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Consumption, Extraction, Recharge and Availability of Water in the Main Subsectors of the Mexican Manufacturing Industry, Regional Levels

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ABSTRACT

If the consumptive use of water in agriculture, domestic, thermoelectric plants and service enterprices does not decrease, will the water be available for consumption in the manufacturing industries? There is no certainty of the availability of this resource in the medium or long term. Aquifer recharge depends on temperature-precipitation cycles and desalination processes, where appropriate. Using gray forecast models, linear and non-linear regression, the main sustainability indicators were calculated considering the subsectors that most demand water, to obtain a medium-term vision, applying scenarios to 2030 of status of resource at the national level, (administrative) water region and federative entity, as well as, by surface or underground source. Pollutant aspects or water quality were not considered. The results show the urgent decision-making to ensure the availability of water.

Keywords: Industrial water consumption, water pressure, water availability industrial use, SDG indicators.

INTRODUCTION

Historically, agriculture consumes about 70% of available water. The self-sufficient industry excluding thermoelectric plants, 4%, the rest for public use, thermoelectric and hydroelectric. The industrial uses of water can be divided into three large groups: heat transfer, power generation and application to processes. The present study focuses on the latter at the national level (N), administrative water region (RHA) and federal entity (EF), taking as a case the Lerma-Santiago-Pacific system (RHA-VIII) and the state of Aguascalientes (AGS). The general methodology can be applied to any other case. In the production line there are stages that need water, one of them is the transport of materials that uses pipes or channels. The industries with high demand for water in Latin America and the Caribbean are the food, paper pulp, textiles, leather tanning, chemical and pharmaceutical, and oil processing industries [1, 2]. In selected regions and main groups of subsectors demanding the resource, their consumption rate by 2030 was calculated. As a comparative case in the manufacturing industry, Revollo et al. [3] established the value of water (VAm) from the San Juan River in the RHA-VI. This subregion was declared in deficit in 2015 by decree [4]. Transforming the values published by subsector and comparing them with those calculated here, there are differences of an order of magnitude between the water consumption indices (ICAm) for the case of AGS, see table 1. It all depends on the recharge of aquifers (RA) and taking care of the volume of extraction (EAm). The RA depends exclusively on rainfall and runoff in the area, as well as temperatures [2] that affect rain cycles, so observing climate change (CC) is decisive. There are other forms of supply such

as desalination of water in the coastal states. Water productivity (PIA) is the ratio between the production of the product (goods and services) and the need for water. Another aspect of interest is the effective use of water (IEA), which is the relationship between the VAm that is used and the value of industrial production (VPI) obtained with said water, that is, a general indicator of performance in the use of the water [5,6]:

$$IEA = \frac{units\ of\ water\ consumed}{amount\ of\ product\ obtained} \ldots\ldots\ldots (1)$$

Mexico in 2006 surpassed El Salvador, Trinidad and Tobago and Guatemala in this aspect [2]. For 2008, the IEA in Mexico, RHA-VII and AGS were 0.012215633, 0.013418551 and 0.005897867. They have been increasing since then, which speaks of the implementation of technology and the use of recycled water. The indicators mentioned together with the population growth rates and the gross domestic product (GDP) are related to the water pressure (PH) and the availability of water (DA) in the future. From data up to 2019, values to 2030 were calculated for three groups of subsectors. NAICS code is used. A) Group 322-323: Paper and cardboard industry. B) Group 324-326: Manufacture of products derived from petroleum and coal. Chemical industry. Plastic and rubber industry. C) Group 333-336: Manufacture of machinery and equipment. Manufacture of computer equipment, communication, measurement and other electronic equipment, components and accessories. Manufacture of accessories, electrical appliances and electrical power generation equipment. Manufacture of transportation equipment.

The objective of this study was to obtain a medium-term overview of the status of water for consumption in the most demanding economic subsectors and to compare its dynamics with that of other related indicators. Section 2 presents the resource status in the three study regions. The methodologies and the scheme are explained in section 3. In section 4, the initial and final results are presented according to the scheme in figure 1. The analysis and discussion of the results obtained appear in section 5. Finally, in section 6, the conclusions.

Brief state of art

In Mexico, 13 RHAs were established, of which RHA-VIII corresponds to 5.78% of the national territory and presents one of the most industrialized and productive areas of the country. Within the region, AGS is the one that suffers the most from the liquid, having a high volume of extraction and low recharge of aquifers, with a semi-arid climate in 86% of its territory and temperate sub-humid in the rest. Annual precipitation, maximum (Tmax) and minimum (Tmin) daily average temperatures from 1926 to 2020 of 526 mm, 30.86°C and -2.69°C, respectively. A positive trend of Tmax of 0.77°C, early shift of the beginning of the rainy season, changes in its frequency and intensity were detected. From 1980 to 2020, the changes in Tmax and Tmin were 0.00008 ºC/day and -0.00017 ºC/day, respectively [7]. AGS corresponds in the territory of the RHA-VIII to 1.8% while Jalisco is the largest with 24.7% [8]. Although it is one with less extension, it has had an explosive economic development in the last decades with the consequent population increase and the requirement of infrastructure and services. Subtle local changes in temperature, soil type and orography affect precipitation cycles and consequently aquifer recharge. There are 5 dams and 32 watercourses for exclusive domestic-industrial use [8,9], the others are for consumptive agricultural use. There are no thermoelectric or hydroelectric plants. There are five aquifers: Aguascalientes Valley, Chicalote Valley, El Llano, Venadero and Calvillo Valley. Which present overexploitation (since 2010) and

in 2021 a deficit (recharge-extraction) of -100.4, -11.9, -5.8, -0.6 and -17.9 [hm^3], respectively. While there is a positive balance in the RHA-VIII (1617.79 hm^3) and in the country (51,245.39 hm^3) [8-11]. With this scenario, how is it possible to maintain productivity while maintaining low water availability?

IEA was built with the particular indicators of Mexico defined in the National Water Program 2020-2024 published in the DOF on December 30, 2020 in the heading Parameter of priority objective 2 [4]. Those shown in this work correspond to the level of regionalized economic subsectors (IEAm). Taking into account all socioeconomic sectors, the minimum value worldwide was 0.1 (Botswana 2000, Libya 2016, Mali 2000-2006, Nigeria 2000-2011) and in Mexico it was 0.17 in 2005 and 2006. The world maximum value was 46331.38 (Saint Vincent and the Grenadines in 2018) and in Mexico of 59.85 in 2018 [6]. In the case of the manufacturing industry (m) in Mexico and the regions studied, the range was from 0.005416098 to 0.055343133. The evolution of the IEAm was calculated using gray methods with up to 13 initial data (2007-2019), the Runge-Kutta interpolation method for some unregistered values based on the analysis of functional forms of behavior of the variables involved.

In 1993 industrial consumption was 1.7%, currently it is 3% for AGS [10,11]. In the RHA-VIII there are four predominant climates: warm subhumid, dry and semi-dry, temperate humid and warm humid, which allows the recharge of aquifers and basins in the Pacific but not in the Santiago River and aquifers in AGS. In case N, seven types of climates are recorded: a) with greater extension the climates: warm sub-humid, dry and semi-dry, very dry or dry desert; b) with a smaller surface, the climates: warm humid, temperate sub-humid, temperate humid and cold with the minimum surface [12].

Arreguín [1] warns about the lack of actions for the efficient use of water since government programs are grouped by scope, that is, there are efficient use programs for industries, municipalities, or basins, but there is no interrelation between them, to really optimize the use of the resource, orienting all in the same direction. In its comprehensive thinking it follows that planning is a priority from the basin level. The chemical, sugar, oil, pulp and paper industries, at the national level, are supplied directly from rivers, streams, lakes or aquifers. EAm reached 7083.6 hm^3 in 2005 and 4400 hm^3 in 2019. In RHA-VIII of 392.9 and 618, AGS of 12 and 22, respectively [10]. Note: 1 hm^3 = 106 m^3. It was observed that water consumption has increased in AGS (83.3%) and RHA-VIII (57.3%), while at the N level it has decreased by 37.9%. The state municipalities that consumed the most water in industries were Aguascalientes and Calvillo, and of underground origin [11]. In the 2000s, the municipality of AGS mainly consumed water from deep wells between 300 and 600 meters [13], currently they have had to drill up to 800 meters in some areas with the presence of heavy metals such as arsenic, zinc and cadmium [8,14]. Revollo et al. [3], calculated VAm for manufacturing activities through Cobb-Douglas and Translog-type production functions, see Table 1.

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Table 1. Comparative example.Value and index of water consumption in the San Juan River water subregion for a group of economic subsectors (2017). Source: Revollo et al. [3][a]. Exchange rate Mexican peso ($Mx) per US dollar, BANXICO 2021[a]. Own elaborationb. Cubic meter [m³]

NAICS code	Water value (VAm) [$Mx/m³][a]	Water consumption index (ICA)[b]
322-323	242.09408 to 272.35584	0.00413 to 0.00367
324-326	166.43968 to 253.44224	0.00601 to 0.00395
333-336	7.56544 to 300.72624	0.13218 to 0.00333

In developed countries, gross value added (GVA) has increased as industrial water use, after peaking in the 1990s, has been declining, with the exception of Italy. Said behavior corresponds to the Environmental Kuznets curve for economic growth (income) vs. water use (natural resources), Rossi et al. [15]. In the case of Mexico and its regions, this dynamic is not evident. In 2011, the Polish manufacturing industry consumed 651.6 hm³ of water, of which 97% was of underground origin [16], with a GDPm 11.85% lower than that of Mexico [17]. Mexico consumed 41% less groundwater for industrial use. In methodological aspects where few data are available, the Gray prediction method is used. It has been applied with a minimum of 4 data. Fang et al. [18] applied the basic method GM(1,1) with improved data, obtaining an accuracy greater than 97% in their forecast of industrial water consumption (CAI). Here, accuracies greater than 92% were obtained with data from 2007 to 2019 except for AGS. With less data the algorithm diverges. One aspect studied by Koval et al. [19] was the impact on water consumption by the population of industrialized cities. They reported that the quality of the water, in the domestic intakes, is compromised due to the extraction in aquifers close to the industries and the deep extraction of water, causing the use in homes and industrial processes of internal methods of purification of heavy metals and biologicals. In Ukraine, 27.6% use bottled water for cooking.

METHODOLOGY

It began by establishing the regional level and indicators related to economic growth and sustainability based on the available data. Rewriting equation 1 for the consumptive use of water in the self-sufficient industry and available information [4]:

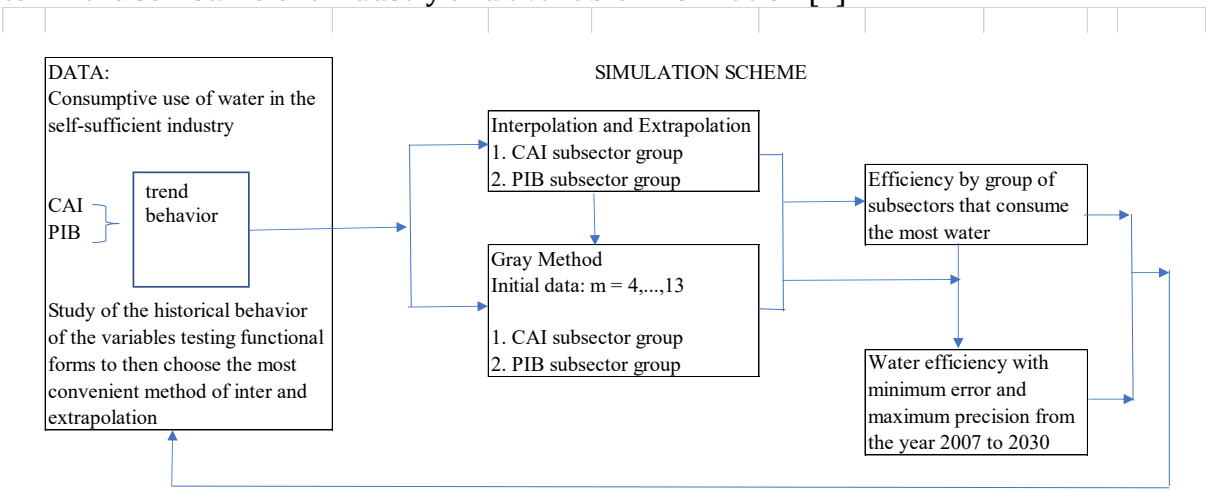

Figure 1. Scheme of the simulation for the calculation of the efficiency indicator in the use of water. Own elaboration

Functional forms

To calculate the trends of each variable, various functional forms and autoregressive models were tested, leaving mainly the following general expressions, where f(t) is the study variable (Q, CAI, EA, RA, GDPm), t is time (in years) and ε_t is error:

$$f(t) = mt + b \dots\dots\dots (3)$$
$$f(t) = At^m + \varepsilon_t \dots\dots\dots (4)$$
$$f(t) = A\ Log(t)^m + b + \varepsilon_t \dots\dots\dots (5)$$
$$f(t) = A\ Exp(t) + b + \varepsilon_t \dots\dots\dots (6)$$

For balance, RA and EA:

$$Ln(GDPm)_t = Ln(CAI_t) + Ln(RA_t) + Ln(EA_t) + \varepsilon_t \dots\dots\dots (7)$$
$$Ln(GDPm)_t = Ln(CAI_t) + Ln(RA_t) + Ln(CAI_{t-1}) + Ln(RA_{t-1}) + \varepsilon_t \dots\dots\dots (8)$$

Interpolation and Extrapolation

As some data are missing in certain years and levels, the widely known Newton-Raphson and Runge-Kutta methods [20] were tried to reconstruct the values that required it.

Simulation

From the forecasting methods applied to the estimation of water consumption, especially the so-called Grays [18,21], the following immediate value is successively constructed maintaining the same number of input data (immediate above). Here we initially worked with sets of 4 data starting from 2016 to 2019. To improve the convergence of the method, the size of the initial group was extended, establishing 13 data (2007-2019) as the data set that minimizes the error and maximizes precision, see figure 1. The approximation took into account even the first order derivatives.

GM(1,1) Prediction Model:

original data,

$$f^{(0)} = \{f^{(0)}(1), f^{(0)}(2), \dots, f^{(0)}(n)\} \dots\dots\dots (9)$$

It is generated

$$f^{(1)} = \{f^{(1)}(1), f^{(1)}(2), \dots, f^{(1)}(n)\} \dots\dots\dots (10)$$
$$f^{(1)} = \sum_{i=1}^{k} f^{(0)}(i) \dots\dots\dots (11)$$

Therefore, the random influence of the original sequence is weakened. Fitting to the weakened white series $\{f^{(1)}(k)\}$, the forecast model is established. According to the adjusted series, the white background $z^{(1)}(k)$ is calculated:

$$z^{(1)}(k) = 0.5f^{(1)}(k) + 0.5f^{(1)}(k-1) \dots\dots\dots (12)$$

From this, the gray differential equation and the whitening differential equation of GM (1, 1) are obtained:

$$f^{(0)}(k) + az^{(1)}(k) = b \dots\dots\dots (13)$$

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$$\frac{df^{(1)}}{dt} + az^{(1)}(k) = b \dots\dots\dots (14)$$

where a is the development coefficient, which reflects the development trend of $f^{(0)}$ and $f^{(1)}$; b is the gray action; a and b are the parameters of the differential equation. Set

$$\vec{A} = (a\ b)^T = \begin{bmatrix} a \\ b \end{bmatrix} \dots\dots\dots (15)$$

$$B = \begin{bmatrix} z^{(1)}(2) & 1 \\ \dots & \dots \\ z^{(1)}(n) & 1 \end{bmatrix} \dots\dots\dots (16)$$

$$\vec{Y} = \begin{bmatrix} f^{(0)}(2) \\ \dots \\ f^{(0)}(n) \end{bmatrix} \dots\dots\dots (17)$$

Solving by least squares:

$$\vec{A} = (B^T B)^{-1} B^T \vec{Y} \dots\dots\dots (18)$$

Initial conditions:

$$f^{(0)}(1) = f^{(1)}(1) = \hat{f}^{(1)}(1) \dots\dots\dots (19)$$

=>

$$\hat{f}^{(1)}(k+1) = \left(f^{(0)}(1) - \frac{b}{a}\right) e^{-ak} + \frac{b}{a} \dots\dots\dots (20)$$

$$\hat{f}^{(0)}(k+1) = \hat{f}^{(1)}(k+1) - \hat{f}^{(1)}(k) \dots\dots\dots (21)$$

$\hat{f}^{(0)}(k)\ and\ \hat{f}^{(1)}(k)$ are the predicted values at time k in the original sequence and the accumulated sequence, respectively.

Equations (20) and (21) are time response function models of the basic gray prediction model. They are the equations of specific functions to predict future data. The farther into the future time, the larger the gray space of the predicted value. Therefore, only a few data points next to the first n data points in the original material have high accuracy and practical importance for prediction.

In the prediction model new information will be added to the data stream and old data will be removed at the same time, equations 9-21. Then there is the same dimension between the new development sequence and the original sequence, that is,

$$f^{(0)} = \left\{f^{(0)}(1), f^{(0)}(2), \dots, f^{(0)}(n)\right\} \dots\dots\dots (22)$$

The new data $f^{(0)}(n+1)$ will be attached to the end of the stream and the data $f^{(0)}(1)$ will be removed at the same time.

$$f^{(0)} = \left\{f^{(0)}(2), f^{(0)}(3), \dots, f^{(0)}(n+1)\right\} \dots\dots\dots (23)$$

It is called as dynamic new information and gray model of equal dimension, equations 30-31. The residual test consists of inspecting the error of the model value and the actual value per point. For a given sequence, $f^{(0)}$, ε(k) is the residue of GM (1, 1). Let ε(prom) be the average residual and p^0 is the modeling accuracy of GM(1, 1).

$$\varepsilon(k) = \frac{f^{(0)}(k) - \hat{f}^{(0)}(k)}{f^{(0)}(k)} 100\% \dots\dots\dots (24)$$

$$\varepsilon(prom) = \frac{1}{n-1}\sum_{k=2}^{n}|\varepsilon(k)| \ldots\ldots\ldots (25)$$

$$p^0 = (1-\varepsilon(prom))100\% \ldots\ldots\ldots (26)$$

Accuracies are obtained by comparing actual data with predicted data. The algorithm was applied to the logarithm of data to minimize the errors given its behavior, *see* equations 3-8, 24-26.

Historical data reported by CONAGUA [8-10] covering the years 1998 to 2019 were used, as well as information on population projections, exchange rate and hydrological aspects [11,22,23]. Scenarios: optimal (minimum price, maximum production), worst (maximum price, minimum production) and trend (average price, average production).

RESULTS

Initial Results

The main results appear in tables 2 to 7, equations 27-50 and in figures 2 to 4. The advisory use of water in the self-sufficient industry is distributed mainly in manufacturing industries followed by services, see table 2.

Table 2. Distribution of the consumptive use of water in the self-sufficient industry. Sources: CONAGUA[a], own elaborated[b]

Distribution use self-sufficient industry (2007[a])	Agroindustry [hm³]	Services [hm³]	Industrial (31-33) [hm³]	Trade [hm³]	% Total consumptive use
N	2.79790862	1174.97475	1955.5986	0.05874874	3.97%
RHA-VIII	0.35918681	150.839604	251.053667	0.00754198	2.90%
AGS	0.01017931	4.27477624	7.11483071	0.00021374	1.82%

Distribution use self-sufficient industry (2017[b])	Agroindustry [hm³]	Services [hm³]	Industrial (31-33) [hm³]	Trade [hm³]	% Total consumptive use
N	3.81000893	1600.00375	2663.00624	0.08000019	4.86%
RHA-VIII	0.51968061	218.238577	363.230831	0.01091193	3.67%
AGS	0.01517967	6.37466633	10.6098353	0.00031873	2.73%

Gross water extraction for industrial use. Figure 2 visualizes the differences in the extraction of water by surface or underground origin at the three regional levels. Equations below summarizes the results obtained from the linear and non-linear adjustments between the variables considered in the evolutionary dynamics.

Gross water extraction for industrial use. Figure 2 visualizes the differences in the extraction of water by surface or underground origin at the three regional levels.

Next, equations 27 to 50, summarize the results obtained from the linear and non-linear adjustments between the variables considered in the evolutionary dynamics.

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All statistical tests were carried out, the main ones are shown here: estimated coefficients, (p-value), R^2, region.

$$VAm_N = 1.7058\ t - 3410.74 \ldots\ldots\ldots (27)$$
$$(0.0000)\quad (0.0001)$$

R^2 = 0.807, Nivel N

$$VAm_{RHA-VIII} = 1.6853\ t - 3367.97 \ldots\ldots\ldots (28)$$
$$(0.0000)\quad (0.0000)$$

R^2 = 0.838, Nivel RHA-VIII

$$VAm_{AGS} = 1.9481\ t - 3883.3 \ldots\ldots\ldots (29)$$
$$(0.0000)\qquad (0.0000)$$

R^2 = 0.975, Nivel AGS

$$Ln(CAI)_N = 66.7555\ Ln(t) - 500.1236 \ldots\ldots\ldots (30)$$
$$(0.0000)\qquad (0.0000)$$

R^2 = 0.899, Nivel N

$$CAI_{RHA-VIII} = 10.7800\ t - 21380.78 \ldots\ldots\ldots (31)$$
$$(0.0000)\qquad (0.0000)$$

R^2 = 0.912, Nivel RHA-VIII

$$CAI_{AGS} = 0.5848\ t - 1168.086 \ldots\ldots\ldots (32)$$
$$(0.0000)\quad (0.0000)$$

R^2 = 0.874, Nivel AGS

$$RA_N = 1361.469\ t - 2651997.3 \ldots\ldots\ldots (33)$$
$$(0.0001)\qquad (0.0000)$$

R^2 = 0.895, Nivel N

$$Ln(RA)_{RHA-VIII} = 40.3069\ Ln(t) - 297.51 \ldots\ldots\ldots (34)$$
$$(0.0000)\qquad (0.0000)$$

R^2 = 0.882, Nivel RHA-VIII

$$EAm_N = 123.689\ t - 245382.8 \ldots\ldots\ldots (35)$$
$$(0.0000)\quad (0.0010)$$

R^2 = 0.892, Nivel N

$$Ln(EAm)_{RHA-VIII} = 81.222\ Ln(t) - 611.61 \ldots\ldots\ldots (36)$$
$$(0.0000)\qquad (0.0000)$$

R^2 = 0.933, Nivel RHA-VIII

$$EAm_{AGS} = 0.93706\ t - 1871.61 \ldots\ldots\ldots (37)$$
$$(0.0000)\qquad (0.0002)$$

R^2 = 0.874, Nivel AGS

$$Ln(DA)_N = -16.18\ Ln(t) + 149.943 \ldots\ldots\ldots (38)$$
$$(0.0013)\qquad (0.0022)$$

R^2 = 0.858, Nivel N

$$DA_N = -0.0264\ RA - 0.0061\ EAm \ldots\ldots\ldots (39)$$
$$(0.1103)\quad (0.0000)$$

R^2 = 0.998, Nivel N

$$Ln(DA)_{RHA-VIII} = -32.098\ Ln(t) + 268.5102 \ldots\ldots\ldots (40)$$
$$(0.0030)\qquad (0.0028)$$

R^2 = 0.830, Nivel RHA-VIII

$$DA_{RHA-VIII} = -0.000051\ RA + 0.0037\ EAm \ldots\ldots\ldots (41)$$
$$(0.8974)\qquad (0.0021)$$

R^2 = 0.995, Nivel RHA-VIII

$$Ln(DA)_{AGS} = 11.697\ Ln(t) - 68.936 \dots\dots\dots (42)$$
(0.0001) (0.0000)
R^2 = 0.983, Nivel AGS

$$PH_N = 0.26404\ t - 513.23 \dots\dots\dots (43)$$
(0.000) (0.0000)
R^2 = 0.939, Nivel N

$$Ln(PH)_N = 0.36817\ Ln(DA) - 0.2817\ Ln(CAI) \dots\dots\dots (44)$$
(0.0015) (0.0002)
R^2 = 0.999, Nivel N

$$Ln(PH)_N = -0.2867\ Ln(DA) + 0.3669\ Ln(EAm) \dots\dots\dots (45)$$
(0.0015) (0.0000)
R^2 = 0.999, Nivel N

$$PH_{RHA-VIII} = 0.63096\ t - 1226.897 \dots\dots\dots (46)$$
(0.0000) (0.0000)
R^2 = 0.930, Nivel RHA-VIII

$$Ln(PH)_{RHA-VIII} = 0.36449\ Ln(t) - 0.2425 \dots\dots\dots (47)$$
(0.0001) (0.0000)
R^2 = 0.999, Nivel RHA-VIII

$$Ln(PH)_{RHA-VIII} = -0.2482\ Ln(DA) + 0.36323\ Ln(EAm) \dots\dots\dots (48)$$
(0.0002) (0.0000)
R^2 = 0.999, Nivel RHA-VIII

$$Ln(GDPm)_N = -30.453\ Ln(CAI) + 0.445\ Ln(RA) + 30.974\ Ln(EAm) \dots\dots\dots (49)$$
(0.0051) (0.0064) (0.0046)
R^2 = 0.999, Nivel N

$$Ln(GDPm)_{RHA-VIII} = -75.348\ Ln(CAI) + 0.756\ Ln(RA) + 76.331\ Ln(EAm) \dots\dots\dots (50)$$
(0.0000) (0.0021) (0.0000)
R^2 = 0.999, Nivel RHA-VIII

From equations 27-29, the value of water for the manufacturing industry showed a linear behavior with a positive trend in the three study regions. Water consumption in the industry presented linear behavior with positive trends in RHA-VIII and AGS, and non-linear behavior at the N level with a positive rate, equations 30-32. From equations 33-37, RA and AEm evolve in a linear and non-linear manner at the N and RHA-VIII levels, respectively.

Net effect on DA is negative, indicating a negative trend, *see* equations 38, 40 and 42. DA for manufacturing use depends mainly on its extraction at both for N and RHA-VIII, equations 39 and 41. The recharge of the aquifers is not statistically significant since it strongly depends on the climatic conditions. It was observed that the recharge speed is less than the extraction speed, this difference being alarming in the RHA-VIII. The consequences of the above are reflected in the PH, equations 45 and 48. From equations 43 and 46, both at N and RHA-VIII levels, the linear trend is positive, but observing its interrelation with consumption and extraction, more water was extracted, so the PH was greater, reducing DA, equations 44, 45 and 48. And, when DA is greater, then greater was its consumption in manufacturing, both with a non-linear dynamic (potential). Finally, from equations 49 and 50, GDPm is related to the water balance. The consumption and extraction rates are similar and differ greatly from the recharge rate, both for N and RHA-VIII levels. The rates are higher in RHA-VIII than at the N level. In a

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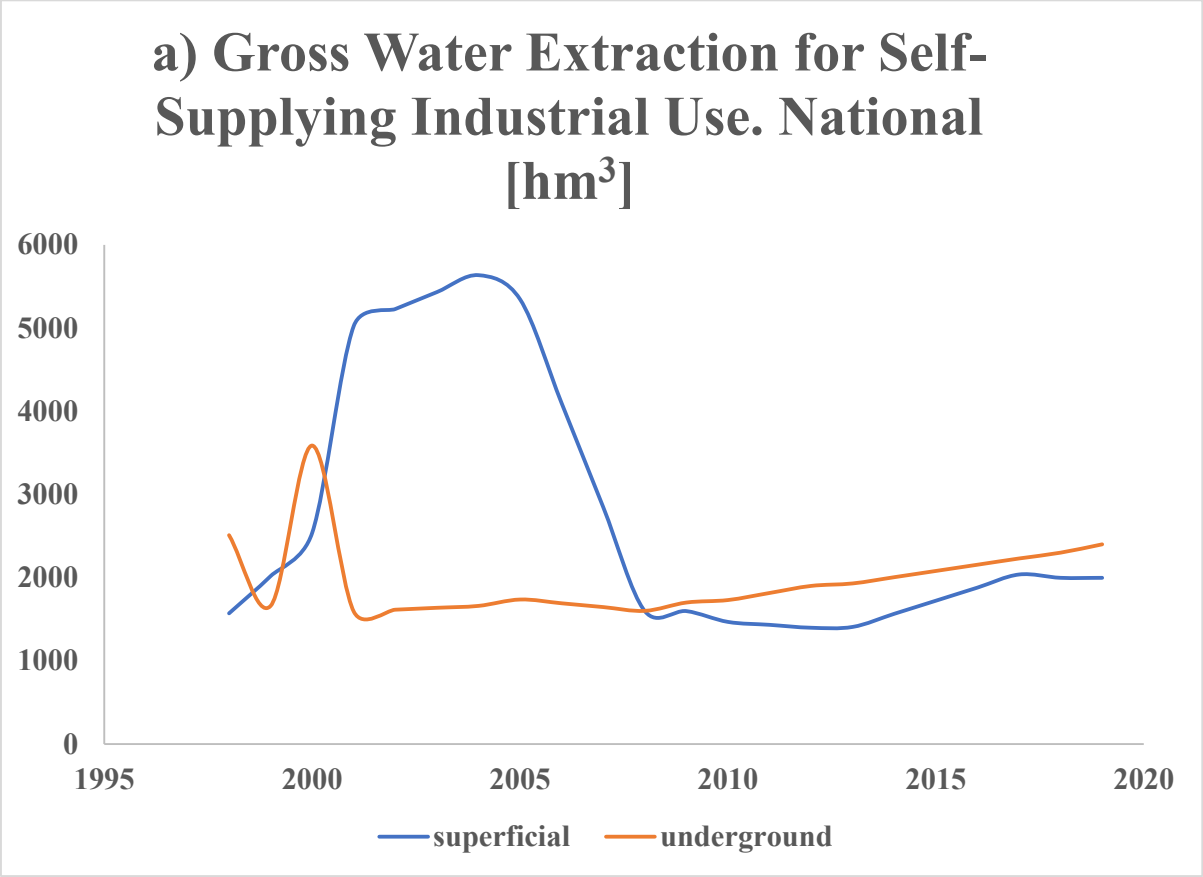
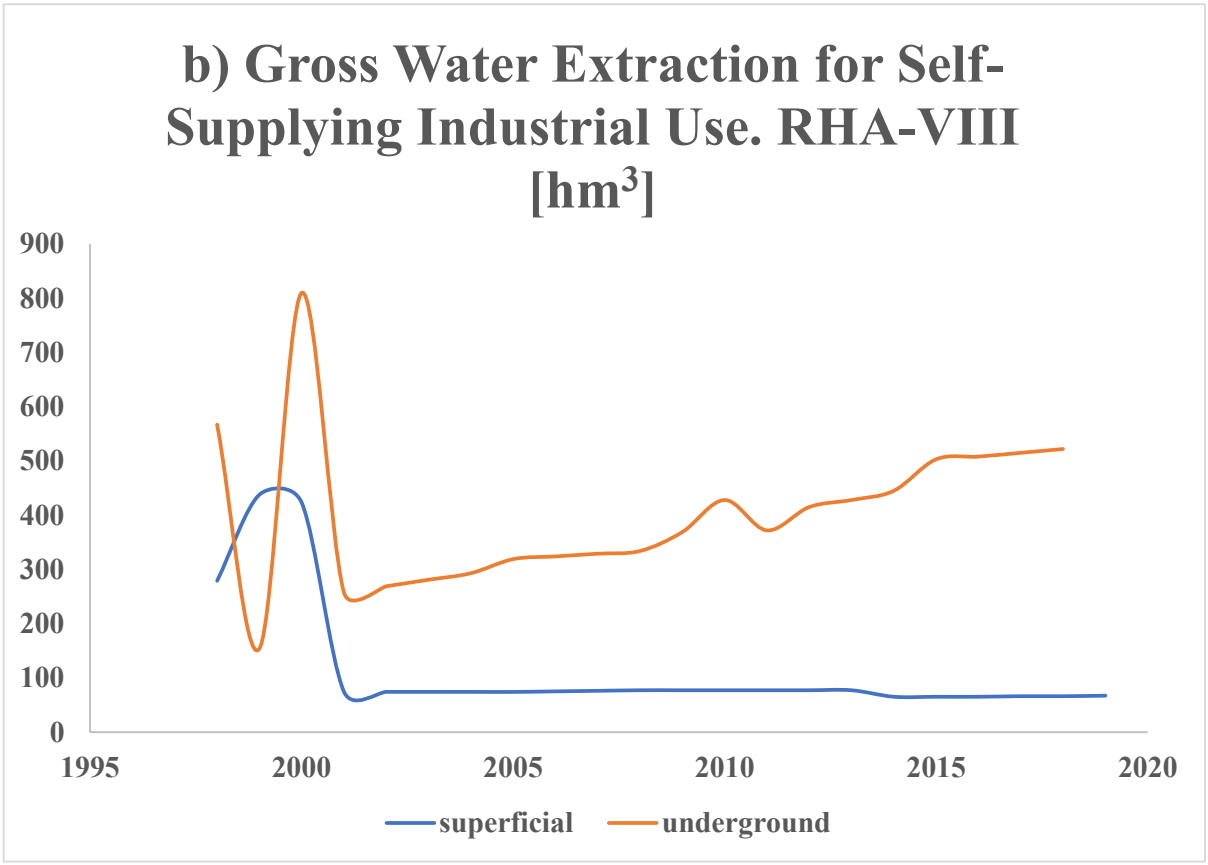
study by Ledesma *et al*. 2021, the change in temperatures and precipitation in AGS due to global climate change was calculated. For an optimal scenario, the global increase would be between 0.3 and 1.7 °C, which corresponded to a change in AGS between 0.0027 and 0.306 °C. They showed that the rain patterns have a tendency to be earlier, changing their intensity. Consequently, aquifer recharge is strongly affected [13].





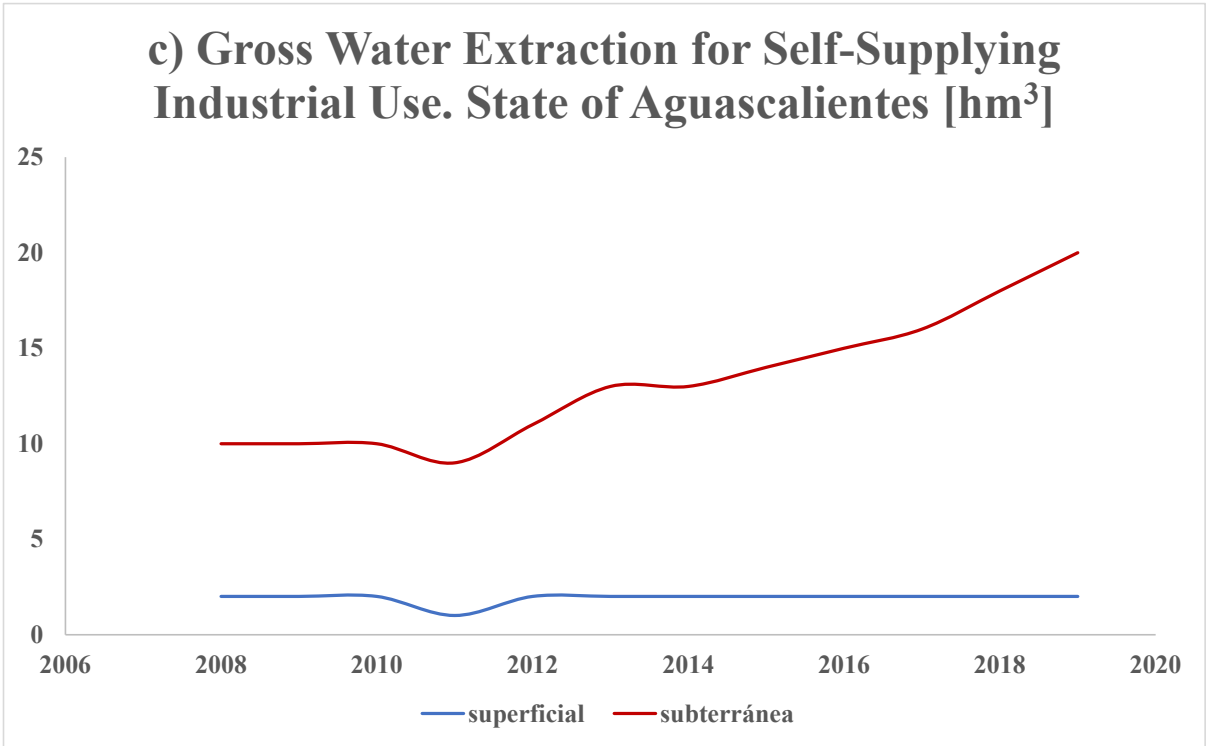


Figure 2. Evolution of water extraction by type of source at a) National, b) RHA-VIII and c) State of Aguascalientes. Sources: CONAGUA original data. Own elaborated

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Figure 3 shows the dynamics between recharge and water consumption by the manufacturing industry. And figure 4 compares water productivity at the three levels by group of subsectors. Its dynamics presents a large non-linear drop.

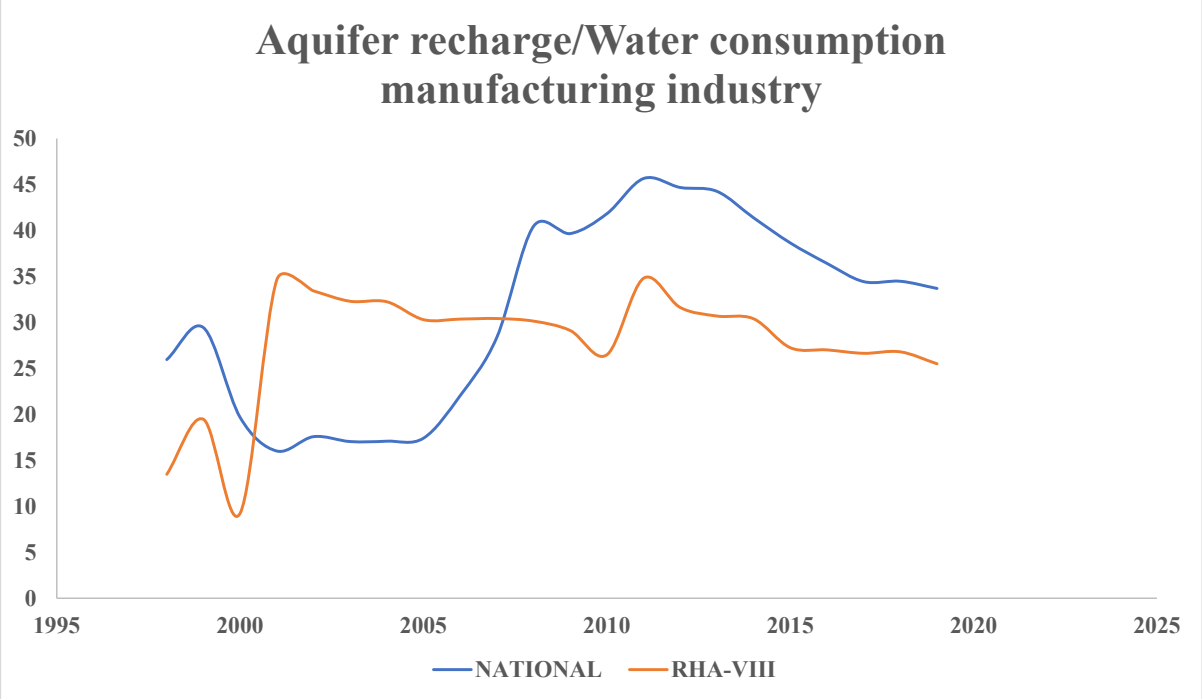

Figure 3 Water recharge/consumption ratio for manufacturing use at both national and RHA-VIII levels. Source: CONAGUA original data. Own elaborated

Finally, applying a GM(1,1) model to logarithms of the CAI with data from 2007 to 2019, the error was reduced to 5.9%, 7.7% and 31.3% at the N, RHA-VIII and AGS, respectively.

The following section presents the results of the simulations to 2030.

Results. Simulations

Using the projections under GDP growth and water consumption scenarios for the manufacturing industry, sectors 31-33, they are observed in table 4 from 1998 to 2030.

Table 3. ICAm. Water consumption index in the manufacturing industry (31-33) [m³/$]. 1998-2019, 2030, 2040 and 2050*

Level/Year	1998	1999	2000	2001	2002
N	0.00117702	0.00103175	0.0016196	0.00179397	0.00190138
RHA-VIII	0.00152424	0.00103708	0.00203639	0.0005593	0.00059249
AGS	ND	ND	ND	ND	ND
Level/Year	2003	2004	2005	2006	2007
N	0.00197668	0.00197977	0.00187413	0.00146305	0.0011294
RHA-VIII	0.00061557	0.00061608	0.00064167	0.00071302	0.00070035
AGS	ND	ND	ND	ND	ND
Level/Year	2008	2009	2010	2011	2012
N	0.00081838	0.00093599	0.00083464	0.00082146	0.0008051
RHA-VIII	0.00073555	0.00068379	0.00071996	0.00062735	0.00065988
AGS	0.00021525	0.00024327	0.00019866	0.00015888	0.00019351
Level/Year	2013	2014	2015	2016	2017
N	0.00080809	0.00083099	0.00085976	0.00090135	0.00092433
RHA-VIII	0.00066985	0.00062175	0.00064494	0.00064769	0.00063264
AGS	0.00020861	0.00017068	0.00017255	0.00017416	0.00018054
Level/Year	2018	2019	2030	2040	2050
N	0.00091429	0.00093013	0.0007563 ± 0.000411	0.000755 ± 0.0003814	0.00072970 ± 0.0003565
RHA-VIII	0.0006248	0.00065321	0.0006721 ± 0.0002827	0.0006695 ± 0.000249	0.0006462 ± 0.0002256
AGS	0.00018964	0.00020782	0.0001937 ± 0.0000197	0.0002075 ± 0.0000170	0.0002101 ± 0.0000158

***Own elaboration**

Table 4. Prospective to 2030 of the main indicators. Years 2019 and 2030*

Indicators (2019)	**National**	**RHA-VIII**	**Aguascalientes**
ICAm (31-33) [m³/$]	0.00093013	0.00065321	0.00020782
Annual growth rate GDP (31-33)	1.8%	2.5%	5.8%
Population growth rate[1]	1.2 (2020)	1.5 (2020)	1.9 (2020)
DA per capita [m³/hab/año]	3501.37827	1326.10335	388.5
GDP(31-33) per cápita	23444.514	23272.994	48803.4567
PH (31-33)	6.22796407	11.5247084	26.1066016
CAI(31-33) [hm³]	2746.07501	385.6987173	13.73037505
Indicators (2030)	**National**	**RHA-VIII**	**Aguascalientes**
ICAm (31-33) [m³/$]	0.0007563 ± 0.000411	0.0006721 ± 0.0002827	0.0001937 ± 0.0000197
Annual growth rate GDP (31-33)	Escenarios: (0.1-3) %	Escenarios: (0.1-4) %	Escenarios: (0.1-6) %
Population growth rate[2] 2020-2030	1.1	1.4	1.7
DA per capita [m³/hab/año]	3540.5555556 ± 237.516367	1356.1111111 ± 91.6108247	378.694341 ± 25.582344
GDP(31-33) per cápita	32967.9925	26478.159	56953.6391
PH (31-33)	6.591154 ± 1.340377	12.5349978 ± 2.272575	27.281634 ± 4.657357
CAI [hm³]: (Eqs. 3-6, 27-50) GM(1,1)	3560.815942 ± 493.251734 1942.127813 p^0 = 94.1% ε = 5.9%	502.7189592 ± 65.1507236 289.4461729 p^0 = 92.3% ε = 7.7%	19.11530652 ± 3.74235744 7.862600125 p^0 = 68.7% ε = 31.3%

[1]INEGI, [2]CONAGUA. *Own elaboration.

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Table 5. Main indices for the group of subsectors 322-323. Levels: National, RHA-VIII and State of Aguascalientes. Years 2019 and 2030*

2019	**National**	**RHA-VIII**	**Aguascalientes**
ICAm [m³/$]	0.00025114	0.00017637	4.5513E-06
PH [%]	1.6815503	3.11167126	0.57173457
IEA	0.010098	0.006771	0.000235
CAI [hm³]	741.4402527	104.1386537	0.300695214
2030	**National**	**RHA-VIII**	**Aguascalientes**
ICAm [m³/$]	0.000204 ± 0.000023	0.000181± 0.000006	0.000004±0.0000004
PH [%]	1.779612 ± 0.361901	3.384449± 0.613595	0.597468 ± 0.101996
IEA	0.014943 ± 0.021197	0.009640± 0.004909	0.000302 ± 0.000057
CAI [hm³]: (Eqs.3-6,27-50) GM(1,1)	961.4203044 ± 76.02779 524.7497482 p^0 = 93.0% ε = 7%	135.734119 ± 8.5699618 78.26041355 p^0 = 90.1% ε = 9.9%	0.418625213 ± 0.0472682 0.154197921 p^0 = 27% ε = 73%

***Owm elaboration**

Table 6. Main indices for the group of subsectors 324-326. Levels: National, RHA-VIII and State of Aguascalientes. Years 2019 and 2030*

2019	**National**	**RHA-VIII**	**Aguascalientes**
ICAm [m³/$]	0.00016417	0.00011529	3.6681E-05
PH [%]	1.09923566	2.03411103	4.60781518
IEA	0.006601	0.004426	0.001894
CAI [hm³]	484.6822393	68.07582361	2.423411196
2030	**National**	**RHA-VIII**	**Aguascalientes**
ICAm [m³/$]	0.000133 ± 0.000015	0.000119 ± 0.000004	0.000034 ± 0.000003
PH [%]	1.163339 ± 0.236577	2.212427 ± 0.401109	4.815208 ± 0.822024
IEA	0.009768 ± 0.013857	0.006302 ± 0.003209	0.002439 ± 0.000461
CAI [hm³]: (Eqs. 3-6, 27-50) GM(1,1)	628.4840138 ± 49.69964 343.1332506 p^0 = 92.5% ε = 7.5%	88.72989631 ± 5.6022158 51.19207969 p^0 = 89.2% ε = 10.8%	3.373851602 ± 0.3809518 1.513930564 p^0 = 23.7% ε = 76.3%

***Owm elaboration**

Table 7. Main indices for the group of subsectors 333-336. Levels: National, RHA-VIII and State of Aguascalientes. Years 2019 and 2030*

2019	**National**	**RHA-VIII**	**Aguascalientes**
ICAm [m³/$]	0.00041902	0.00029427	0.00009362
PH [%]	2.80569781	5.19188112	11.761024
IEA	0.016849	0.011298	0.004834
CAI [hm³]	1237.106792	173.7572722	6.18553396
2030	**National**	**RHA-VIII**	**Aguascalientes**
ICAm [m³/$]	0.0003407± 0.00004	0.000303 ± 0.000009	0.000087 ± 0.000001
PH [%]	2.969315 ± 0.603840	5.647016 ± 1.023795	12.290376± 2.098139
IEA	0.024932 ± 0.035367	0.016085 ± 0.008191	0.006224 ± 0.001177
CAI [hm³]: Eqs. 3-6, 27-50) GM(1,1)	1604.147582 ± 126.8538 875.2820191 p^0 = 93.5% ε = 6.5%	226.4748911 ± 14.29914 130.4961041 p^0 = 91.1% ε = 8.9%	8.611445589 ± 0.972344 3.576685087 p^0 = 56.1% ε = 43.9%

***Owm elaboration**

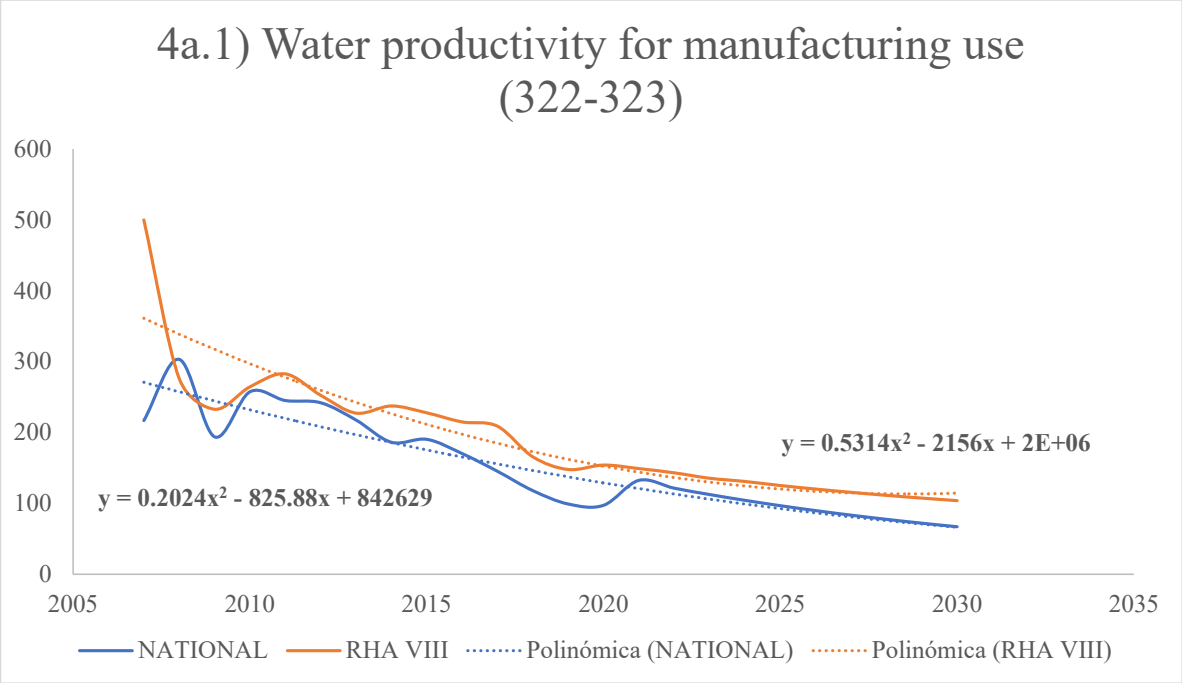

Figura 4. Productivity of water for manufacturing use at both national and RHA-VIII levels by group of economic subsectors: a1) 322-323 level national and RHA-VIII, a2) 322-323 level State of Aguascalientes, b) 324-326 and c) 333-336

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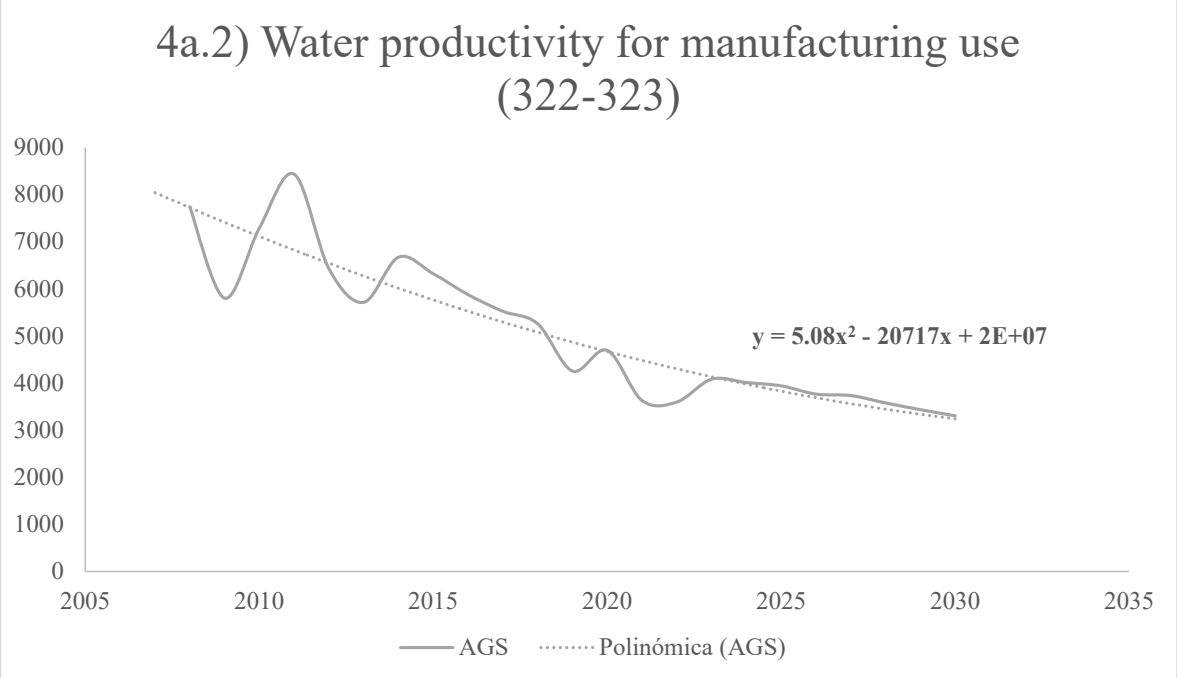
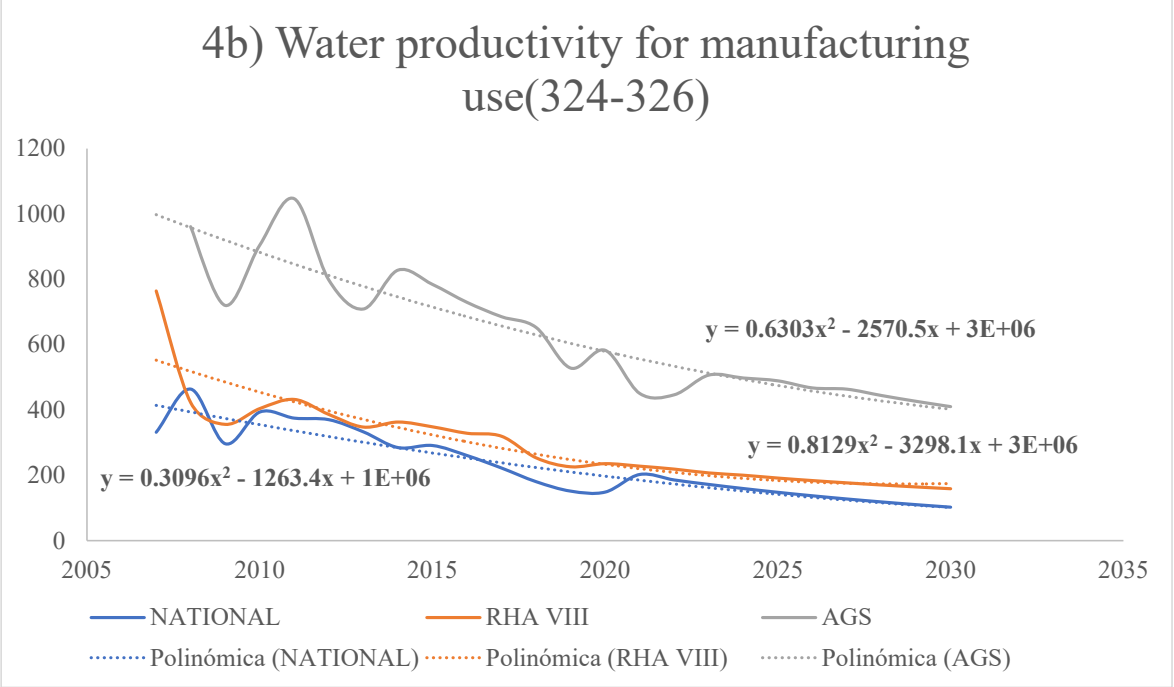

4a.2) Water productivity for manufacturing use (322-323)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
2005
2010
2015
2020
2025
2030
2035
y = 5.08x² - 20717x + 2E+07
AGS
Polinómica (AGS)


4b) Water productivity for manufacturing use(324-326)
1200
1000
800
600
400
200
0
2005
2010
2015
2020
2025
2030
2035
y = 0.6303x² - 2570.5x + 3E+06
y = 0.8129x² - 3298.1x + 3E+06
y = 0.3096x² - 1263.4x + 1E+06
NATIONAL
RHA VIII
AGS
Polinómica (NATIONAL)
Polinómica (RHA VIII)
Polinómica (AGS)

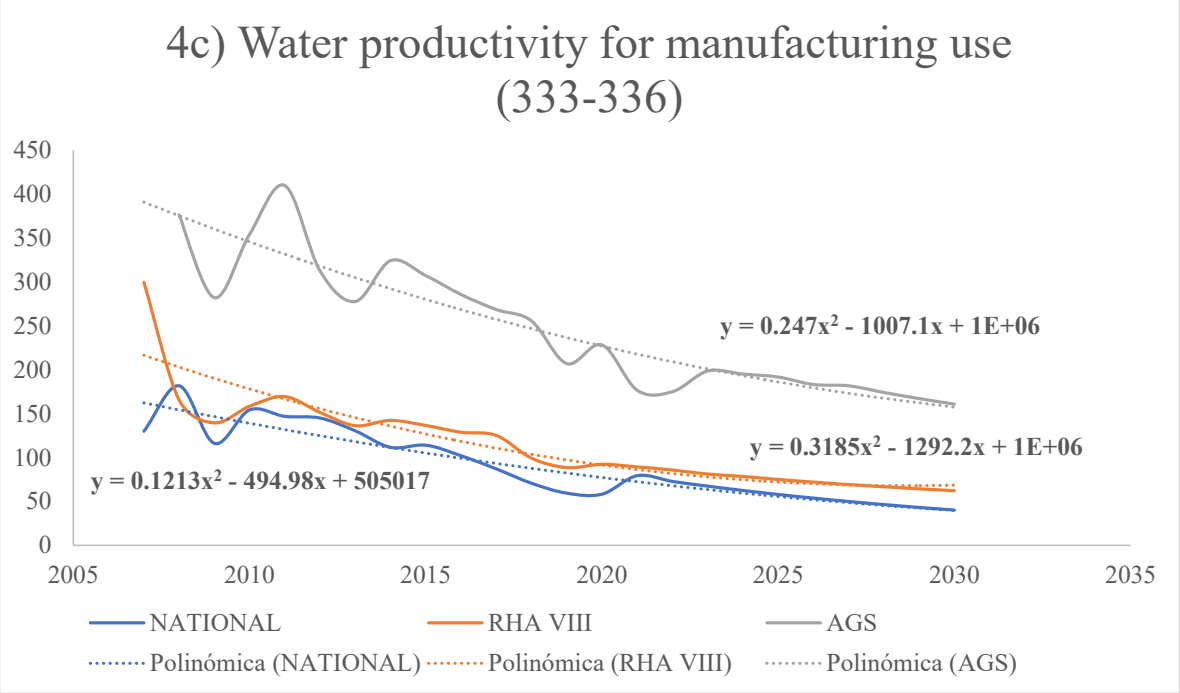
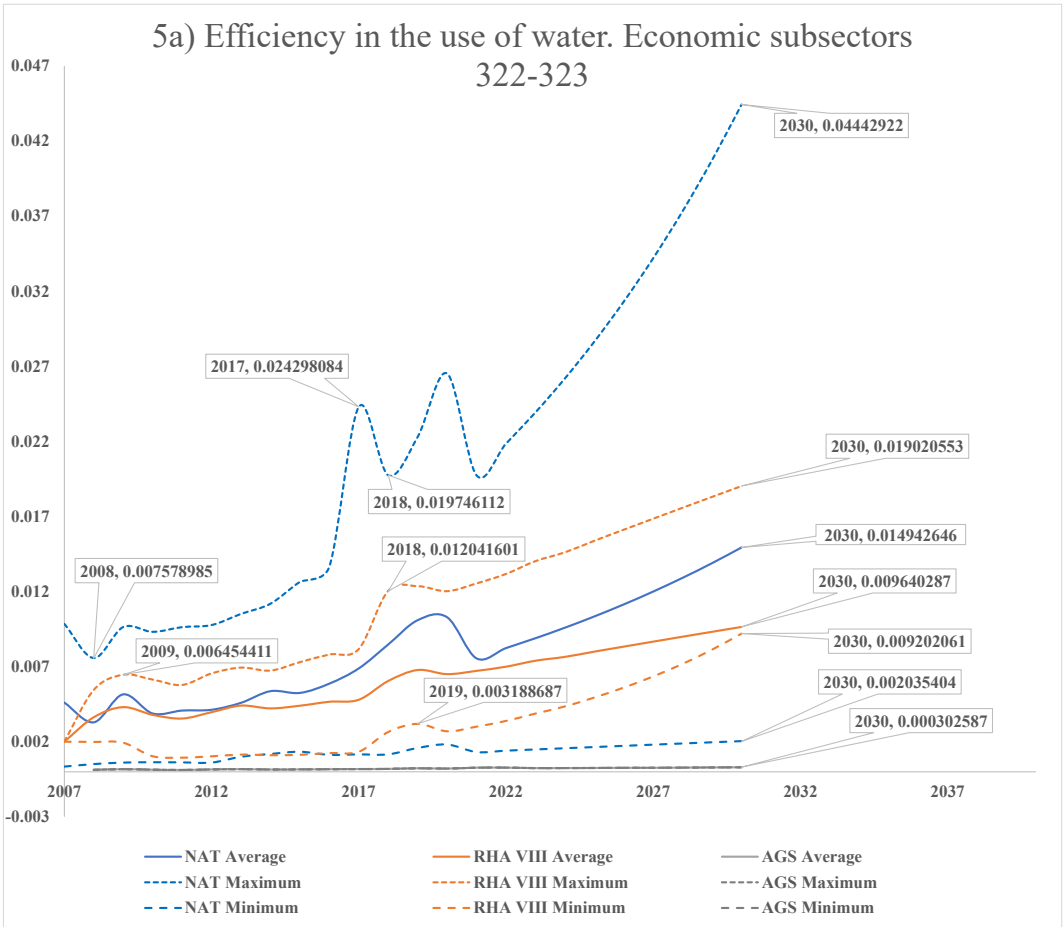


Figure 5. Efficiency of water for manufacturing use by group of economic subsectors: a) 322-323 , b) 324-326 and c) 333-336. Levels: National, RHA-VIII and State of Aguascalientes. Scenarios: Maximum, average and minimum prices



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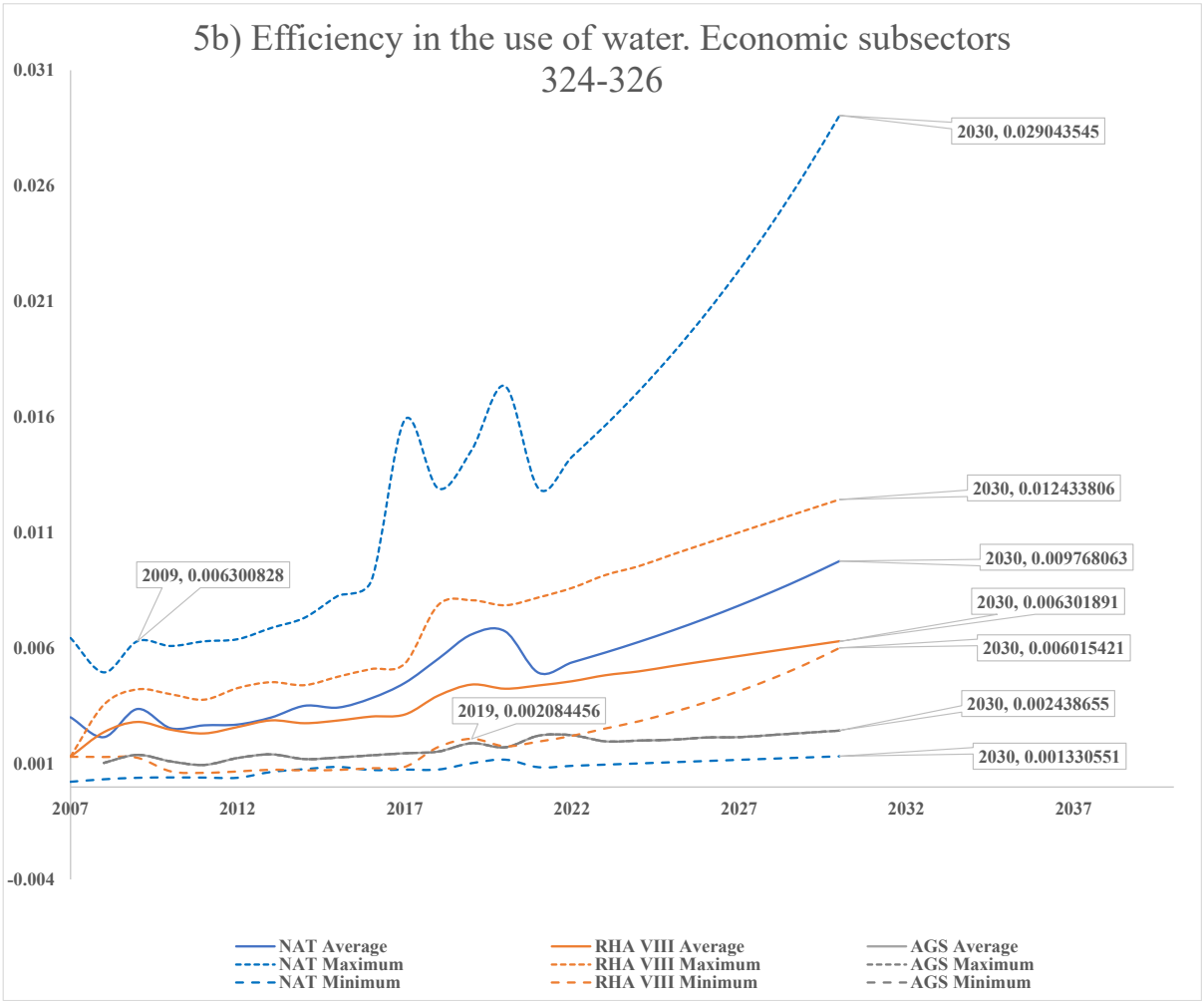
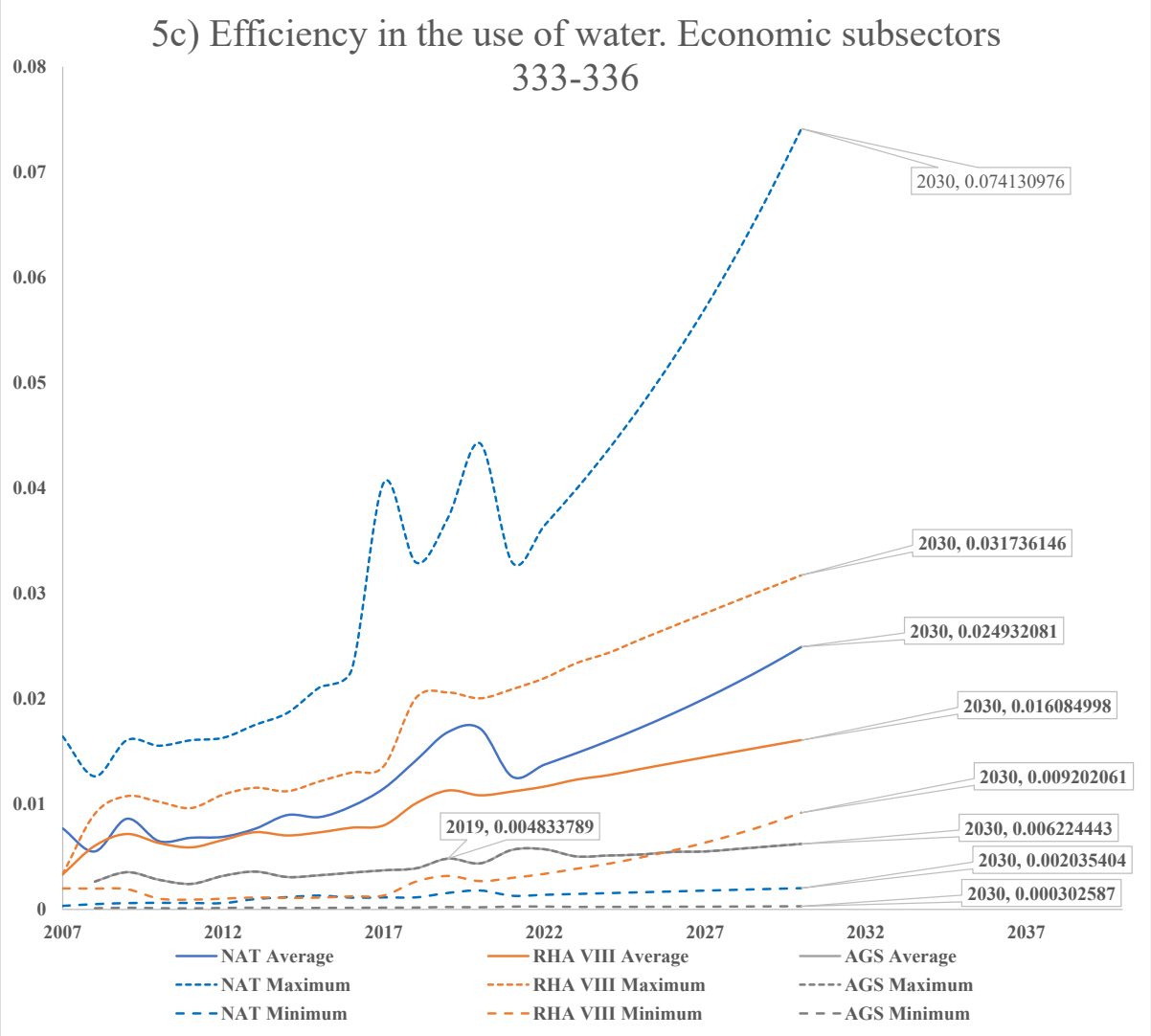

5b) Efficiency in the use of water. Economic subsectors 324-326
0.031
0.026
0.021
0.016
0.011
0.006
0.001
-0.004
2007
2012
2017
2022
2027
2032
2037
2030, 0.029043545
2030, 0.012433806
2030, 0.009768063
2030, 0.006301891
2030, 0.006015421
2030, 0.002438655
2030, 0.001330551
2009, 0.006300828
2019, 0.002084456
NAT Average
NAT Maximum
NAT Minimum
RHA VIII Average
RHA VIII Maximum
RHA VIII Minimum
AGS Average
AGS Maximum
AGS Minimum



ANALYSIS AND DISCUSSION

From tables 1, 5,6, 7 and taking the average $Mx-USD (BANXICO 2021) exchange rate in 2017 of 18.91, the ICAm ranges between (0.00367167, 0.0041303) for the 322-323 group. Similarly, for groups 324-326 and 333-336: (0.00394567, 0.00600818) and (0.00332528, 0.13218002), respectively. Comparing the values obtained by Revollo et al. 2018, in AGS, RHA-VIII and N, differences between 87.5 and 99.9% were found in the three groups of subsectors and the three regional levels, exceeding the values obtained for the San Juan River by an order of magnitude. The difference in increase from 2017 to 2019 for the three regions studied was 0.6% (N), 3.3% (RHA-VIII) and 15.1% (AGS), with AGS being the one with the largest increase in two years.

In contrast, the changes in these two years of IEA at the N level, RHA-VIII and AGS ranged from -8.2 (minimum AGS) to 139% (maximum RHA-VIII). In general, the increase in IEA exceeds the increase in CAI, with the increase in PH: 5.5% (N), 11.5% (RHA-VIII) and 21% (AGS), with AGS being the most pressured, see Tables 5, 6, 7 and figure 4. From Table 2, the percentage change in the distribution of industrial water use in ten years, from 2007 to 2017, was -36.2 (N), -44.7 (RHA-VIII), and -49.1 (AGS). RA shows a negative trend with respect to CAI, mainly at the RHA-VIII level, that is, it consumes more and more than is recharged, so it is not enough to ensure

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the availability of the natural resource in the long term, see tables 4, 5 , figures 1 and 2. As can be seen in figure 1a, at the national level, as of 2005, surface extraction fell rapidly, not recovering its volume and compensating it with water from underground sources. Levels prior to 2005 were not extracted. The opposite occurs in RHA-VIII, where since 1999 underground EA was privileged in a 3:1 ratio with respect to surface EA. This ratio has been increasing since 2002, see Figure 2b. The extreme case was AGS, where the underground EA with a potential dynamic was always preferred compared to the linear dynamic of surface EA (figure 2c).

From figure 2, until the year 2000 and after 2007, RA surpassed CAI at level N, but from 2001 to 2007, RA dominated in RHA-VIII (exceeding the national recharge). As of 2011, recharges in N and RHA-VIII showed a decreasing trend, and CAI in RHA-VIII grew more than the volume of recharge, which was a consequence of economic growth in the region. From figures 4a and 4b, productivity for group 322-323, from 2007 to 2013, showed similar behavior in RHA-VIII and N. From 2013 onwards, both show a positive trend with a maximum in 2017, later separating more and more, figure 2. This last behavior is repeated in groups 324-326 and 333-336. From Figure 4c, subsectors 324-326 showed slightly lower productivities than those shown by 322-323. Subsectors 333-336 surpass the other two, Figure 4.

From Table 5 and figures 5, comparing the outlook to 2030 of the main SDG indicators, ICAm decreases in N and AGS. While the GDP per capita only decreases in the latter and, the greater PH will be felt in RHA-VIII. The MG(1,1) models applied to the CAI adjusted the logarithms of the data well, with the exception of the AGS case, with the regressive adjustments being better in the behavior observed in conjunction with the RA and EAm. For the groups of subsectors studied, these models had an acceptable fit at the N and RHA-VIII levels, tables 5-7 and figures 4-5. A broader view was obtained when comparing the relationship between CAI, RA and EAm. It was found in India that the ICAm can be improved in production and administrative processes. There it was reduced by up to 50% [24], so there are technological optimization mechanisms for CAI and IEA. At the city level, Aguascalientes and Guadalajara belong to a densely populated and industrialized RHA. Similar cases were reported with data from 2011 in Poland, where EAm of underground origin intensified by 97% [17] that exceeds 90% AGS, 82.85% RHA-VIII and 55.85% N, [8-10]. Creating the programmed management of water use at subregional levels determined by local climate changes. If, in addition, water quality were incorporated into studies of this type [25], the economic impact on industries could be estimated by spending on purification methods to ensure quality in their processes, and the control of both emissions and transfers of pollutants [14,26].

CONCLUSION

The main sustainability indicators related to the economic activities that most demand water in their processes were calculated.

With the methodology used, a specific quantification was obtained by region and therefore of the status of the natural resource. The comparative importance of the three regions contained in each other contrasts the differences in consumption-extraction-availability of water. It was shown that the consumption indices reflect non-linear dynamics, which is why medium- and long-term resource management is urgent, since the availability of water in the three study regions is compromised. Water pressure increases as the rate of water extraction exceeds that

of recharge. As the three regional levels are intimately related socio-economically, the management of water distribution must be prioritized in the coming years.

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