO in the period 2019-2021. Communes: 1: Oro del Pueblo, 2: Centro-Oeste Lago Los Tacariguas, 3: Tacarigua Sur, 4: Socialista Carabalí. Adapted from López-Calatayud *et al*. (2022c).

Conclusions

In this study, the experiences of DWSS management model in the San Joaquin Municipality (SJM), Carabobo State (CS), were made up of direct-complex public management represented by the San Joaquin Water Autonomous Municipal Institute (IAGUASANJO, in Spanish) affiliated to the SJM-CS mayor's office, and the Central Hydrological Company (HIDROCENTRO) belonging to Hydrological Company of Venezuela (HIDROVEN, in Spanish). The institutional reform was based on the horizontal structure of the DWSS industry, where the processes of capture, storage in artificial water reservoirs, treatment and distribution of the drinking water obtained from the water surface source as well as the collection and treatment of the wastewaters are performed by the regional company (HIDROCENTRO) and IAGUASANJO has been complying a type of joint work to rehabilitate, maintain, extend the DWSS, with a special emphasis in a sustainable use of the SJM-CS aquifer as a water source to satisfy the need of an important fraction of the inhabitants within the SJM-CS, all these actions within the frame of the municipal transferring process from regional company to the municipal institution in compliance with the national DWSS regulation.

The provision model of the drinking water and sanitation services (DWSS) in the San Joaquin Municipality (SJM), Carabobo state (CS), Bolivarian Republic of Venezuela is a type of direct-complex public management model represented by a horizontalized structure counting with the participation of public companies-delegates in the representations of the Central Hydrological Company (HIDROCENTRO) and the San Joaquin Water Municipal Autonomous Institute (IAGUASANJO). Under this model, IAGUASANJO manages the DWSS provision for the community councils, private associations (urban planning condominiums) and industries that make up the territorial activities in the municipality. From its creation in 2020 to the present, IAGUASANJO has followed an perfect alignment with the Sustainable Development Goals in the frame of the Agenda 2030 established by United Nations, which has been focused the DWSS provision carrying out the actions to strength the maintenance, and rehabilitation of the existing drinking water pipe network systems that extract the resource from surface and underground water sources and the existing wastewater collection systems, which have reached more than 30 years offering the services for SJM-CS communities as well as the creation of new drinking water and sanitation systems to extend the services, improving the DWSS provision quality by guarantying pressure, continuity and water quality in the DWS, and a suitable sanitary solution to protect the water resources and the environment, which contributes to enhance the life quality of the SJM-CS citizens. The model for the DWSS provision in SJM-CS was represented by the evaluation of several water quality management indexes with approaches for human consumption and water for agricultural irrigation where excellent results were found, demonstrating the favorable levels of the physicochemical characteristics of the groundwaters from SJM-CS aquifer, constituting a safe water source to cover the demand required by the inhabitants of the SJM-CS. As well, in a specific way, this study has evaluated and proposed three management indexes, involving an index to take into account in an integrated manner to the provision of the drinking water and sanitation services (IMPSAPS), a model index for the provision of drinking water services (IMPSAP) and model index for the provision of sanitation services (IMPSS), according to which the IAGUASANJO has oriented 65 % of the activities towards the provision of sanitation services and 35 % of the actions towards the provision of drinking water services in the period 2020-2023, leading to validate its actions to significantly improve the DWSS quality.

Acknowledgements

It is extended an acknowledgment to the Hidrolab Toro CA Laboratory for its contribution in the water quality determination for the city wells.

Data availability

All data, models, and code generated or used during the study appear in the submitted article.

Annex

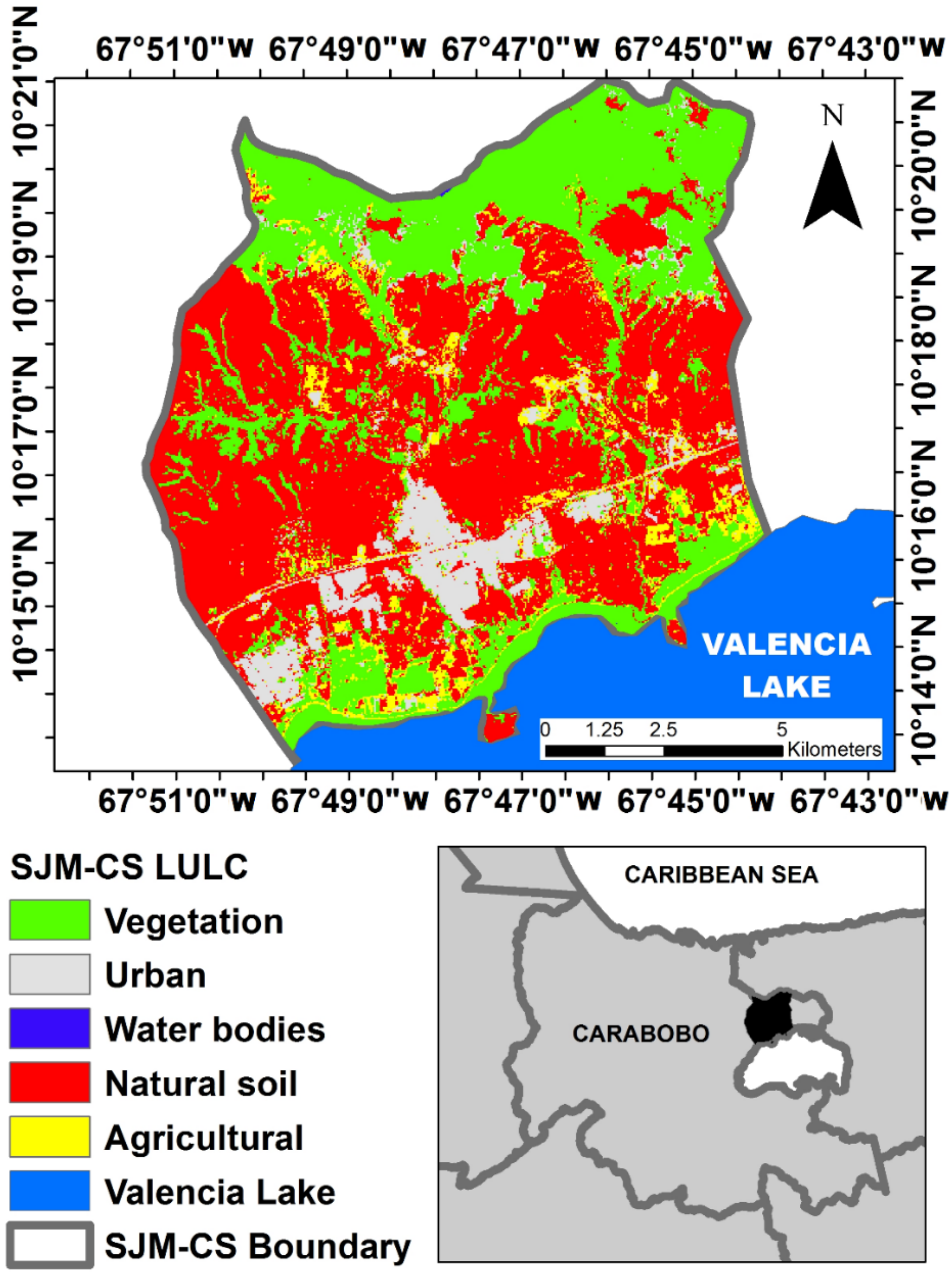

Figure A1. Land use and land cover of San Joaquin Municipality, Carabobo state (SJM-CS), Bolivarian Republic of Venezuela.

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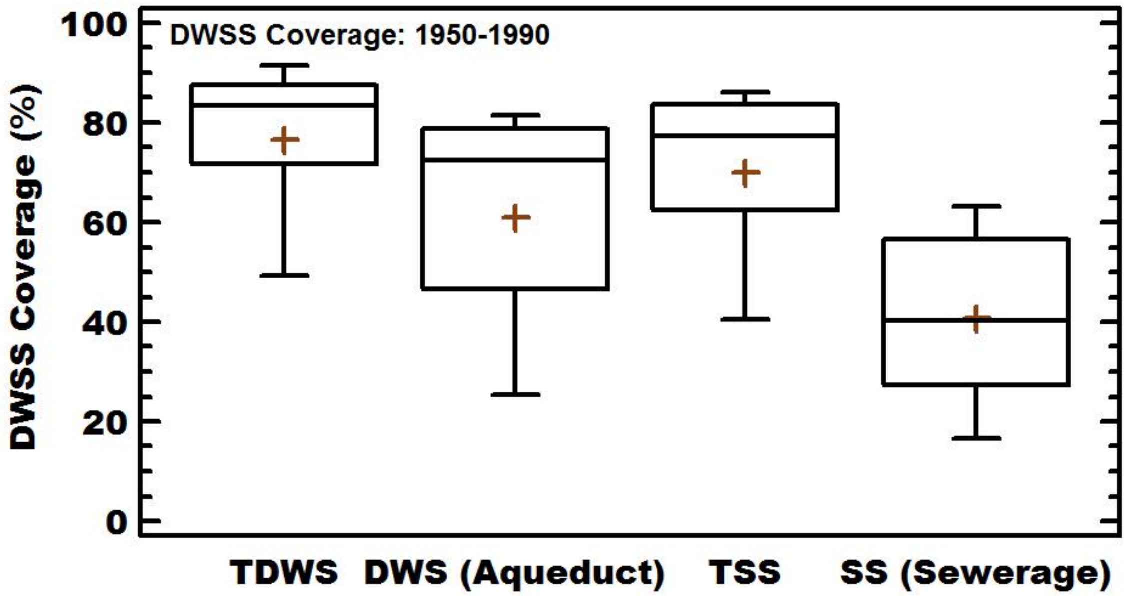

Figure A2. Drinking water and sanitation services (DWSS) coverage percentage in Venezuela during the period between 1950 and 1990. Adapted from Corrales (2004) and OCEI (1996).

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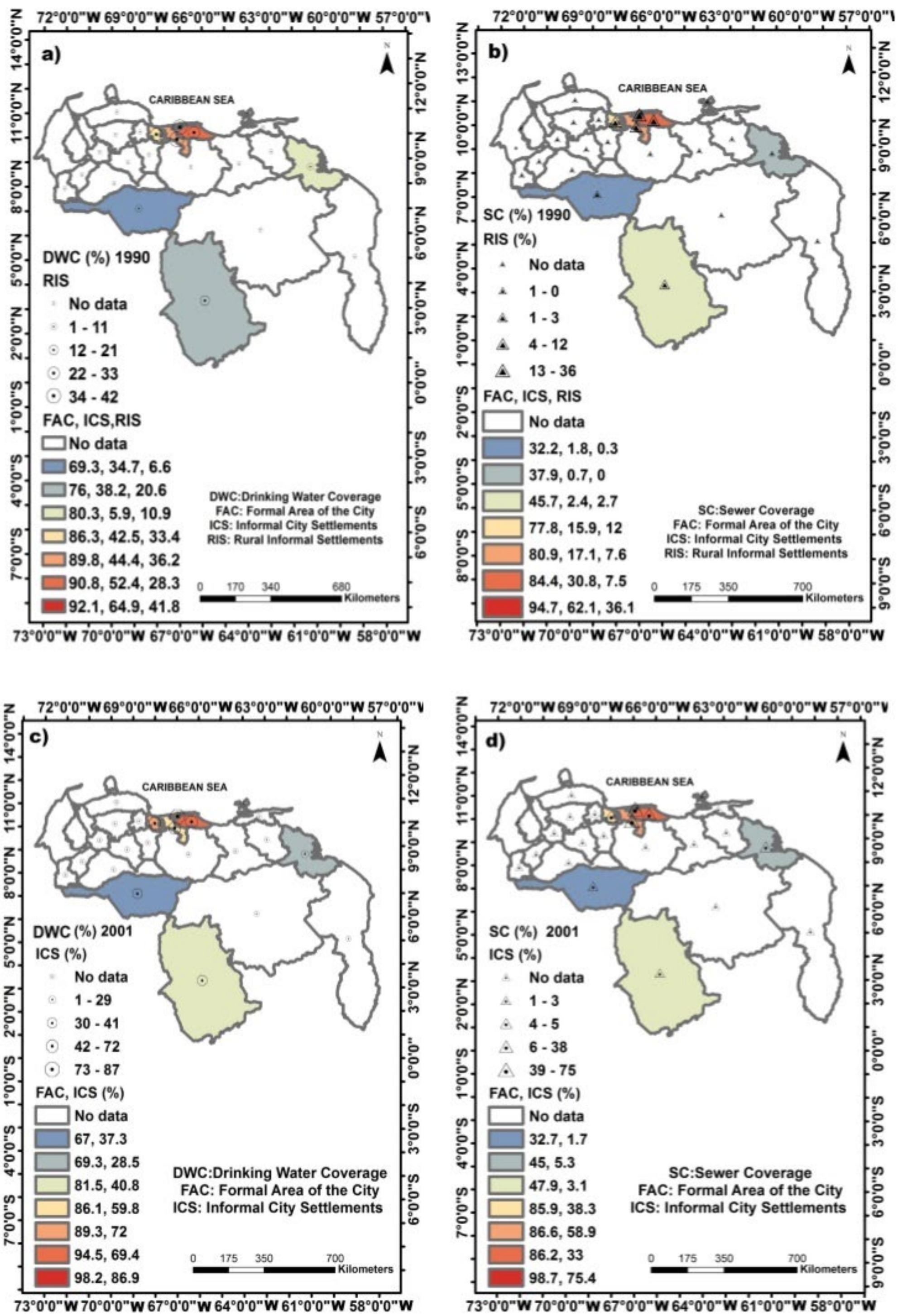

Figure A3. Drinking water and sanitation services (DWSS) coverage percentage according to socioeconomic stratum in Venezuela for 1990 and 2001. Adapted from OCEI (1996), INE (2001) and Corrales (2004).

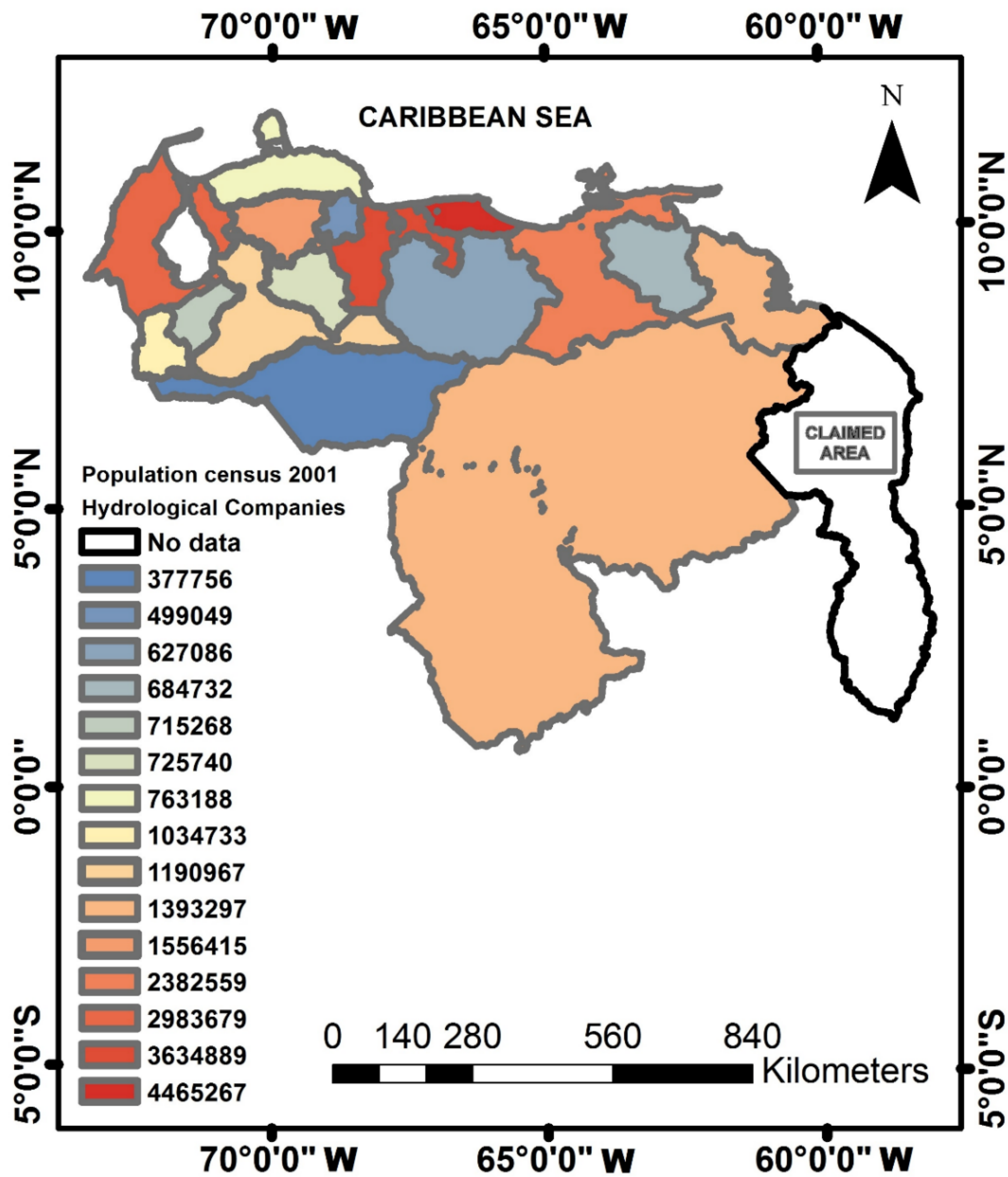

Figure A4. Spatial distribution of the censused population by the Venezuelan Hydrological Companies for 2001, whose regional delineations corresponds to the affiliated companies to the Hydrological Company for Venezuela (HIDROVEN) and the decentralized companies in the Bolivarian Republic of Venezuela. Adapted from INE (2001) and Corrales (2004).

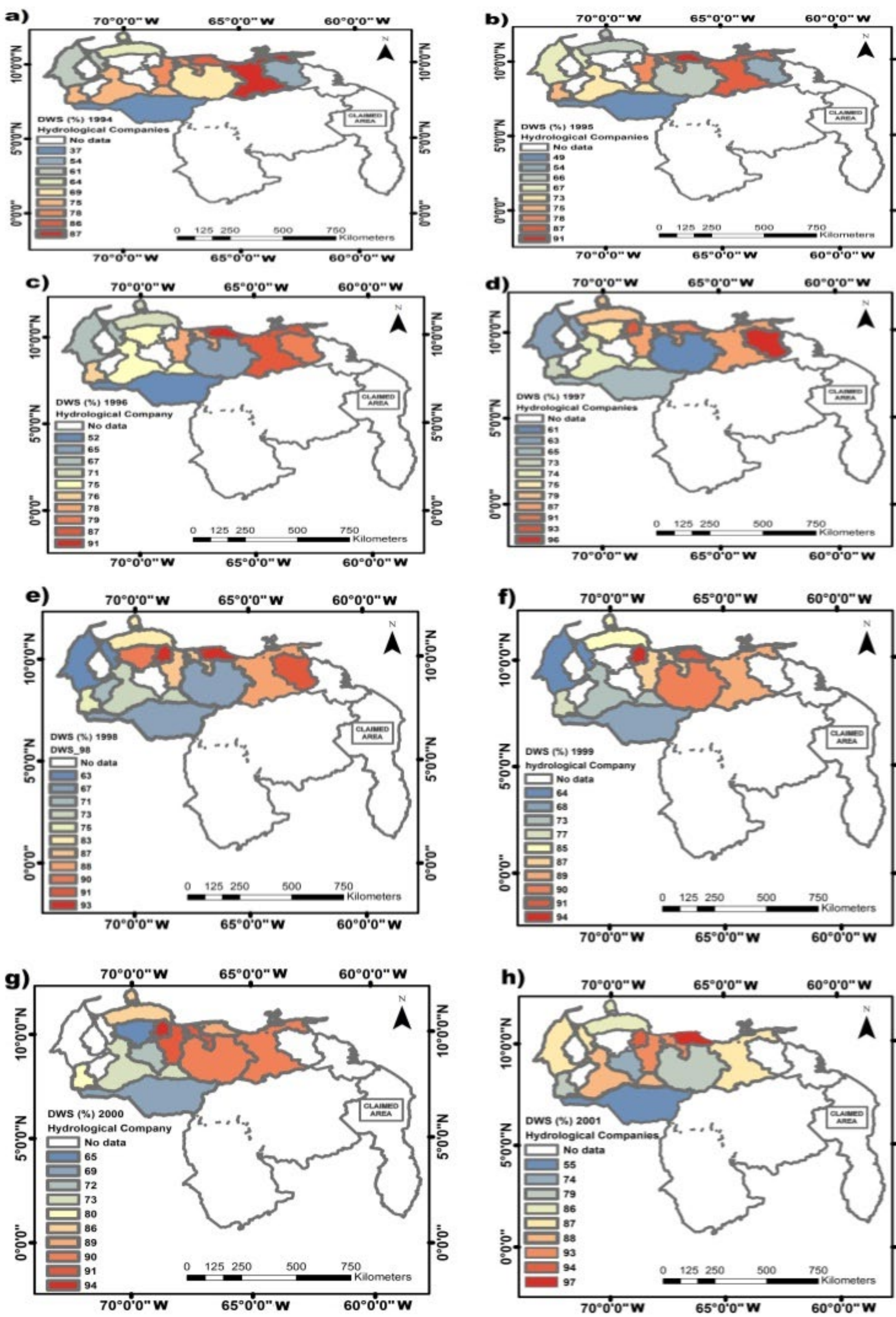

Figure A5. Drinking water services from HIDROVEN and decentralized companies during the period 1994-2001. Adapted from HIDROVEN-CAF (2002) and Corrales (2004).

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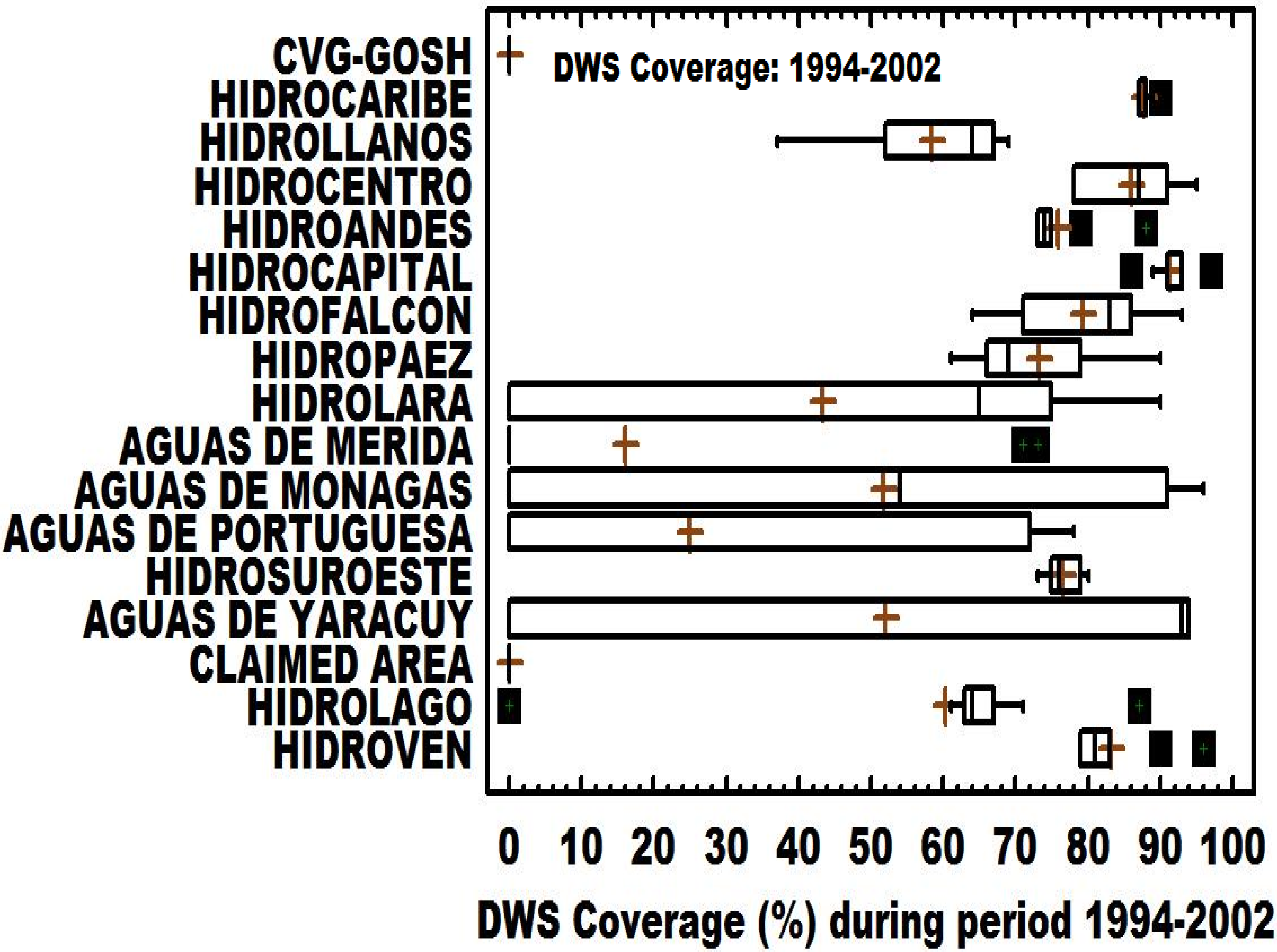

Figure A6. Box and whisker diagrams of the drinking water services (DWS) from HIDROVEN and decentralized companies during the period 1994-2002. Adapted from HIDROVEN-CAF (2002) and Corrales (2004).

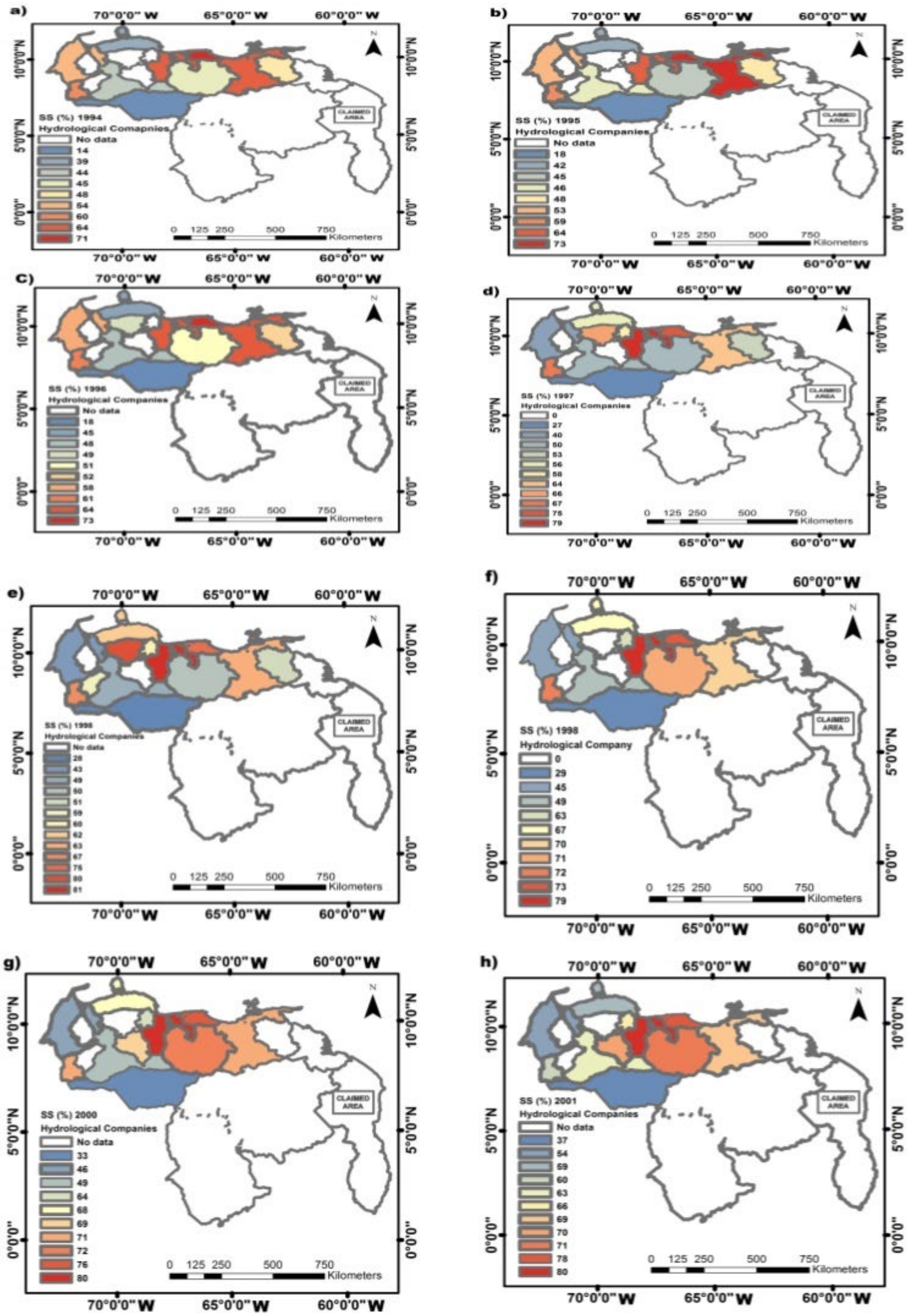

Figure A7. Sanitary services from HIDROVEN and decentralized companies during the period 1994-2001. Adapted from HIDROVEN-CAF (2002), Corrales (2004).

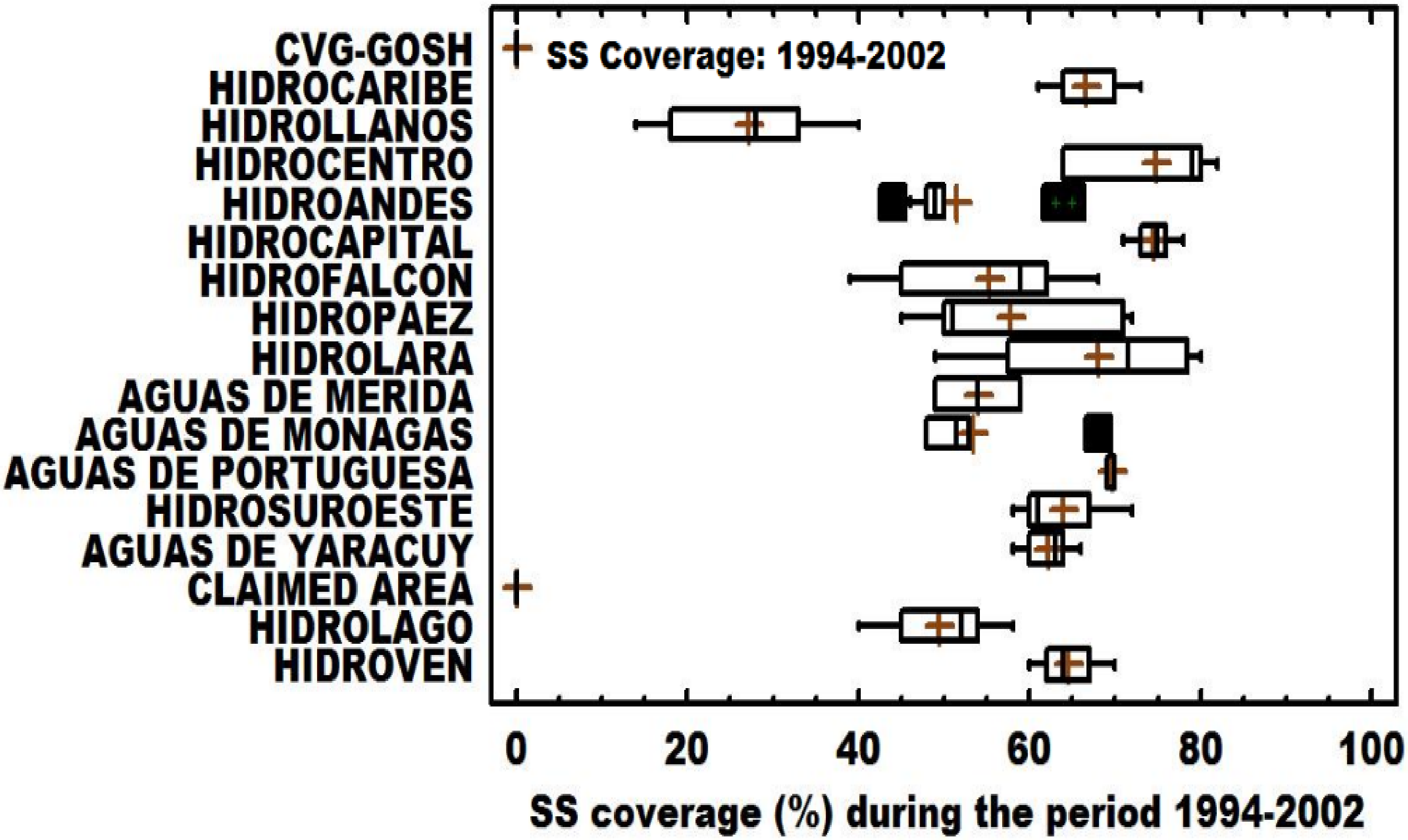

Figure A8. Box and whisker diagrams of the sanitary services from HIDROVEN and decentralized companies during the period 1994-2002. Adapted from HIDROVEN-CAF (2002) and Corrales (2004).

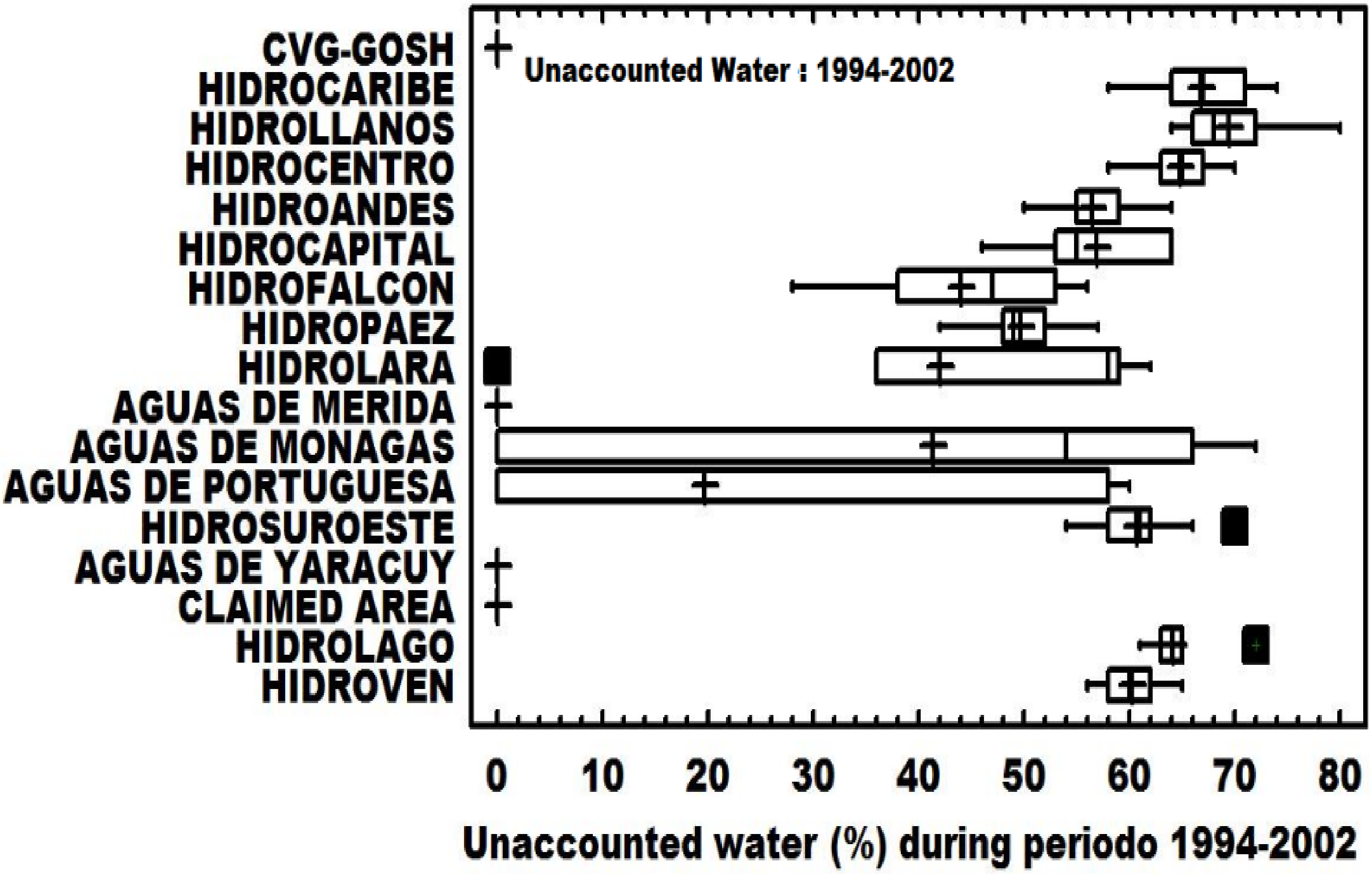

Figure A9. Box and whisker diagrams of the unaccounted water from HIDROVEN and decentralized companies during the period 1994-2002. Adapted from HIDROVEN-CAF (2002) and Corrales (2004).

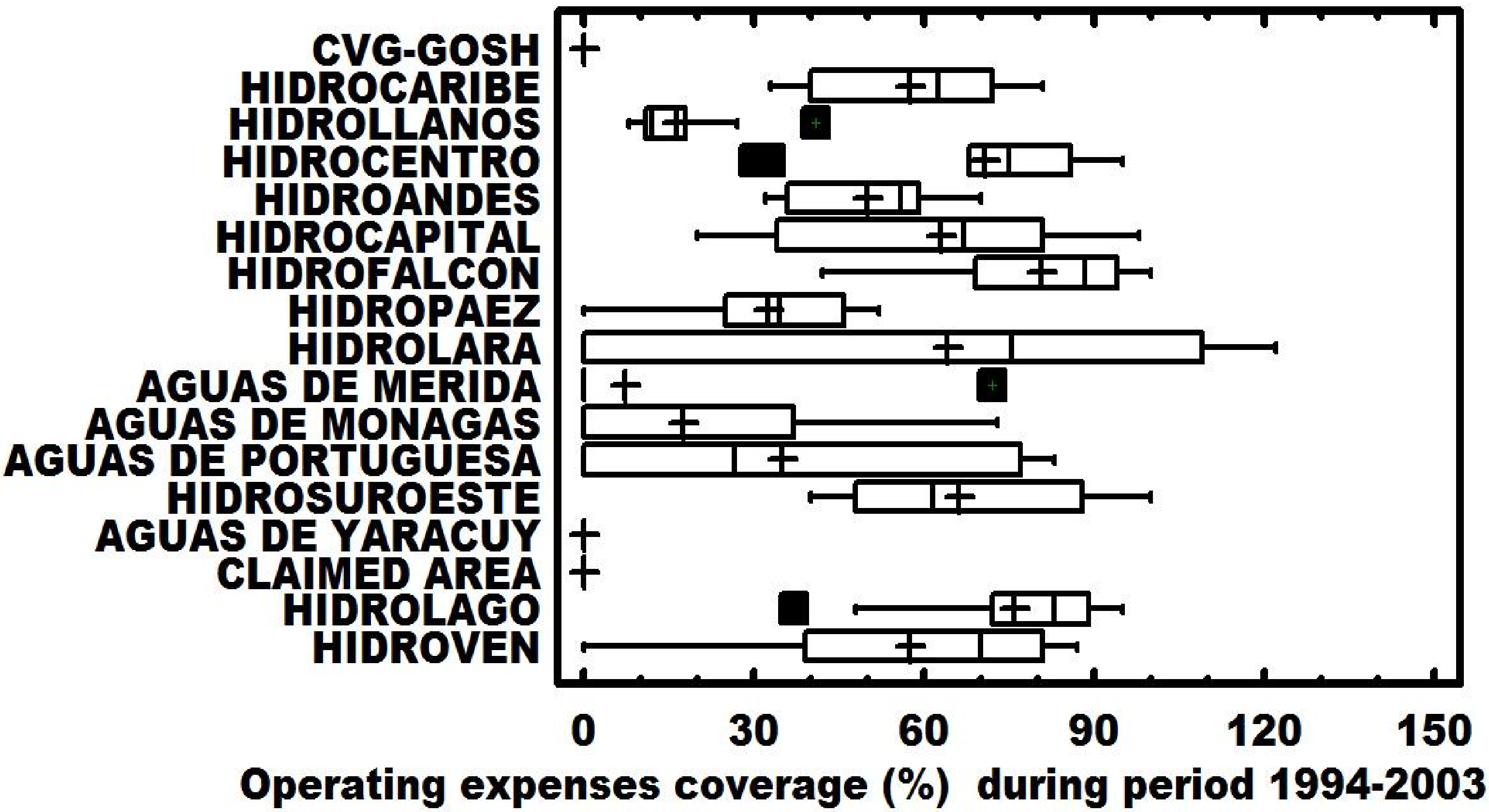

Figure A10. Box and whisker diagrams of the operating expenses from HIDROVEN and decentralized companies during the period 1994-2003. Adapted from HIDROVEN-CAF (2002) and Corrales (2004).

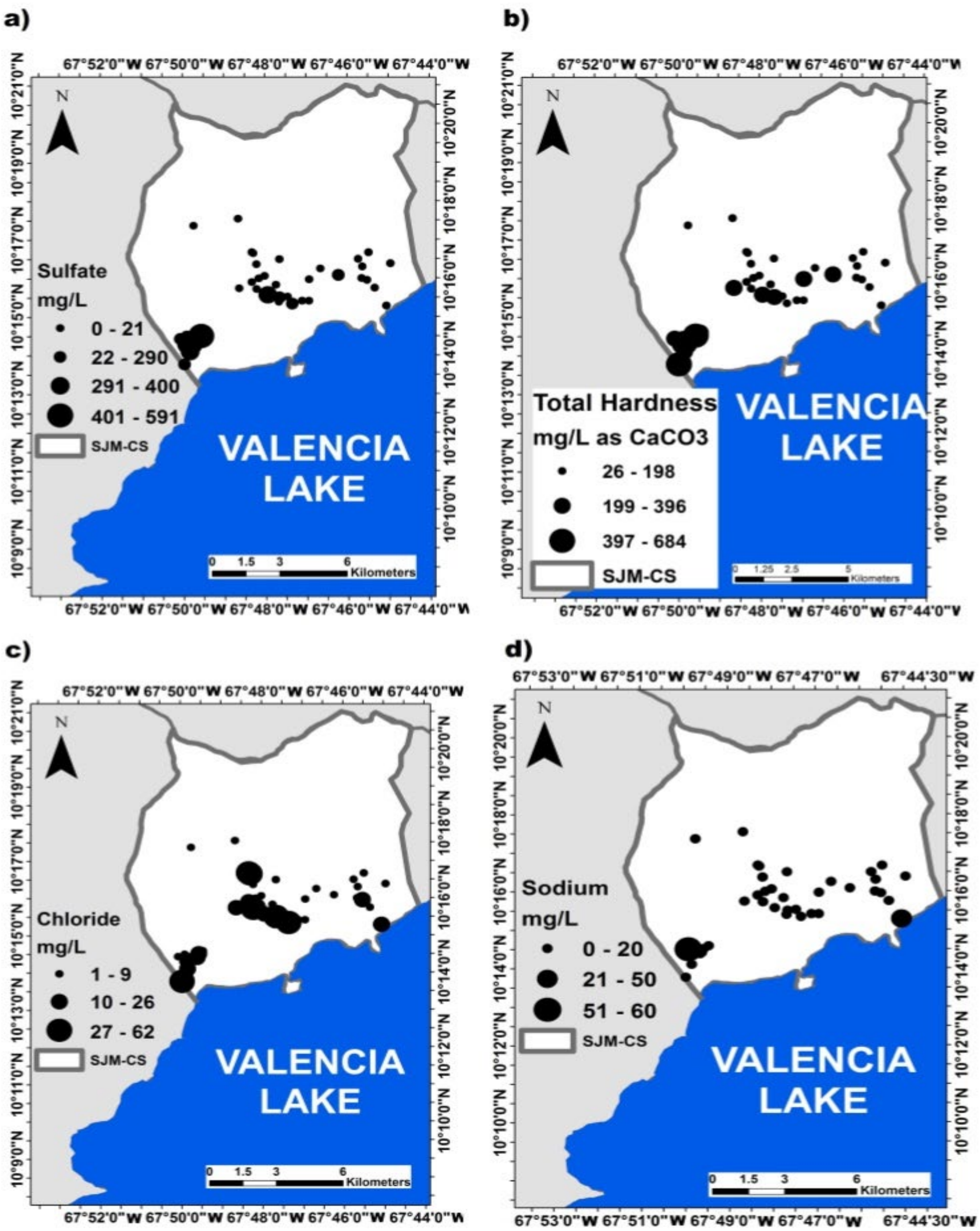

Figure A11. Spatial distribution of water quality parameters in groundwaters of wells in SJM-CS during period 1971-2023. Adapted from MINEC and IAGUASANJO (2020), Peraza-Barreto *et al*. (2022), UTAA and IAGUASANJO (2022).

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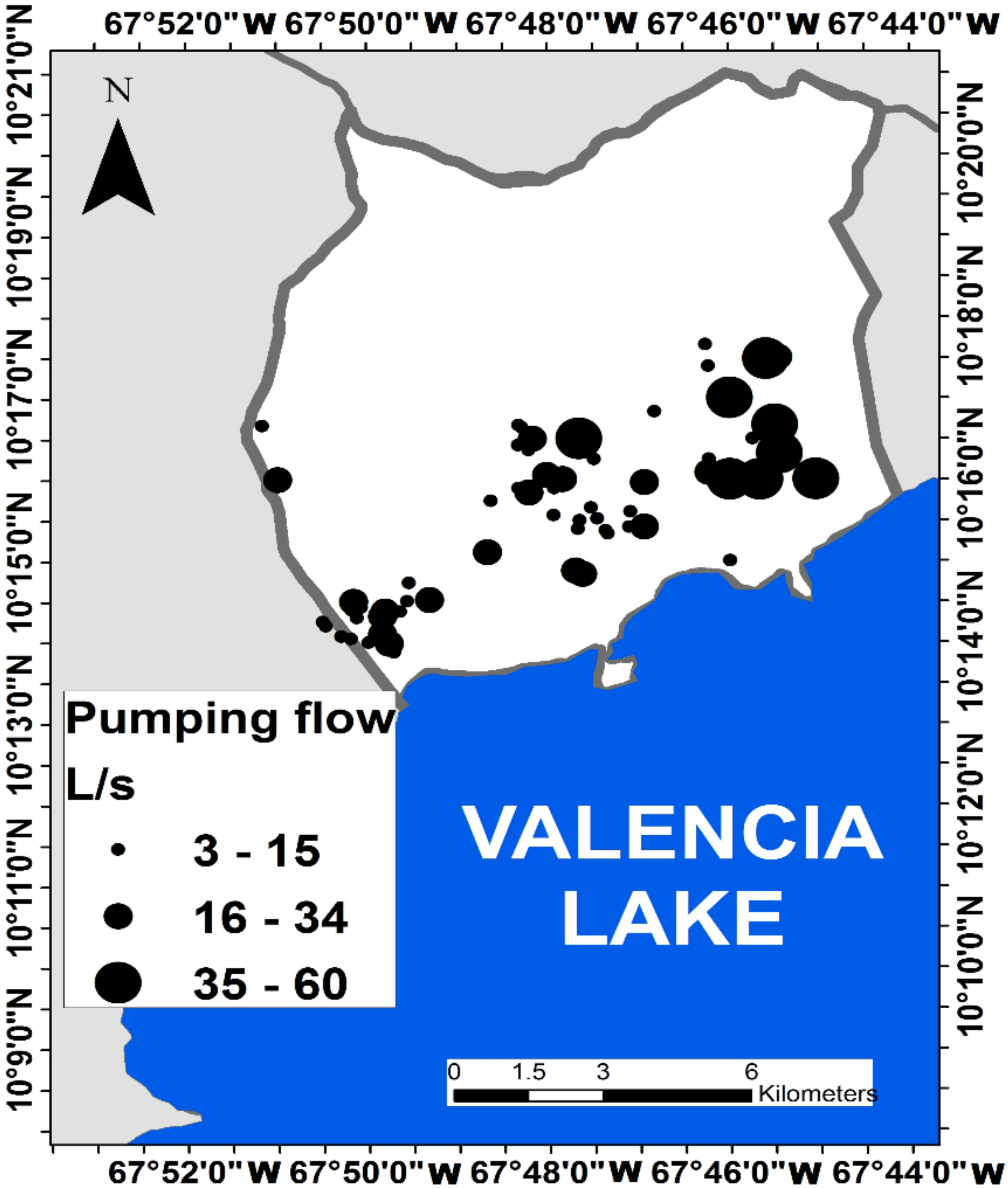

Figure A12. Spatial distribution of pumping flow from groundwaters of wells in SJM-CS during period 1971-2023. Adapted from Peraza *et al*. (2021), Peraza-Barreto *et al*. (2022), and IAGUASANJO (2021).

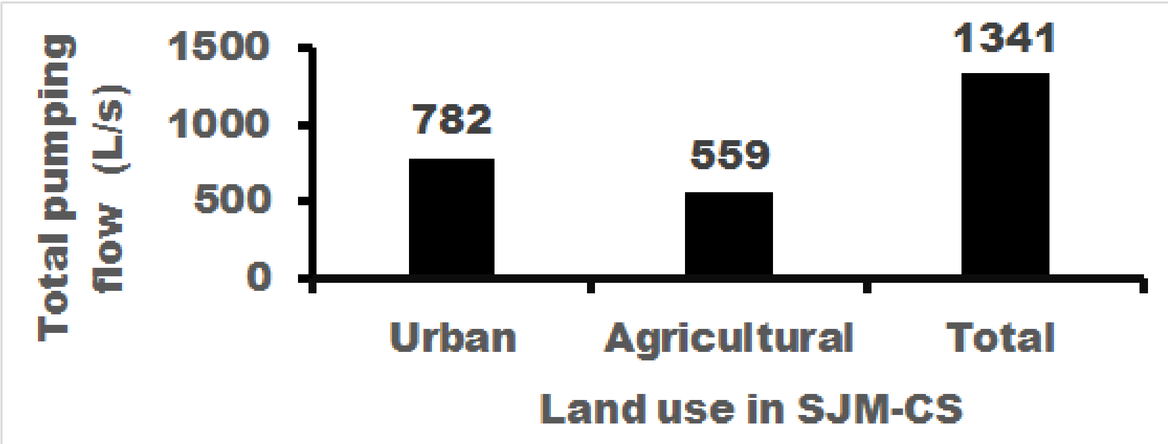

Figure A13. Total pumping flow from groundwaters of wells in SJM-CS during period 1971-2022. Adapted from Peraza *et al*. (2021), Peraza-Barreto *et al*. (2022) and IAGUASANJO (2021).

References

BCV, Banco Central de Venezuela. (2002). *Anuario de Cuentas Nacionales. Colección Estadística. Diversos años*. Caracas, Venezuela: Banco Central de Venezuela.

Centro del Agua para América Latina y el Caribe. (marzo, 2012). *Gestión comercial para los organismos operadores de agua, drenaje y saneamiento*. Recovered from https://es.scribd.com/document/504794913/Curso-Tec-Monterrey

CEPAL, Comisión Económica para América Latina y el Caribe. (2009). *Políticas sobre el uso sustentable del agua y la prestación eficiente de los servicios públicos vinculados*. Recovered from https://es.scribd.com/document/504796336/CURSO-CEPAL

CODIA & AECID, Conferencia de Directores y Autoridades Iberoamericanos del Agua & Agencia Española de Cooperación Internacional para el Desarrollo. (julio, 2012). *Hidrogeología VI. Programa de Formación Iberoamericana en Materia de Aguas*. Recovered from https://es.scribd.com/document/504795167/HIDROGEOLOGIA

Corrales, M. E. (2000). *El reto del agua.* Caracas, Venezuela: Editorial Galac, S.A.

Corrales, M. E. (2004). *Venezuela: análisis del sector agua potable y saneamiento*. Recovered from https://scioteca.caf.com/handle/123456789/396

Corrales, M. E. (2008). Infraestructura pública y servicios asociados. En: Instituto de Investigaciones Económicas y Sociales, Universidad Católica Andrés Bello (eds.). *Acuerdo social. Venezuela: un acuerdo para alcanzar el desarrollo* (pp. 229-262. 572). Recovered from https://www.ucab.edu.ve/wp-content/uploads/2017/09/INV-IIES-REV-084-Infraestructura-publica-y-servicios-asociados.pdf

Dunning, D. J., Ross, Q. E., & Merkhofer, M. W. (2000). Multiattribute utility analysis for addressing. Section 316(b) of the clean water act. *Environmental Science & Policy*, 3, 7-14. DOI: 10.1016/S1462-9011(00)00022-8

EUREAU, European Federation of National Associations of Water Services. (2020). *The governance of water services in Europe*. Recovered from https://www.eureau.org/resources/publications/eureau-publications/5219-the-governance-of-water-services-in-europe-2020-edition/file

Tecnología y ciencias del agua, ISSN 2007-2422, 16(6), 80-146. DOI: 10.24850/j-tyca-2025-06-03

Ferro, G. (2017). *América Latina y el Caribe hacia los Objetivos de Desarrollo Sostenible en agua y saneamiento: reformas recientes de las políticas sectoriales* (núm. S.17-00195). Recovered from https://repositorio.cepal.org/handle/11362/41136

Gómez, J. V. (1997). Localización industrial venezolana: municipios y paisajes industriales. *Espacio y Desarrollo*, (9), 311-322. DOI: 10.1075/btl.19.31ind

Guevara, E. (1990). *Ingeniería de riego y drenaje*. Valencia, Venezuela: Consejo de Desarrollo Científico y Humanístico de la Universidad de Carabobo.

Guevara, E., & Cartaya, H. (2004). *Hidrología ambiental*. Valencia, Venezuela: Facultad de Ingeniería de la Universidad de Carabobo.

Guevara, E. (2019). *Modelo de manejo integrado de cuencas*. Lima, Perú: Autoridad Nacional del Agua. Recovered from https://hdl.handle.net/20.500.12543/4302

Hajkowicz, S., & Collins, K. (2007). A review of multiple criteria analysis for water resource planning and management. *Water Resources Management*, 21, 1553-1566. DOI: 10.1007/s11269-006-9112-5

HIDROLAB-TORO & IAGUASANJO (2021). Análisis bacteriológicos y fisicoquímicos del agua de seis pozos del Municipio San Joaquín, Estado Carabobo. Valencia, Venezuela: HIDROLAB-TORO-IAGUASANJO. Disponible en: https://es.scribd.com/document/504793061/Informe-HIDROLABTORO-Tesis-KL

HIDROVEN-CAF. (2002). *Estadísticas de aguas y cloacas*. Caracas, Venezuela: HIDROVEN-CAF.

Huguet-Sierra, G. A., Márquez-Romance, A. M., Guevara-Pérez, E., Pérez-Pacheco, S. A., & Buroz-Castillo, E. (2023a). Calibration and validation of models to estimate the hydraulic parameters of a confined aquifer in a tropical region. *DYNA*, 90(225), 111-121. DOI: 10.15446/dyna.v90n225.106250

Huguet-Sierra, G. A., Márquez-Romance, A. M., Guevara-Pérez, E., Pérez-Pacheco, S. A., & Buroz-Castillo, E. (2023b). Sustainable use of water from a tropical aquifer. *Environmental Quality Management,* 33(1), 257-277. DOI: 10.1002/tqem.22053

INE, National Statistics Institute. (2001). *XIII general census of population and housing*. Recovered from http://www.ine.gob.ve/index.php?option=com_content&view=category&id=95&Itemid=9#

INE, Instituto Nacional de Estadísticas. (2011). *Censo de población y vivienda 2011*. Recovered from http://www.ine.gov.ve/CENSO2011

IAGUASANJO, Instituto Autónomo Municipal del Agua de San Joaquín. (2021). *Aval de datos de catastro de pozos y variables de gestión*. Recovered from https://es.scribd.com/document/504766970/Aval-datos-IAGUASANJO

López, N., & González, A. (2003). *Diseño de un modelo de organización del sistema de agua potable y saneamiento del estado Carabobo, Venezuela* (tesis de maestría). Universidad de Carabobo. Naguanagua, Venezuela.

López, N., Márquez-Romance, A., & Guevara-Pérez, E. (2020). Change dynamics of land-use and land-cover for tropical wetland management. *Water Practice & Technology*, 15(3), 632-644. Recovered from https://doi.org/10.2166/wpt.2020.049

López-Calatayud, N. C., Márquez-Romance, A. M., & Guevara-Pérez, E. (2021). Spatio-temporal prediction of water balance in the Urama river basin, Venezuela. *DYNA*, 88(217), 58-67. DOI: 10.15446/dyna.v88n217.88222

López-Calatayud, N., Márquez-Romance, A. M., & Guevara-Pérez, E. (2022a). Wetland management modeling in the frame of Ramsar convention. *Journal of Applied Water Engineering and Research*, 10(4), 296-310. DOI: 10.1080/23249676.2021.1982028

López-Calatayud, N. C., Márquez-Romance, A. M., Guevara-Pérez, E., & Buroz-Castillo, E. (2022b). An approach for management modeling of a tropical wetland. *Environmental Quality Management*, 31(3), 423-439. DOI: 10.1002/tqem.21798

López-Calatayud, N. C., Márquez-Romance, A. M., & Guevara-Pérez, E. (2022c). Design of a management model for a tropical wetland. *Environmental Quality Management*, 31(3), 219-231. DOI: 10.1002/tqem.21773

López-Calatayud, N., Márquez-Romance, A. M., & Guevara-Pérez, E. Pérez-Pacheco, S. A., & Buroz-Castillo, E. (2023). *Management modeling of a tropical wetland*. 1st IAHR International Conference on Global Water Security and 4th International Forum on Water Security and Sustainability. October 29-November 1, Changzhou, Jiangsu.

Lucena, H., & Álvarez, H. C. (2011). La industria venezolana, auge y ocaso a través de tres modelos productivos. *Ensayos de Economía,* 21(39), 73-90. Recovered from https://dialnet.unirioja.es/servlet/articulo?codigo=9018666

Lugo, K. Z., Peraza, Y. G., Márquez, A. M., Guevara, E., Pérez, S. A., & Buroz, E. (octubre, 2023). Modelo de prestación de servicios de agua potable y saneamiento a escala municipal en Venezuela. En: Academia Nacional de Ingeniería y Hábitat de Venezuela. *Segundo Simposio Venezolano de Recursos Hídricos*. Academia Nacional de Ingeniería y Hábitat-CIDIAT-ULA. Recovered from http://web.ula.ve/wp-content/uploads/sites/87/2022/09/Memorias_II-Simposio-Venezolano-Recursos-Hidricos-BFinalcorre.pdf

Márquez A., & Carrillo F., V. E. (2015). *Vulnerabilidad hidrogeológica del acuífero del municipio de San Diego, estado Carabobo* (tesis de maestría). Universidad de Carabobo, Naguanagua, Venezuela. Recovered from http://www.riuc.bc.uc.edu.ve/bitstream/123456789/2420/1/vcarrillo.pdf

Márquez, A., & Peraza, Y. G. (2018). *Análisis de la vulnerabilidad del acuífero del municipio Guacara del estado Carabobo* (tesis de maestría). Universidad de Carabobo, Naguanagua, Venezuela. Recovered from http://www.riuc.bc.uc.edu.ve/bitstream/123456789/7664/1/yperaza.pdf

Márquez, A. M., Guevara, E., & Rey, D. (2018). Spatio-temporal geostatistical modeling of hydrogeochemical parameters in the San Diego Aquifer, Venezuela. *Journal of Remote Sensing GIS & Technology*, 4(3). Recovered from http://matjournals.in/index.php/JORSGT/article/view/2799

Márquez, A. M., Guevara, E., & Rey, D. (2019a). Hybrid model for forecasting of changes in LULC using satellite techniques. IEEE *Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 12(1), 252-273. DOI: 10.1109/JSTARS.2018.2885612

Márquez, A. M., Guevara, E., & Rey, D. (2019b). Soil and groundwater remediation proposal in an aquifer of Venezuela by hydrocarbon transport geostatistical modeling. *Journal of Remote Sensing GIS & Technology*, 5(1). Recovered from http://matjournals.in/index.php/JORSGT/article/view/2965

Márquez, A. M., Guevara, E., Pérez, S., & Rey, D. (2020). Avances de la Universidad de Carabobo en formación de recursos humanos y estudios sobre recursos hídricos. En: Academia Nacional de Ingeniería y Hábitat de Venezuela. *I Simposio Nacional de Recursos Hídricos.* Academia de Ingeniería y Hábitat de Venezuela-CIDIAT-ULA. Recovered from https://www.youtube.com/watch?v=cR9I-YdWuSE

Márquez, A., Freytez, E., Maldonado, J., Guevara, E., Pérez, S., & Buroz, E. (2023). Soil and groundwater remediation proposal for hydrocarbons in a tropical aquifer. *Journal of Applied Water Engineering and Research*, 11(4), 423-452. DOI: 10.1080/23249676.2022.2089246

Márquez-Romance, A. M., Farías-de-Márquez, B. E., & Guevara-Pérez, E. (2022a). Land use and land cover change detection using satellite remote sensing techniques in a tropical basin. *Environmental Quality Management*, 31(4), 183-196. DOI: 10.1002/tqem.21802

Márquez-Romance, A., López-Calatayud, N., Farías-De-Márquez, B., & Guevara-Pérez, E. (2022b). Approach to a new forecasting method of hydrological variables in tropical basins. *Environmental Quality Management*, 31(4), 433-448. DOI: 10.1002/tqem.21829

Márquez-Romance, A. M., Freytez-Boggio, E., Cárdenas-Izaguirre, S. F., Maldonado-Maldonado, J. I., Guevara-Pérez, E., Pérez-Pacheco, S. A., & Buroz-Castillo, E. (2022c). An approach to remediation of a tropical aquifer contaminated with hydrocarbons. *Environmental Quality Management*, 31(4), 357-390. DOI: 10.1002/tqem.21820

Márquez-Romance, A., Freytez-Boggio, E., Maldonado-Maldonado, J., Cárdenas-Izaguirre, S., Pérez-Rodríguez, M., Luque-Mirabal, O., Guevara-Pérez, E., Pérez-Pacheco, S., & Buroz-Castillo, E. (2023). An approach for restoration of the water quality with emphasis on the removal of organochlorine pesticides and eutrophic conditions in tropical rivers. *Environmental Quality Management*, 33(1), 183-202. DOI: 10.1002/tqem.22038

MINEC & IAGUASANJO, Ministerio del Poder Popular para el Ecosocialismo & Instituto Autónomo Municipal del Agua de San Joaquín. (2020). *Endorsement of supply of data on deep well coding, lithological profiles and physicochemical parameters in the period 1970-2020*. Recovered from https://es.scribd.com/document/504766970/Aval-datos-IAGUASANJO

Municipal Gazette No. 4664. (2020). *Ordinance for the creation of the San Joaquin Municipal Autonomous Water Institute*. Recovered from https://es.scribd.com/document/504775065/Ordenanza-IAGUASANJO

National Assembly of the Bolivarian Republic of Venezuela. (November 6, 2007a). *Law of Partial Reform of the Organic Law for the Provision of DWSS*. Recovered from https://asambleanacionalvenezuela.org/leyes/sancionadas/ley_de_reforma_parcial_de_la_ley_org%C3%A1nica_para_la_prestaci%C3%B3n_de_los_servicios_de_agua_potable_y_de_saneamiento

National Assembly of the Bolivarian Republic of Venezuela. (2001). *Organic Law for the Provision of Drinking Water and Sanitation Services*. Recovered from https://consensomontevideo.cepal.org/es/instrumento/ley-organica-de-prestacion-de-servicio-de-agua-potable-y-saneamiento-2001

National Assembly of the Bolivarian Republic of Venezuela. (2007b). Water Law. *Official Gazette*, (38), 595. Caracas, Venezuela: National Assembly of the Bolivarian Republic of Venezuela.

OCEI, Oficina Central de Estadística e Informática. (1996). *La OCEI y su información*. Recovered from http://isbn.cenal.gob.ve/catalogo.php?mode=detalle&nt=42785

Regulations for the classification and quality control of the waters of the Lake Valencia Basin. (January 13, 1999). *Official Gazette*, (5), 305.

Peraza, Y. G., Lugo, K. Z., Márquez, A. M., Guevara, G. E., Pérez, S. A., & Buroz, E. (2021). Design and evaluation of a model for the provision of drinking water and sanitation services at municipal scale for Venezuela. *Journal of Remote Sensing GIS & Technology*, 7(2). Recovered from http://matjournals.in/index.php/JORSGT/article/view/6987

Peraza-Barreto, Y. G., Lugo-Piña, K. Z., Márquez-Romance, A. M., Guevara-Pérez, E., Pérez-Pacheco, S. A., & Buroz-Castillo, E. (2022). A novel approach to model for the management of drinking water and sanitation services at municipal scale. *Environmental Quality Management*, 32(2), 341-355. DOI: 10.1002/tqem.21851

Reyes, S. W., & Márquez, A. (2019). *Sustainable management of water resources in the northern zone of the Guacara municipality of Carabobo state* (tesis de maestría). Universidad de Carabobo, Naguanagua, Venezuela. Recovered from http://www.riuc.bc.uc.edu.ve/bitstream/123456789/8188/1/sreyes.pdf

Sanitary Standards for Drinking Water Quality. (February 13, 1998). *Official Gazette*, (36), 395.

Tortajada, C. (2020). Contributions of recycled wastewater to clean water and sanitation Sustainable Development Goals. *NPJ Clean Water*, 3(1), 22. DOI: 10.1038/s41545-020-0069-3

UN, United Nations. (2023). *Agenda 2030*. Recovered from https://sdgs.un.org/2030agenda

UTAA & IAGUASANJO, Unidad Territorial de Atención de las Aguas & Instituto Autónomo Municipal del Agua de San Joaquín. (2022). *Water quality evaluation. Laboratory of Ministry of Waters (Report of results)*. Maracay, Venezuela: Unidad Territorial de Atención de las Aguas & Instituto Autónomo Municipal del Agua de San Joaquín.