



Article Assessing Industrial Impact on Water Sustainability in El Bajío, Guanajuato State, Mexico

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Abstract: Five municipalities in El Bajío present the highest industrial investments: Celaya, Irapuato, León, Salamanca, and Silao. Public and private investments, further to the support received from the government, have been decisive to industrialize the zone. The official discourse to encourage these activities has emphasized the economic and social benefits for inhabitants, the decrease in the use of water volumes, and the consequent improvement of water sources in each region. The main objective of the present work is to present a global industrial impact index to evaluate the industrial impact on water management by analyzing the evolution of some parameters regarding the official data available, in order to determine whether the industry has a positive outcome on the environmental, social, economic and hydrological aspects. For this study, we use Fuzzy Logic (FL) to complete a previous study, which was conducted using the Analytic Hierarchy Process (AHP). A combination of both approaches is used to define the global impact of industrialization, and the results obtained show that the benefits claimed by governmental policies are not being achieved. The use of this proposed index may guide the decision-making processes to encourage water sustainability.

Keywords: aquifers; economic; El Bajío; environmental; fuzzy logic; Guanajuato; hydrological; impact; industries; management; social; sustainability

1. Introduction

Currently, Mexico presents significant problems in the management of its water sources that have caused considerable levels of pollution and over-exploitation of them. Conversely, these problems are aggravated in those states or regions that have important industrial or agricultural centers.

To solve these problems, it has been sought to change the economy of these regions, especially those with the greatest agricultural and livestock activities, as well as those which are large consumers of water, by attracting different types of industries with the intention of reducing water consumption, and increasing both water productivity and household incomes.

The region in Mexico known as El Bajío is the alluvial plain formed by the Lerma River and its river's tributaries. This plain includes the territory without mountains within Guanajuato state and other states [1,2]. This region has had difficulties and accessibility issues with the water supply for many years [3,4].

The National Water Commission (CONAGUA) has determined that some of the most important water issues in the state of Guanajuato are ones of inefficiency, and they are related to the excessive use of water, under-utilization of treated water, over-concession of water rights to exploit the available sources, low water productivity, and low profitability of some economic activities, mainly related to primary sectors such as agriculture [5].

This situation could be aggravated by the process of industrialization that occurs in the region, mainly in the municipalities of Celaya, Irapuato, León, Salamanca, and Silao



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). (Figure 1), which have been the main receivers of new companies, triggering important conflicts regarding their water sources. These municipalities were chosen because, historically, they have been the main economic, agricultural, livestock and industrial centers in Guanajuato state. Their hydrological problems have more importance owing high deterioration of their water sources, their inhabitant number, and political importance. Moreover, they have important communication routes between ports on the Atlantic and Pacific coast, and cities central and north of the country.



Figure 1. Localization of Guanajuato state and municipalities of study.

The goal of this work is to determine, by the calculation of a global industrial impact index, whether there has been progress or advances on environmental, social, hydrological and economic issues in the aforementioned municipalities during the time span in which the industrialization policy has been in force in them, since the year 2000. The hypothesis of our work is that the benefits promised by public policies are not being achieved and there are no social, economic, environmental, and hydrological benefits for their inhabitants. The use of this proposed index may guide the decision-making processes to encourage water sustainability.

The contents of this work are as follows: Section 2 explains the methodologies used to achieve our goal. Section 3 shows how both methodologies were used. Section 4 sets out the results obtained by the methodologies used and the interpretation of the values obtained. Section 5 provides the reflections and conclusions reached on the basis of the values shown in Section 4. Finally, Appendices A and B contain all official data used, besides FL values and functions.

2. Materials and Methods

For the calculation of the global industrial impact index, this work uses the Analytic Hierarchy Process (AHP) [6] and Fuzzy Logic (FL) [7].

2.1. The Analytic Hierarchy Process

The AHP is a methodology developed by Thomas Saaty [6]. In [8–11], the AHP evolution and applications are documented. The AHP has been widely used since its development in several study fields and it is still used today [12–18]. It is used to understand and study complex problems by constructing hierarchical structures. It establishes different priority levels where problems to be solved or objectives to be achieved are placed at the top, followed by criteria and alternatives for their resolution in the lower part.

Currently, there are methodologies such as TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), PROMETHEE (Preference Ranking Organization METHod for Enrichment of Evaluations), and others. However, these are based in AHP, which was the first methodology of this type created, owing to the fact that both methodologies are used to solve multi-criteria problems, using a selection of alternatives or actions, these are ordered in matrices or tables where the elements are compared between them, looking for the best and/or worst element or preference. Finally, they show the results similarly at eigenvector from the AHP, identifying the degree of preference or the importance of scores in each element.

Moreover, the AHP is relatively easy to use. It does not need complicated informatics programs to analyze the information. The AHP allows researchers to evaluate both qualitative and quantitative criteria and their alternatives in the same scale of preferences (numerical, graphical, or verbal). In this paper, a linear scale designed by Saaty was used that is also the basis for other scales [6,19,20].

Therefore, this methodology was selected because water-related problems are very complex and multidisciplinary, involving social, economic, environmental, political, and other elements. This methodology allows for the division of these type of problems into elements and/or simpler relationships, which facilitates their study and understanding, with the ultimate purpose of finding the most appropriate solution according to the opinion and/or point of view of the experts consulted.

In this study, we start from the premise that the reason for allowing the establishment of industries in the study municipalities, according to what was stated by the authorities, was to better manage the available water (aquifers), and improve the income and standard of living of its inhabitants [21].

In [22], an explanation of the Mexican context is described. We recognize that governance is not a topic included in our work, but the available evidence warranted consideration of the idea that the state and municipal authorities have changed the proposed priority objectives, water and social, for industrialization without considering whether the conditions and characteristics of the municipalities are appropriate for the different types of industry that are to be implemented. In addition, it was considered that the application of regulations on the use and exploitation of water have been relaxed to benefit industries to the detriment of other users, as well as in the authorized extraction volumes, so it is likely that extraction volumes are not being complied with or reported to the authorities.

To establish whether these assumptions were founded, this study sought to treat this situation differently by basing its results on the opinion of those responsible for implementing the water policy, those making the respective decisions, and scholars on the subject, rather than relying solely on the numerical data provided by official bodies.

In this paper, the problem was defined as "the impact of industrialization on water sustainability", which analyzed the effects that industries have had on the region since their arrival in the municipalities of study—around 2000 and afterwards—on the management of their water resources.

Following the process indicated by the AHP, several values were obtained that showed the level of importance of the different elements considered in the study, and the impact of each of them on water management.

With this, a discrepancy of opinion was established between economic policy makers and experts regarding water issues, and on what should be the most important goals to be achieved with the industrialization of municipalities [23].

2.2. Fuzzy Logic

Conversely, FL seeks to give numerical and linguistic values to the vagueness and uncertainty present in the information available in a given situation with the intention of making a decision. The concept of a fuzzy set was created by Lofti A. Zadeh in the 1960s. Unlike classical logic, which only uses the values 0 and 1 to indicate if an element belongs to a set, FL also uses all intermediate values [24].

This feature allows to use mathematical values to process and measure uncertainty and vagueness, using linguistic variables (such as "a lot", "very", "a little", etc.), which might be defined based on experts' opinions and, in consequence, a proposition may be partially true or false, which allows us to consider whether an element belongs to a set or sets in a certain degree of membership, and if this degree is expressed with a numeric value in the interval (0, 1).

To apply FL, it is necessary to define the next four elements [25]: a) a set of variables, and to each of them a membership function, which defines the degree of belonging that a given variable has in a group, expressed usually with a linguistic term, such as "high" or "low"; b) statements or rules to relate every variable with its membership function of the result obtained, usually through an IF-THEN series, where IF represents a condition, and THEN means a consequence; c) rules to evaluate the statements or rules mathematically; d) rules to evaluate the resulting function through a process called *defuzzification* in order to get crisp values. These crisp values are real numbers between 0 and 1 indicating the degree of belonging of every variable or element in X with respect to a fuzzy set A, called *membership value* or *degree of membership*.

Some methodologies of defuzzification are Center of Area (COA), Center of Gravity (COG), and Mean of Maxima (MeOA). In our case, the trapezoidal membership function was used and its values are given for the corresponding intervals, such as (Functions (1) and (2)):

$$\mu_A(x) = \begin{cases} 0x \le a \\ \frac{x-a}{b-a} & a < x \le b \\ 1x \ge b \end{cases}$$
(1)

$$\mu_A(x) = \begin{cases} 1x \le a \\ \frac{b-x}{b-a} & a < x \le b \\ 0x \ge b \end{cases}$$
(2)

where *a* indicates the lower limit; *b* indicates the upper limit; *x* is the value to estimate; $\mu_A(x)$ is the membership function for a fuzzy set *A* on the universe of discourse *x* and is defined as $\mu_A: x \rightarrow [0,1]$.

Membership functions allow for the quantification of linguistic terms (which are variables whose values are words in colloquial language, used to indicate a relevant trait); for example, temperature is a variable and in colloquial language can be defined as "low", "medium" or "high", and may represent a fuzzy set mathematically and graphically.

It is important to note that membership ranks, which define the membership value for each linguistic term (such as 0, 0.25, 0.5, 0.75, 1) in the fuzzy set, were established according to values reported in many studies and documents about the situation and expectations for different parameters, reported in many government agencies [25].

Contributions from specialists of different areas have permitted the application of FL in industrial processes, such as production systems [24,26], water management and treatment [27,28], transportation systems [29], agricultural production [30], mining [25,31], and in general, in those areas and processes susceptible to being automated, partially or totally.

Moreover, FL has been used for a variety of different research to study different problems about water, analyzing the more appropriate parameters and study object for each case [32–34].

Conversely, some products cataloged as "intelligent" incorporate functions and programming based on FL to adapt their functioning to certain parameters and being friendlier to users. Likewise, FL has been applied in conjunction with some other methodologies of analysis in order to correct their limitations and increase their effectiveness, as in the case of the TOPSIS method [35].

Thus, to determine if the objectives proposed by the state government were achieved when it allowed companies to be established in the municipalities analyzed, this study used FL as a form of evaluation, with a value of 1 when the objectives were achieved and 0 otherwise.

The values used to apply this methodology were obtained from different official sources, with which historical and average series were developed, and later, compared with recorded values prior to industrialization [5,25,36–38] for the official sources.

In this case, parameters relating to environmental, social, hydrological, and economic conditions were analyzed. These are the main aspects that are expected to improve by allowing the settlement of industries in our municipalities of study, according to the current economic policy.

3. Application of Methodologies

3.1. Application of the AHP

Below is the decision tree (Figure 2) that was defined during the application of the AHP [21]. On the left hand side is the study problem, and on the right are the criteria (C) and the sub-criteria (SC).



Figure 2. Decision tree [6,21].

The comparison matrices constructed for the criteria and for each of the sets of subcriteria shown in the decision tree (see Figure 2) were made in accordance with Saaty, as well as the scale of values used to perform comparisons between their different elements [6].

3.2. Application of FL

In the case of FL, its application was based on four points for each parameter:

(1) Obtaining data on the evolution or current situation of each of the parameters (subcriteria defined in the decision tree), through bibliographical searches in various official sources in order to define the evolution over time of each parameter, or to know its current situation.

Thus, we set out to investigate whether the arrival of companies in the municipalities of interest has caused any change in their situation, either by benefiting them, by keeping them relatively the same, or by aggravating their situation.

- (2) The definition of the membership functions to quantify the membership values of the linguistic terms considered.
- (3) Graphical representation of the membership function.
- (4) Obtaining fuzzy values.

Furthermore, a number of considerations were made for the better handling and interpretation of the data available in each parameter:

Temperature (*T*): For this parameter, the Ecology Institute of Guanajuato State (IEE) predicts a possible increase in the average temperature of the state of 0.6-0.8 °C due to climate change [25], as well as alterations on the volume and patterns of rainfall, and higher possibilities of drought, for the same reason.

In order to understand the evolution of the average temperatures, measurements were taken from 2005 to 2016, and their averages were compared at the National Water Commission (CONAGUA), against the historical average temperature registered in each municipality.

Given the relative homogeneity of the municipalities studied with this parameter, an increase of temperature could make the municipalities prone to desertification, as well as to the alteration of other important environmental variables.

Precipitation (*P*): According to the IEE, the rainfall patterns are expected to be altered by climate change, as well as a state-wide decrease in rain precipitation in Guanajuato, which will intensify and become more frequent, with the possible effect of floods and the overflow of the different bodies of water [25,38].

A similar study was conducted by CONAGUA, in the same period of time (2005-2016), measuring and averaging precipitation in the region, and these results in turn were compared to against the historical average precipitations in each municipality.

Then, based on high sensitivity of the municipalities to rain alterations and its evolution in time, we proposed ranks where a decrement of rain equal or higher to 85 mm is considered the worst possible situation, reducing progressively its impact if the decrement is lowered to 85 mm.

Drought (*D*): According to a study done by the IEE, climate change is expected to prolong the dry season, which will likely increase the risk of forest fires—with concomitant emission of greenhouse gasses—greater degradation and erosion of soils, among other effects [25,38].

For this analysis, an index of drought was proposed based on the classification elaborated by the Drought Monitor of North America (DMNA), where a zero value was assigned to days without drought, while dry days are assigned the value 1; moderate drought has a value of 2; severe drought has a value of 3; extreme drought has a value of 4, and exceptional drought has a value of 5 [37].

In that study, the year was divided in months without drought and months with any level of drought. According to the drought level indicated, each month was multiplied by a corresponding number on the scale: if a month has only dry days it is multiplied by 1; if a month presents moderate drought it is multiplied by 2, and so on for every month within the span of the study.

Once the drought-values for every month were obtained, they were added to get the value by year and this number was used to calculate the fuzzy value for every year. Subsequently, this process was repeated yearly for a certain period in every municipality. Finally, the fuzzy values were added to obtain an average for each municipality, and this value was used in subsequent calculations.

Education level (*E*): It is important to know if the arrival of industries to our municipalities has caused an increment of the education level of their inhabitants, due to the need for qualified personnel in their productive processes.

This parameter was taken as the difference between the average study-grade at the national level and the corresponding average of the inhabitants of our municipalities, and it serves as the base parameter of measurement.

The methodological hypothesis is that if the difference between the national and municipal averages is positive, the lesser the education level at the latter scale is considered. This is justified by considering the national average as the minimum educational level requested for most job vacancies at these industries. If this level falls below this threshold, the possible consequence is the inability of people in these regions to be employed by these companies at a managerial or technically-skilled level.

Per capita income (*Pc*): Until around 2000, most of the economically active population (EAP) in the region had incomes between one and two daily minimum wages (m.w.), and was attributed to a considerable proportion of workers being employed in agriculturaland livestock-related activities.

The arrival of several companies to the region was expected to increase the income average of the population hired by them, and that this would improve the living standard of the inhabitants; it was one of the main reasons to allow industrial growth in the region.

Taking all of the above into account, we consider as viable subjects of study those workers earning 1-3 m.w., where 3 m.w. would be the minimum income to sustain a family. Thus, a Pc closer to zero means that a higher percentage of people are above the 3 m.w. mark, and that industrial growth has had a positive economic impact on the population. Conversely, values closer to 20 mean that most people are below the 3 m.w. mark, and that the impact of industrial growth has been deficient. In this last case, a change of economic policy must be implemented or at least considered.

Population growth (*PG*): With the arrival of heavy industry to the municipalities under study, an increase in population growth would be expected due to new employment opportunities. In turn, this would imply an increased stress on the water supply system, especially at its sources, while a population decrease would diminish this stress.

This parameter was calculated as the difference between the national population growth average and the average in the municipalities we studied. It means that if a PG < 0, it represents a municipal growth lower than the national average, and it is considered as positive; a value of PG = 0 means a growth of the population equal to the national average; and a PG > 0 means a higher growth of population in the municipalities studied, and it is considered as negative.

The comparison with national values is done so as to provide a reference framework on the growth of municipalities, where an increase in population higher than the national average means the industries are attracting more people that other regions in Guanajuato, or even other states. This situation must generate important impacts on social structure, environmental management, and hydric resources—among other factors—in the municipalities.

Commuting infrastructure (*C*): This parameter measures the evolution in the length of the state highway network in time, at the beginning of the industrialization in our municipalities, up to around 2000. This is relevant because highways are the main commuting means for the population, and the way in which most of the products and supplies to the industries are transported, in addition to be among the main decision parameters when deciding on the location of the companies. Thus, a value of $C \le 0$ means there was no construction of new roads, or some stretches were lost in the existing ones; other values mean there was an increase in the road network.

Traditional agriculture and agro-industry (*A*): This parameter was considered because, before the year 2000, the main economic activities in our municipalities were related

8 of 26

to traditional agriculture and traditional crops such corn, wheat, soy, and others, covering most of the land-surface designated for productive activities.

However, since the year 2000, the economic importance of traditional agriculture has decreased and its crop lands have been assigned to other economic activities, such as agro-industry and industrial parks. Thereby, this parameter measures how the use of land has shifted from traditional agriculture and agro-industry over time. Both parameters were calculated as the difference in hectares of the total area sown from one agricultural cycle to another, with emphasis on the agro-industry production of different types of crops destined for export. Here, a value of $A \le 0$ means that the sown area remains unchanged or undergoes some reduction, and values of A > 0 indicate the ranges in which the sown area has increased, making no distinction between traditional agriculture and agro-industry.

Shift of use of soil (*Us*): It is the percentage of soil which has lost its natural cover of vegetation to be destined to other uses, like economic activities or human settlement. Its importance is that it allows to determinate if industries have caused a higher or faster loss in vegetation in our municipalities, due to the impact of industrial activities caused in the places where they settle.

Due to the great variety throughout our municipalities on the use of land, we considered data in the time span 2009–2016. To compare the changes in the use of the soil, we assigned a weight to each point considered:

* *Agricultural*: It is the surface-area destined to traditional agriculture, agro-industry and artificial grassland.

	If $X < 100 \rightarrow 0$	The agricultural surface has decreased. It has weight 0.
Where	If X = 100 \rightarrow 1	The agricultural surface remains without changes. It has weight 1.
	If $X > 100 \rightarrow 2$	The agricultural surface has increased. It has weight 2.

* *Settlement/Urban area:* It is the sum—total of hectares destined to human settlement, urban areas, industrial parks, and industrial areas.

Where	$\begin{array}{l} \text{If } 0 < X \leq 20 \rightarrow 1 \\ \text{If } 20 < X \leq 40 \rightarrow 2 \\ \text{If } 40 < X \leq 60 \rightarrow 3 \\ \text{If } 60 < X \leq 80 \rightarrow 4 \\ \text{If } 80 < X \leq 100 \rightarrow 5 \\ \text{If } X > 100 \rightarrow 6 \end{array}$	The urban area has increased at most 20%. It has weight 1. The urban area has increased at most 40%. It has weight 2. The urban area has increased at most 60%. It has weight 3. The urban area has increased at most 80%. It has weight 4. The urban area has increased at most 100%. It has weight 5. The urban area has increased more than 100%. It has weight 6.
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* *Other uses:* Is the surface destined to environmental conservation in the municipalities and includes forests and other types of wilderness, and bodies of water.

	If $X > 100 \rightarrow 0$	The conservation surface has increased. It has weight 0.
Where	If X = 100 \rightarrow 1	The conservation surface remains without changes. It has weight 1.
	If $X < 100 \rightarrow 2$	The conservation surface has decreased. It has weight 2.

Studying the previous values, the worst-case scenario is when agricultural surface increases (weight 2); the urban area increases by more than double (weight 6), and the conservation surface decreases (weight 2). The sum of the weights is 10. By the same token, the best-case scenario is when agricultural surface decreases (weight 0), the urban area increases at most 20% (weight 1), and conservation surface increases (weight 0). The sum of these weights is 1. The weights obtained for each municipality were used to get the corresponding FL-value.

Parks/industries (*I*): In this parameter we used the number of Economic Units (EU), which are all new productive units registered officially in the National Statistical Directory of Economic Units (DENUE), because the problem of separating all types of units by economic sector, year by year in each municipality of study, from 2010 to 2017, and comparing the number of EU in one year against the number of the subsequent year is too cumbersome; we instead obtained the difference between them.

In this case, a value equal to or less than zero means that no new EU were opened or that their number decreased compared to the previous year and, conversely, values greater than zero mean an increment of Economic Units with respect to the previous year.

This difference over the years was used to obtain the fuzzy value corresponding to each period (2010–2011, 2011–2012, etc.). Afterwards, these fuzzy values were added and divided by six to get a fuzzy average-value in each municipality. The fuzzy ranks were defined considering the maximum and minimum values reached in the municipalities in the appropriate time span.

Water sources (*W***)**: This aspect measures the contribution that a new water source can provide to the municipalities of study, with the aim of reducing over-exploitation of the water sources currently in use and/or of diversifying the water sources available, to fulfill current or future needs in water.

The current situation of water sources in all of the El Bajío region does not permit getting a greater volume of water from the existing sources, due to all sources available on the surface and underground being over-exploited.

For instance, the municipality of León has developed the project called "El Zapotillo" to cover domestic and industrial water needs, and the municipality of Celaya built the project called "El Realito" to supply water for domestic use.

In the rest of the municipalities, there are no plans to obtain water from traditional or alternative sources. Fuzzy ranks were defined as the percentage of water these new sources may provide, with respect to a deficit in aquifers currently exploited by municipalities.

The fuzzy ranks proposed in this work consider that a new source with a contribution of at least 20% with respect to an aquifer's deficit has a large weight and is thus a very viable option to increase the resources of the water supply.

Water extraction (*We*): This parameter measures the difference between the refill rate and extraction rate in a water source as a percentage; the closer it is to 20%, the more engaged the aquifer is considered to be. The fuzzy ranks are proposed considering the values of extraction and refill showed in documents of CONAGUA, indicating the current situation of over-exploitation of the aquifers.

Use of water efficiency (*Ue***):** The higher the value of this parameter, the greater efficiency in the use of water, and the lower the extraction volume from a source, thus reducing the impact on the water sources. It is defined as the volume of water used in different sectors such as agricultural, industrial, and domestic, with their correspondent efficiency of application, meaning the volume of water delivered to the end-user with respect to the volume of water extracted.

These fuzzy ranks were defined considering the agricultural use, which is the main use of water in Guanajuato, with more than 80% of the total of water extracted, and also the end-user which overall has the lowest application efficiency, at about 30–40% in general, with a peak efficiency of 63–65% rising up to 90% depending on the type of irrigation used in each case [39]. For domestic users, the best values reach an efficiency of 80% or greater, especially in buildings with a more up-to-date infrastructure and distribution systems. However, when the infrastructure is not in appropriate operating conditions, this efficiency can be much lower. For the industrial sector there was not enough available information to compute an accurate efficiency percentage.

Aquifer refill (*R*): It is the difference between the volume of refill of the aquifer and the volume of extraction, where ideally, the refill rate should be higher than—or at least similar to—the extraction rate, allowing a balanced use of the aquifer.

With regard to the fuzzy ranks, the higher the difference between extraction and refill, the worse the aquifer's situation is considered to be, particularly if this value is greater than 5%, given the current problematic of over-exploitation of these bodies of water. This aspect should be a priority for the authorities because aquifers are the main source of supply for all municipalities studied, and these water sources have several deficiencies in this regard [40].

Other sources (*Os*): This is the percentage of volume that the new water source will contribute with respect to the volume obtained from traditional exploited sources, such as rivers, lakes, aquifers, etc. These are currently considered among the first options when the more traditional ones are at full capacity.

The current hydric situation in the area makes rainwater harvesting the only nontraditional option currently available. However, the irregularity of rainfall, the lack of appropriate facilities for collection and storage, the poor support and promotion from authorities, and the fact that this option would be useful only during the rainy season (June–September), make its application difficult in the short term.

Considering the short duration of the rainy season, the fuzzy ranks consider the best situation to be when volume of rain can cover 30% or more of the annual water consumption volume in an average house, according CONAGUA's average rain values obtained during a long timespan in every municipality of study, in all cases of 25 years or higher.

CONAGUA has developed technical guidelines to build systems for rainwater harvesting for domestic purposes [41]. In this case, taking [42] as a reference, the calculation is considering that only 10% of the houses in the municipalities of study will adopt this technology. Our diffuse ranks were computed, and if 100% of houses implemented this alternative, all values relative to the contribution of this method would increase tenfold.

Treatment (*Tr*): It is the relation between the capacity of currently active treatment plants and the current volume of human-generated wastewater processed by them. This is relevant because a proper network of such plants might decrease the pollution of water bodies, thus increasing the volume of available resources.

In this case, if the volume treated is close to the installed capacity, we must consider that a large number of users are connected to this treatment system, and that a great volume of wastewater is treated before it is released into receptor bodies.

Conversely, if the output-volume of these plants is reduced, equal or lower than 10%, compared to their nominal capacity, we conclude that not many end-users are connected to this system, and so a large volume of wastewater is released into receptor bodies, thus polluting them.

The fuzzy ranks were defined based in the percentage of treatment of wastewater in every municipality, where zero indicates the absence of treatment facilities, and the rest of the values are indicators that represent the level of treatment-volume considering the values in all of the municipalities.

Reuse (*Re*): The reuse of water is the percentage of wastewater treated for its later use on different activities to replace the use of fresh water, which is related with the parameter of Treatment, because the higher the volume of wastewater is treated, potentially the more treated water will be available to be used for consumption (either human or industrial).

The fuzzy ranks were established considering the volume of water reused by the municipalities, where zero indicates the absence of reused water and the rest of values indicate the increase of water reused overall. This parameter has a high potential of relevance because a well-implemented treatment system is a viable option to reduce the exploitation of the water sources.

As explained in Section 3.2, the next step was to conduct a bibliographic search of different official sources for each of the parameters explained above, and in this way observe their behavior from the beginning of the arrival of industries in the municipalities of study up to the latest year available prior to the elaboration of this article.

In this way, four types of graphs were identified according to their starting and ending points (see Figure 3), and it was considered that it was more convenient to consider that the best situation of the parameters would be when their membership value was equal to 1 or as close as possible to it, while values equal to zero or close would indicate increasingly alarming levels of deterioration.

Thus, Chart A indicates that the value of the parameter starts from values considered optimal by reaching membership value 1, and from a certain point onward there begins

to be a deterioration of the conditions for that particular parameter until the parameter reaches a number located at the zero membership value, at which the worst conditions established in the FL are reached for that case.

Chart B represents the conditions opposite to those on Chart A, since it starts with values defined as deficient, and from a certain point onward the conditions begin to improve progressively, until a number located at membership value 1 is reached, from which the rest of the values are optimal for the parameter.

For Charts C and D, the same reasoning is followed as in Charts A and B, from which they are derived, with the difference that their start is indicated by a single value from which the rest of the values would show an improvement or progressive deterioration of the relevant parameter.

Once the chart types were defined, the corresponding membership functions were developed, which were programmed using the statistical software *R* to facilitate and accelerate the computation of results, and in which the values obtained from the bibliographic search were entered for each parameter.



Figure 3. Types of graphics defined.

When the computational analysis was completed, the corresponding fuzzy values and linguistic variables were obtained in each case, resulting in a perspective on the type of impact caused by the establishment of industries in the municipalities we study.

4. Results

4.1. Results of the AHP

Once the interviews with the specialists were conducted and the values obtained from the comparison matrices were analyzed, the average of the values obtained for each of the parameters were as follows (Table 1):

Rank	Parameter	ID	Value
	Environmental	C1	0.192
Criteria	Social	C2	0.125
	Economic	C3	0.111
	Hydrological	C4	0.573
	Temperature	SCA1	0.196
Environmental Aspects	Precipitation	SCA2	0.443
	Drought	SCA3	0.361
	Education Level	SCS1	0.515
Social Aspects	Per capita Income	SCS2	0.235
	Population Growth	SCS3	0.251
	Ways of Communication	SCE1	0.213
	Traditional Agriculture	SCE2	0.131
Economic Aspects	Agro-industry	SCE3	0.197
	Shift of use of soil	SCE4	0.137
	Industries	SCE5	0.323
	Water Sources	SCH1	0.179
	Extraction Volume	SCH2	0.169
Hydrological Aspects	Water use Efficiency	SCH3	0.161
,	Recharge of Aquifers	SCH4	0.157
	Another sources of supplying	SCH5	0.115
	Treatment and reuse of water	SCH6	0.219

Table 1. Results of the AHP to Criteria and Sub-criteria [21].

In this table, the importance of hydrological criteria, treatment, and refill rates are quite explicit; this contrasts with the relatively lesser importance attached to economic factors, which are usually the ones followed by policymakers in the state of Guanajuato.

4.2. Results of FL

The results of the FL for the sub-criteria are shown in Table A1, Appendix A, where the membership function used with the number 1 or 2 is indicated, as well as the type of graph with the letters A, B, C or D. Due to the amount of data, the tables and information for the "Drought" parameter (Table A2) are shown in Appendix B.

4.3. Mixing of the Results from the AHP and FL

Once the results of both methodologies were obtained, they were combined with the intention of developing an index showing the status of the parameters in the municipalities. Table 2 shows the comparison of the results achieved, sorted in decreasing order, highlighting those that had values of 0 and 1.

It should be clarified that the parameter "Water treatment and reusing" appears as one in the AHP, but because the information used for the FL is located separately, we divided the AHL value by 2 to maintain the consistency of the results. Similarly, information on "Efficiency of Use" and "Per Capita Income" is at the municipality level and not at the state level.

From this table, the values obtained from the AHP were multiplied by the values of the FL of the corresponding parameter in each municipality. Subsequently, these results were added according to the criterion of which they are part; for example, temperature +

Criteria	AHP	Sub-Criteria AHP	AHP		V	alues of Fl	L	
	Values		Sub-Criteria Values	Celaya	Irapuato	León	Salamano	a Silao
		Treatment of water	0.1095	1	0.498	1	1	1
		Reuse of water	0.1095	0.494	0.101	0.861	0.007	0.012
rical		Water sources	0.179	0.353	0.0	1	0.0	0.0
golog	0.573	Extraction volume	0.169	0.0	0.492	0.453	0.492	0.0
łydr		Water use efficiency	0.161	0.419	0.419	0.419	0.419	0.419
4		Recharge of aquifers	0.157	0.0	0.0	0.468	0.0	0.0
		Other supply sources	0.115	0.061	0.063	0.077	0.097	0.132
ntal		Precipitation	0.443	1	1	1	0.912	0.564
ronmei	0.192	Drought	0.361	0.742	0.723	0.754	0.729	0.723
Envi		Temperature	0.196	0.0	1	0.533	0.617	0.35
		Education level	0.515	0.520	0.467	0.487	0.413	0.278
ocia	0.125	Population growth	0.250	1	0.800	0.650	1	0.700
S		Per capita income	0.235	0.0	0.0	0.0	0.0	0.0
		Industries	0.323	0.693	0.663	0.286	0.773	0.767
omic	0 111	Commuting infrastructure	0.213	0.708	0.622	0.667	0.868	0.667
conc	0.111	Agro-industry	0.197	0.995	0.858	0.917	0.750	0.726
Ĥ		Change of use of soil	0.137	0.714	0.571	0.571	0.0	0.286
_		Traditional agriculture	0.130	0.698	0.500	1	0.750	0.250

Table 2. Comparison of results of the AHP and FL.

Source: Own elaboration.

In addition to the above, a number of feasibility criteria were defined to establish whether allowing industries to enter municipalities would mean some improvement in the conditions of their hydrological, environmental, social, and economic conditions. The feasibility criteria that were established were as follows (Table 3):

Table 3. Viability index.

 $0 < X \le 0.250$: *Very unfavorable trend*. The objective is not met and there is considerable deterioration or impact on various parameters. The establishment of new industries is not recommended until the parameters are balanced or consistent improvements are observed. The impact of industries on improving the water situation is irrelevant (they may be a factor that aggravates the situation).

 $0.250 < X \le 0.50$: *Unfavorable trend*. The objectives are not met and different levels of deterioration are presented in various aspects. It is not recommended to accept the arrival of new industries, and in those already established there must be strict supervision in their water consumption and waste discharge. Their contribution to solving water problems is marginal or unimportant.

 $0.50 < X \le 0.75$: *Positive but insufficient progress.* The objectives are being met, but there are still aspects that require special attention. The arrival of new industries can be considered, but with strict supervision of their water consumption and waste dumping, among other limitations. Their contribution to solving water problems has some relevance.

 $0.75 < X \le 1$: *Positive trend:* The goals are being reached and the parameters are in balance or close to being therein. New industries can be allowed to arrive if they meet the relevant standards and have resource-efficient technologies and infrastructure for the treatment of their wastewater. The contribution of present companies to solving water-related problems is remarkable.

Source: Own elaboration.

Once all the values combined from the sub-criteria were computed, Table 4 was built, highlighting the values in which municipalities are in better and in worse conditions. Similarly to what was previously done, each of the values obtained for each municipality was multiplied by the corresponding number obtained by the AHP, and a summary of the four criteria was made to obtain an impact index of the industries in the municipalities.

Components	Components AHP Value		Irapuato	León	Salamanca	Silao				
Hydrological	0.573	0.301	0.224	0.609	0.272	0.194				
Environmental	0.192	0.711	0.900	0.820	0.788	0.579				
Social	0.125	0.519	0.441	0.414	0.463	0.319				
Economic	0.111	0.760	0.659	0.624	0.680	0.604				
Global Industrial Impact Index		0.458	0.429	0.627	0.441	0.329				
Feasibility criterion		Unfavorable trend	Unfavorable trend	Positive trend	Unfavorable trend	Unfavorable trend				
	Source: Own elaboration.									

 Table 4. Global industrial impact index.

Thus, based on the values achieved by the index and its corresponding range within the feasibility table, the trend followed by each municipality so far was established with the existing industries in them.

5. Discussion and Conclusions

The region of El Bajío has been affected by problems of water management for many years, due to the prevalence of economic and political interests above opinion and recommendations of hydrological experts over time. Therefore, the current situation of scarcity and over-exploitation of water sources is a consequence of the decisions made by different government officials over the years.

It can be seen that there is a clear relationship between the opinions issued by the experts in the AHP. Regarding the priority of water aspects, and the current situation of the aquifers that supply the municipalities. This also highlights the importance given to the treatment and reuse of water as a way to reduce water extraction from aquifers, where it surpasses the effort that needs to be made to better take advantage of the available treated water.

Conversely, only the municipalities of Celaya and León have projects aimed at supplying them with water from sources other than aquifers; only the project carried out in Celaya is in operation, and the one in León is on hold. We observe that if the latter were not carried out, it would significantly affect its impact index, putting it at a value close to that of the rest of the municipalities.

Similarly, with the exception of the aquifer of La Muralla, aquifers have significant levels of over-exploitation, and that is caused by various factors, above all the low efficiency in the use of water by agriculture and domestic use, motivating the over-exploitation of aquifers and altering their recharge capacity (which is currently exceeded). The same applies to the municipalities where the only source of water available (other than those already used) is the harvest of rainwater, due to climatic and orographic characteristics; however, its use only applies during the rainiest months of the year.

By analyzing the results reported by the last four governors of Guanajuato state (Juan C. Romero Hicks, Manuel Oliva, Miguel Márquez and Diego Sinhue) in their last governmental reports, we can observe if the actions carried out by them in each of the aspects had some positive impact.

In the case of hydric issues, Romero Hicks favored the construction of infrastructure for wastewater treatment, increased drinking water coverage, planned the construction of different dams, and sought to optimize the use of water in agriculture [43]. Oliva did

the same as Romero Hicks, and he finished some dams previously planned [44]. Márquez encouraged the care of water through forums and consultations. He sought to improve the agencies in charge of managing water, making them more efficient. He reported an increase in the supply of drinking water, the efficiency of water used for irrigation, the information on aquifers, and on water treatment [45]. Due to the current pandemic situation, Sinhue has sought to expand and make more efficient the coverage of drinking water, drainage and sanitation; streamline the use of agricultural and livestock water, generate information about aquifers and surface waters, encouraged the care of water through forums and consultations, and sought to improve the functioning of the agencies in charge of managing water [46].

In general, the results reported by the governors are practically the same in all cases. However, according to the official data available, there is no evidence that those actions had had a real impact on water sustainability.

As for the environmental aspects as a whole, despite the AHP results indicating greater importance to precipitation—which is supported in part by the values available from official sources—further observations of the parameters are still needed to get a clearer picture of the trend that will prevail in each municipality.

In this case, the governors did not mention these parameters in their reports, and it is necessary to carry on with the measures and studies by official dependences to understand the tendencies that the parameters will follow in the future.

Similarly, none of the variables that make up the social aspect has had any improvement in their situation prior to the implementation of most of the current companies, although they have been announced as the main reasons to promote the shift of productive structures in municipalities, from agriculture to industrial, with the intention of improving the aspects studied here (among others), so in this respect, the implemented policy can be seen as a failure.

All governors indicated that in their administrations have favored the arrival of companies and the generation of jobs and that have increased, in different ways, educational coverage in all grades, reducing the educational gap [43–46]. However, the data show that these jobs are not improving workers' incomes. In the same way, there is no evidence that an increase in the educational offering has served to improve the socioeconomic level of people.

Finally, for the economic aspect, the most important criterion was the industrial activity, according to the AHP, which makes sense because of the current development policy implemented in the municipalities, which is supported by the number of companies arriving at them each year; to facilitate the arrival of industries, the construction of highways and roads in municipalities has been promoted.

At the same time, it has been sought to allocate existing agricultural areas to the cultivation of vegetables and legumes instead of traditional cereals and other traditional crops in municipalities; all of which has had an impact on the deterioration of the soil conditions available in the municipalities, which have mostly been intended for other uses, leaving a very small area of conservation soil, in addition to the constant reduction of the traditional agricultural area.

Here, the actions indicated in the government reports showed that, in general, they have invested resources to increase and create better communication routes, to improve agricultural areas and reduce their water consumption. Similarly, the reports claim that they have implemented conservational measures to recover and rehabilitate protected natural areas, but at the same time, urbanization and industries were promoted, as well as the diverse infrastructure to support them [43–46].

Thus, the available information allows us to affirm that actions carried out in the economic aspect are insufficient and contradictory. In the same way, the actions carried out to recover protected natural areas have been ineffective, and it is necessary to rethink the best way to address this situation in order to correct it.

With regard to Table A1, in four of the studied municipalities (except León), there is an unfavorable or very unfavorable tendency in the hydrological aspect to continue the policy of facilitating the arrival of industries to them; that is, the water conditions of municipalities have not been improved despite being one of the main reasons to shift the economic focus from agricultural to industrial activities; furthermore, a clear deterioration of these conditions is evident, and this might have significant negative consequences on them in the future.

Similarly, it should be clarified that the reason why León achieves a better result in its hydrological conditions is because the calculations consider the realization of the project "El Zapotillo", which is currently stopped. If it is not finished, León would subtract its equivalent value in the results obtained, placing them almost at the same level as the rest of the municipalities.

Likewise, in Irapuato, León, and Salamanca the environmental components show a clear positive trend; although this condition is due to the need for the available measurements of their parameters; at the time of this study, they showed some improvement or no difference from their historical conditions. Nevertheless, it is necessary to have a greater number of measurements to establish a clearer trend of parameters in each municipality, as well as to observe the possible impacts that climate change could cause on the environment of municipalities according to the study carried out by the IEE [28].

As for the impact on economic components—except in Celaya—there are tight similarities in the results of municipalities, indicating the great momentum given to industrialization with the consequent facilities for this purpose, such as the expansion and improvement of commuting routes, the shift in land use (whether territorial reserves or other land such as agricultural lands in production), the change in agricultural production, etc., shows uniformity in the implementation of the current economic policy in these municipalities.

Finally, regarding the global industrial impact index in the municipalities, there is a great similarity in its value to the municipalities of Celaya, Irapuato, and Salamanca. In the case of León, despite having a higher index than the rest of the municipalities, as mentioned above, this value will only be maintained if the project "El Zapotillo" is carried out; otherwise, its index would be very similar to that of the first three and would go from grading as Positive Advances to having an Unfavorable trend.

Silao was the municipality that obtained the lowest values in all the parameters of the index, and that is why it has the least impact on the global industrial index; so far it has benefited the least from the industrial policy implemented.

From all of the above, it can be gathered that the development policy of municipalities to attract more industries and companies to their territory as a way to improve their economic, social, hydrological, and environmental conditions must be redesigned and modified, since many of the results show a clear difference between the opinion of experts and that of those responsible for designing developmental and economic policies, on which parameters should be the most relevant when deciding whether or not to follow certain forms of development in the different municipalities and regions, especially in those that are struggling to obtain better results such as the level of education, the availability of resources such as water, soils appropriate for planned activities, among other variables previously considered in the planning.

In addition, it is necessary to mention the competition between municipalities of the region to attract these companies. Political benefits are privileged over the environment and population.

In this way, although initially the intention to allow the settlement of industries and companies in these municipalities—and this can be extrapolated to the entire region of El Bajío—was justified as a way to improve the hydrological, social, and economic conditions of their inhabitants, the difference between the political and economic interests of the public and private sectors have given greater importance to economic factors at the detriment of the rest of them. This could compromise the economic, environmental, and hydrological viability of municipalities to maintain current trends.

Thus, it is necessary to rethink the current development model and its context. Responsible authorities must stop the construction of new industries and/or reduce the rate of construction, and seek to attract those that best adapt to the general conditions of the municipalities and can effectively improve the conditions of their inhabitants.

It is necessary to give the responsible institutions for the management of water, such as Ground Water Technical Committee, Water Councils and others [21], a higher operative, economic and punitive capacity. This, with the goal of prioritizing the management of natural resources, mainly water, should be considered above economic and political criteria.

The AHP can be used to facilitate agreements between the different sectors implicated or affected by the design of political developments, allowing a better decision-making process via which to implement new policies.

The FL can be used in combination with the AHP in making measurements of the parameters and to observe their evolution in percentage (or another scale), as well as the tendencies followed by them following implementation.

Finally, the global industrial impact index mixes the results of both methodologies and shows if the goals raised are being achieved, indicating where modifications may be necessary, or if municipalities should carry on with the already established plans.

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Appendix A

Table A1. Official values, linguistic terms, functions, graphics used and diffuse values gotten from the Fuzzy Logic methodology.

	Temperature (Function 2; Graphic C)											
Aı	nalyzed Valı	ues (°C) [36]	Linguist	Linguistic and Numeric Terms			Diffuse Values				
				Values	Linguistic terms	Index						
Municipalit	Average 05-16	Historic	Differenc	$T \leq 0$	No increase/Decrea se	1	Municipality	Value				
<u> </u>	27.34	26.62	0.72	$0 < T \le 0.1$	Small increase	0.85	Celaya	0				
Irapuato	26.77	26.94	-0.17	0.1 < T < 0.2	Important	0.7	Irapuato	1				
León	27.84	27.56	0.28	$0.1 < T \le 0.2$	increase	0.7	León	0.533				
Salamanca	27.82	27.59	0.23	$0.2 < T \le 0.4$	Significant	0.35	Salamanca	0.617				
Silao	27.54	27.15	0.39		increase		Silao	0.350				
II			1	$0.4 < T \le 0.6$	increase	0.01						
				$06 < T \le 0.8$	Critical increase	0						

	Precipitation (Function 1; Graphic B)													
	A	nalyzeo	d values	(mm)			Linguist	ic and nu	meric t	erms		D	oiffuse val	ues
							Value	Where	Lingui term	stic 1	ndex			
							<i>p</i> > 0	Increase	Releva	ant	1			
	Avora	no proci	nitation	zaluce [?	01		p = 0	Stable	Witho	out	0.9			
Munici	Averag	ge preci			Differenc		r -	Reductio	chang Smal	ge II		Muni	cipality	Value
v	ран	Histo	ric AV	5–16	e		$-1 > p \ge -10$	n 0.14–	import	ant 0	0.75	Ce	lava	1
Celay	va	604.2	25 6	31.26	27.01			1.4%	reduct	ion		Irar	viato	1
Irapua	ato	592.7	78 64	1 9.77	56.99	-	$-10 > p \ge -25$	n to 3.5%	reduct	ion (0.5	Le	eón	1
Leói	n	664.5	56 73	18.62	54.06			Poductio	Very	7		Salar	nanca	0.912
Salama	anca	639.2	22 63	32.68	-6.54	-	$-25 > p \ge -50$	n to 7%	signific	ant 0	0.25	Si	lao	0.564
Sila	0	631.5	54 59	95.06	-36.48			Reductio	Extrer	ion ne			luo	0.001
						-	$-50 > p \ge -85$	n to 12%	reduct	ion 0	0.01			
								Reductio	Critic	al				
							p < -85	n higher to 12%	reduct	ion	0			
	Education level (Function 1: Graphic B)													
Analyzed values Linguistic and numeric terms Diffuse values														
Diff	ferenc	e betwe	en natio	nal muni	cipal		0							
e	educat	ional le	vels over	years [4	7]									
	Year	National	Celaya	Difference	e									
_	2016	9.3	9.42	0.12			Values	Lin	guistic	In	day	Year	Municipality	Value
-	2015	9.2 8.6	9.39	0.19			values	t	erms		luex	2016	Culum	0.520
	Year	National	Irapuato	Differenc	e		E > 3	Pro	minent		1	2015	Celaya	0.532
-	2016	9.3	9.1	-0.20			2 > T > 1	Na	ational		17	2016		0.467
F	2015	9.2 8.6	8.5	-0.14			3 > E 2 1	av	verage		J.7	2015	Irapuato	0.477
	Year	National	León	Differenc	e		$1 > E \ge -0.5$	S	mall		0.4	2016		0.487
-	2016	9.3 9.2	9.22	-0.08		-		diff	terence			2015	León	0.498
	2010	8.6	8.6	0.00			$0.5 > E \geq -1$	51g1	foronco	(0.3	2010		0.500
	Year	National	Salamanc	Differenc	e	-		Ext	tensive			2015	Salamanca	0.425
-	2016	9.3	a 8.78	-0.52			$-1 > E \ge -2$	diff	ference	0	.15	2010		0.433
	2015	9.2	8.75	-0.45			2 . T > 0	C	rítical		0	2015	Silao	0.278
-	2010 Year	8.6 National	8.2 Silao	-0.40	'e		$-2 > E \ge -3$	diff	ference		0	2010		0.283
	2016	9.3	7.97	-1.33										
-	2015	9.2	7.93	-1.27										
	2010	8.0	7.3	-1.30										
					Per capita	a inco	ome (Functi	on 2; Gra	phic C)					
		Analy	zed valu	es			Linguist	ic and nu	meric t	erms		C	oiffuse val	ues
Level of	f incon	ne of th	e EAP at 48,491	the state	level (%)		Values	Lingu terr	ustic ns	Index				1
		L		Until			Pc = 0	Irrele	vant	1		Yea	r Va	lue
		1	Until					Slight	ntlv		I	200	0	0
Year	1 m	.s. ≈	2 m.s.	≈3 <u>m.s</u> .	Total		$0 < Pc \le 5$	relev	vant	0.75			-	-
Year 2000	1 m 16.4	s. ≈ 41	2 m.s. 50.60	≈3 m.s. 15.66	Total 82.66		$0 < Pc \le 5$ $5 < Pc \le 10$	relev Relev	vant vant	0.75 0.5	-	200	5	0
Year 2000 2005	1 m 16.4 22.4	.s. ≈ 41 ± 49 4	2 m.s. 50.60 44.46	≈3 m.s. 15.66 19.38	Total 82.66 86.33		$0 < Pc \le 5$ $5 < Pc \le 10$	relev Relev	vant vant ry	0.75	-	200 201	5 1	0
Year 2000 2005 2011	1 m 16.4 22.4 20.7	s. ≈ 41 49 18 4	2 m.s. 50.60 44.46 46.32	≈3 m.s. 15.66 19.38 14.85	Total 82.66 86.33 81.35		$0 < Pc \le 5$ $5 < Pc \le 10$ $10 < Pc \le 15$	relev Relev 5 Ve: relev	vant vant ry vant	0.75 0.5 0.2	-	200 201 201	5 1 6	0 0 0 0
Year 2000 2005 2011 2016	1 m 16.4 22.4 20.7 19.7	I I 41 1 49 4 18 4 26 4	2 m.s. 50.60 44.46 46.32 49.38	≈3 m.s. 15.66 19.38 14.85 11.17	Total 82.66 86.33 81.35 79.82		$0 < Pc \le 5$ $5 < Pc \le 10$ $10 < Pc \le 11$ $15 < Pc \le 20$	5 Relev Relev 5 Ve: 5 relev 0 Extrem 1 relev	vant vant ry vant mely vant	0.75 0.5 0.2 0.01	-	200 201 201 201	5 1 6 7	0 0 0 0 0

Table A1. Cont.

			Po	ation grow	th (Function	2; Graphic C)					
	Analy	zed value	S		Linguistic a	nd numeric ter	ms	Diffuse values			
Differe pop	nce in the vulation in	average g percentag	rowth of the ge [41,50]								
Year	National	Celaya	Difference					Year	Celaya	Value	
2000	1.6	1.96	0.36					2000	1.96	0.820	
2005	1.6	1.96	0.36					2005	1.96	0.820	
2010	1.4	1.2	-0.20					2010	1.2	1.000	
2015	1.4	1.2	-0.20					2015	1.2	1.000	
Year	National	Irapuato	Difference					Year	Irapuato	Value	
2000	1.6	1.8	0.20		Values	Linguistic	Index	2000	1.8	0.900	
2005	1.6	1.8	0.20		values	terms	muex	2005	1.8	0.900	
2010	1.4	1.8	0.40			Slightly		2010	1.8	0.800	
2015	1.4	1.8	0.40		$Cp \le 0$	important	1	2015	1.8	0.800	
		Salaman				important		Year	Salamanca	Value	
Year	National	ca	Difference	0	$0 < Cp \le 1$	Important	0.5	2000	1.31	1.000	
2000	1.6	1.31	-0.29			Verv		2005	1.31	1.000	
2005	1.6	1.31	-0.29	1	$< Cp \le 1.5$	important	0.2	2010	1	1.000	
2010	1.4	1	-0.40			important		2015	1	1.000	
2015	1.4	1	-0.40	1	5 < Cn < 2	Extremely	0.01	Year	Silao	Value	
Year	National	Silao	Difference		<i>c</i> + <i>cp</i> = -	important	0.01	2000	2.48	0.560	
2000	1.6	2.48	0.88		Cn > 2	Crítical	0	2005	2.48	0.560	
2005	1.6	2.48	0.88			Cincu	v	2010	2	0.700	
2010	1.4	2	0.60					Year	- León	Value	
2015	1.4	2	0.60					2000	2.31	0.645	
Year	National	León	Difference					2005	2.31	0.645	
2000	1.6	2.31	0.71					2010	2.1	0.650	
2005	1.6	2.31	0.71					2015	2.1	0.650	
2010	1.4	2.1	0.70					ι	· · · · · ·		
2015	14	21	0.70								

Table A1. Cont.

Ways of communication (Function 2; Graphic A)

Analyzed values Linguistic and numeric terms **Diffuse values** Variation in the length for road communication, values in km [48-53] 2001-2010 Municipality Road Road 0.123 Celaya Municipality network network Variation 2001 2010 0.000 Irapuato Celaya 102.5 284 181.5 León 0.000 Linguistic 134.8 425 290.2 Irapuato Values Index 0.603 Salamanca 538.9 León 171.1 710 terms Salamanca 125.5 235 109.5 Silao 0.000 Extremely Silao 131.6 429 297.4 0 Municipality 2010-2012 200 < Cimportant Road Road Celaya 1.000 Municipality network network Variation Very Irapuato 1.000 2012 2010 $150 < C \le -200$ 0.25 Celaya important 284 284 0 León 1.000 Irapuato 425 430 5 $100 < C \leq 150$ Important 0.65 Salamanca 1.000 710 710 León 0 Silao 1.000 235 235 Slightly Salamanca 0 0.99 $0 < C \le 100$ 2012-2016 Municipality Silao 429 429 0 important Road Road Celaya 1.000 $C \le 0$ Irrelevant 1 Municipality network Variation network Irapuato 0.867 2012 2016 León 1.000 Celaya 284 317 33 Irapuato 430 500 70 Salamanca 1.000 710 748 38 León 1.000

49

20

Salamanca

Silao

235

429

284

449

Silao

Traditional agriculture (Function 2; Graphic A)											
	Analyzed	d values	5		Linguistic ar	nd numeric ter	Diffuse values				
Variation in area	sown fo	r tradit	ional agricu	lture,							
	values ir	ha [54]]								
Municipali	ty 2011	2012	Difference					Municipality	Period	Value	
Celaya	19,212	20,265	1053					Celaya		0	
Irapuato	39,817	40,463	646					Irapuato		0	
León	23,425	23,390	-35					León	2011-	1.000	
Salamanca	a 53,476	36,871	-16,605			T · · · ·		Salamanca	2012	1.000	
Silao	12,658	14,593	1935		Values	Linguistic	Index	Silao	l F	0	
Municipali	ty 2012	2013	Difference			terms		Celava		0.79	
Celaya	20,265	20,370	105			Slightly		Irapuato		0	
Irapuato	40,463	47,601	7138		$A \le 0$	important	1	León	2012-	1 000	
León	23,390	20,725	-2665		a 1 . a aa	T	t 0.6	Salamanca	2013	0	
Salamanca	a 36,871	48,127	11,256		$0 < A \le 200$	Important		Silao		0	
Silao	14,593	17,027	2434		Very	0.2	Colava		1 000		
Municipali	ty 2013	2014	Difference		$200 < A \le 350$	important	0.3	Celaya		1.000	
Celaya	20,370	18,980	-1390			Extromoly		Irapuato	2013-	1.000	
Irapuato	47,601	47,339	-262		$350 < A \le 500$	Extremely	0.01	Leon	2014	1.000	
León	20,725	19,667	-1058			important		Salamanca		1.000	
Salamanca	48,127	45,726	-2401		A > 500	Crítical	0	Silao		1.000	
Silao	17,027	11,686	-5341					Celaya		1.000	
Municipali	ty 2014	2015	Difference					Irapuato	2014-	1.000	
Celaya	18,980	16,569	-2411					León	2014	1.000	
Irapuato	47,339	45,116	-2223					Salamanca	-010	1.000	
León	19,667	16,146	-3521					Silao		0	
Salamanca	45,726	40,217	-5509								
Silao	11,686	15,756	4070								
				Agro-indu	ustry (Function 2; 0	Graphic A)					

Linguistic and numeric terms

Diffuse values

Variation in area sown for agro-industry, values in							
		ha [5	4]				
	Municipality	2011	2012	Difference			
	Celaya	122	60	-62			
	Irapuato	646	460	-186			
	León	53	0	-53			
	Salamanca	1006	721	-285			
	Silao	107	130	23			
	Municipality	2012	2013	Difference			
	Celaya	60	31	-29			
	Irapuato	460	636	176			
	León	0	6	6			
	Salamanca	721	1221	500			
	Silao	130	367	237			
	Municipality	2013	2014	Difference			
	Celaya	31	35	4			
	Irapuato	636	744	108			
	León	6	6	0			
	Salamanca	1221	924	-297			
	Silao	367	115	-252			
	Municipality	2014	2015	Difference			
	Celaya	35	41	6			
	Irapuato	744	538	-206			
	León	6	166	160			
	Salamanca	924	785	-139			
	Silao	115	402	287			

Analyzed values

			Municipality	Period	Value
			Celaya		1.000
			Irapuato	2011	1.000
1	.		León	2011-	1.000
Values	Linguistic	Index	Salamanca	2012	1.000
Values	terms	macx	Silao		0.95
	Slightly		Celaya		1.000
$A \le 0$	Jugituy	1	Irapuato	2012-	0.648
	important		León		0.988
$0 < A \le 200$	Important	0.6	Salamanca	2015	0
	1 X7		Silao		0.526
200 < A < 350	Very	0.3	Celaya		0.992
200 < 71 ≤ 550	important		Irapuato	2012	0.784
	Extremely		León	2015-	1.000
$350 < A \le 500$	Extremely	0.01	Salamanca	2014	1.000
	important		Silao		1.000
A > 500	Crítical	0	Celaya		0.988
			Irapuato	2014	1.000
			León	2014-	0.68
			Salamanca	2015	1.000
			Silao		0.426

Table A1. Cont.

			5	Shift of u	se of soil (Functior	n 2; Graphic C)					
		Analyzed	values		Linguistic a	and numeric te	rms	Diffuse values			
Use of soi	l in t	he municip	palities (in ha) [55–57]		.					
A Municipality Year		Agricultural (include	Settlements/Urban	Other	Values	terms	Index	Municipality	Year 2009	Value	
		pasture)	area	areas	$0 < U_{s} \le 10$	Irrelevant	1	Celaya	2011	0.875	
	2009	39441.43	5343.839	10,074.39			-		2010		
Celaya	2011	39441.18	5343.837	10,074.64	10 .17 .00	Slightly	0.05	Turnet	2009	0.750	
	2016	39,054.40	5878.618	9926.65	$10 < Us \le 20$	important	0.85	Irapuato	2011	0.750	
-	2009	42,259.95	4905.227	16,414.85		mponan			2016		
Irap.	2011	42,004.02	5754.387	16,345.45	$20 < 11 \le 30$	Important	0.75		2009	0750	
	2016	41,862.33	6706.609	16,047.66	20 < 45 200	important	0.75	León	2011		
- /	2009	45,886.81	13,576.447	53,209.06		Verv			2016		
León	2011	45,459.93	14,652.478	51,937.47	$30 < Us \le 40$	very	0.5		2009		
	2016	42,896.83	17,641.728	50,953.59		important		Salamanca	2011	0.125	
	2009	41,730.96	3112.337	15,985.53		Extracted			2016	1	
Salaman.	2011	41,732.70	5313.344	15,907.58	$40 < 11 \le 50$	Extremely	0.25		2000		
2	2016	41,994.62	5802.657	15,806.70	10 5 00 200	important	0.20	Silaa	2009		
C:1	2009	40,570.39	1123.423	11,493.27		1		51140	2011	0	
51140	2011	40,496.11	1223.988	11,243.62	$U_{s} > 50$	Crítical	0		2016		
	2016	39,037.23	2302.739	12,455.42	L						

Table A1. Cont.

Industries (Function 2; Graphic A)

Analyzed values

Linguistic and numeric terms

Variation in number of enterprises [23]

Municipality	2010	2011	Differ.	2011	2012	Differ.
Celaya	13,032	13,123	91	13,123	13,226	103
Irapuato	13,597	13,680	83	13,680	13,957	277
León	38,749	39,233	484	39,233	39,994	761
Salamanca	6378	6421	43	6421	6503	82
Silao	3333	3347	14	3347	3418	71
Municipality	2012	2013	Differ	2013	2014	Differ
Celaya	13,226	13,309	83	13,309	24,139	10,830.00
Irapuato	13,957	14,030	73	14,030	25,042	11,012.00
León	39,994	40,610	616	40,610	78,924	38,314.00
Salamanca	6503	6503	0	6503	11,180	4677.00
Silao	3418	3492	74	3492	6017	2525.00
Municipality	2014	2016	Differ	2016	2017	Differ
Celaya	24,139	24,584	445	24,584	24,704	120
Irapuato	25,042	25,483	441	25,483	25,634	151
León	78,924	80,513	1589	80,513	80,939	426
Salamanca	11,180	11,347	167	11,347	11,417	70
Silao	6017	6219	202	6219	6259	40
		-				

Values	Linguistic terms	Index
$I \leq 0$	Irrelevant	1
$0 < I \le 100$	Slightly important	0.9
$100 < I \leq 300$	Important	0.75
300 < <i>I</i> ≤ 650	Very important	0.3
650 < <i>I</i> ≤ 1000	Extremely important	0.01
I > 1000	Crítical	0

Municipality	Period	Value	Period	Value
Celaya		0.909		0.897
Irapuato	2010	0.917	2011	0.723
León	2010-	0.516	2011-	0.239
Salamanca	2011	0.957	2012	0.918
Silao		0.986		0.929
Celaya		0.917		0
Irapuato	2012	0.927	2012	0
León	2012-	0.384	2015-	0
Salamanca	2015	1.000	2014	0
Silao	I	0.926		0
Celaya		0.555		0.88
Irapuato	1	0.559	2017	0.849
León	2014-	0	2016-	0.574
Salamanca	2016	0.833	2017	0.93
Silao	I	0.798		0.96

Diffuse values

Water sources (Function 1; Graphic B)

Anal	vzed	val	lues
	y Lea		aco

.

Linguistic and numeric terms

Diffuse values

Diffuse value 1 0.353

					Values (% contribution)	Linguistic terms	Index		
	¥7-1	- 13 [= 0	E0]		W>20	Extremely important	1		
·i	values 11	n nm° [58	,59]	——————————————————————————————————————		contribution		D	Τ
Municipality	Project	Deficit	Contributed volume	% of volume		Very		Project	
León	El Zapotillo	117.67	119.84	101.84	$15 < W \le 20$	important contribution	0.75	El Zapotillo	
Celaya	El Realito	306.4	31.54	10.3		Important		El Realito	
					$5 < W \le 10$	contribution	0.5		
						Slightly			
					$1 < W \leq 5$	important	0		
						contribution			

	A 1	-1	LAHACHU						D'40	1		
	Analyzed v	alues		Linguist	ic and	d numeric tei	rms		Diffuse values			
N	alues in hr	n ³ [40]		Values (% extraction)	Li	inguistic terms	Inde	c	Aquifer			
Aquifer (Municipality)	Recharge	Water	Variation %	$0 < We \le 3$		Aquifer in equilibrium	1		(Municipality) Silao-Romita (Silao)	Diffuse value		
Silao-Romita (Silao)	243.5	364	49.49	0.111.10		Important	0.6		Valle de León (León)	0		
Valle de León (León)	156.1	204	30.69	$3 < We \le 10$		extraction	0.6		Valle de Celaya	0		
Valle de Celaya (Celaya)	286.6	593	106.91	$10 < We \le 17$	V	ery important extraction	0.2		(Celaya) Irapuato Valle			
Irapuato Valle (Irapuato and Salamanca)	522.2	583	11.64	$17 < We \le 20$	imp	Extremely	0.1		(Irapuato and Salamanca)	0.492		
La Muralla (León)	34.8	36.4	4.6		mp	ortant extractio	11	_	La Muralla (León)	0.906		
				We > 20	Cr	itical extraction	. 0					
			Water use	efficiency (Fund	ction 1	1; Graphic B)						
	Analyzed v	alues		Linguist	ic and	d numeric tei	rms		Diffuse va	lues		
				Values (% efficiency)	Linguistic terms	Index					
Efficiency po	ercentage, v	values in hr	n ³ [39]	Ue > 80		Extremely			r	Diffuse		
Sector	Water	% of	efficiency		_	Very			Sector	value		
	extraction		$70 < Ue \le 8$	0	important	0.8		Agricultural	0.273			
Agricultural	3360	3360 40		$50 < Ue \le 7$	0	Important	0.45		Industrial	No data		
Industrial	120	N	lo data			Slightly			Domestic	0.564		
Domestic	520	I	00	$25 < Ue \le 5$	$25 < Ue \le 50$ im		0.2		L			
				$1 < Ue \le 25$	1 < Ue ≤ 25 Very unimportant		0					
			Recharge	of aquifers (Fun	ction	1; Graphic B)						
	Analyzed v	alues		Linguist	tic an	d numeric ter	rms		Diffuse va	lues		
v	/alues in hn	n ³ [40]		Values (hm	3)	Linguistic terms	Inde	¢	Aquifer (Municipality)	Diffuse value		
Aquifer (Municipality)	Recharge	Extraction	Deficit	$R \ge 0$		Aquifer in equilibrium	1		Silao-Romita (Silao)	0.0		
Silao-Romita (Silao)	243.5	364	-120.50	$0 > R \ge -5$		Slightly important	0.9		Valle de León	0.0		
Valle de León (León)	156.1	204	-47.90			deficit Important	_	-	(León) Valle de			
Valle de Celaya (Celaya)	286.6	286.6 593 -306.4		$-5 > R \ge -10$)	deficit	0.8		Celaya (Celaya)	0.0		
Irapuato Valle				$-10 > R \ge -2$	0	deficit	0.6		(Celdyd)	+		
(Irapuato and	522.2	583	-60.80			Extremely	+	\neg	Irapuato Valle	0.0		
Salamanca)				$-20 > R \ge -2$	5	important	0.2		(Irapuato and	0.0		
La Muralla	34.8	36.4	-1.6			deficit			Salamanca)			
(León)		ļ		R < -25		Critical deficit			La Muralla	0.936		
				N > 20		critical activiti	· · ·	1	(León)	1		

Table A1. Cont.

			Anothe	r source	s of supplying	(Function 1; Graph	ic D)				
	Analy	zed values			Lingui	stic and numeric te	rms	Diffuse values			
Percenta	ges of con	tribution fo	or rainwa	ter	Values (% aportation)	Linguistic terms	Index				
Municipality	Days with enough rainwater	Contribution Extraction %		$Os > 3$ $2 < Os \le 3$	$\begin{array}{c c} & \text{Extremely} \\ \hline Os > 3 & \text{important} \\ \hline contribution \\ \hline 2 < Os \le 3 \\ \hline \end{array}$		Municipality Celaya Irapuato	Value 0.061 0.063			
Celaya Irapuato	120 91	720,602.07 836,707.64	39,286,12 44,105,18	1.8321.90	$1 < Os \le 2$	Important contribution	0.5	León Salamanca Silao	0.077		
León Salamanca	164 91	2006,785.33 460,000.24	86,920,09 15,735,73	3 2.31 5 2.92	$0 < Os \le 1$	Slightly important contribution	0.25	51140	0.132		
Silao	170	234,803.49	5898,94	3 3.98	$Os \approx 0$	Zero contribution	0				
			Tı	eatment	of water (Fun	ction 1; Graphic D)					
	Analy	zed values			Lingui	stic and numeric te	Diffuse values				
					Values (% treatment)	Linguistic terms	Index]			
	Values	in l/s [38,61]		$80 < Tr \le 10$	0 High coverage	1				
Municipality	Number of plants	Installed capacity	Treated discharge	% of water	$65 < Tr \le 80$) Extremely important	0.9	Municipality Celava	Value 1.0		
Celava	1	750	663	treated 88.4	$50 < Tr \le 65$	5 Very important	0.8	Irapuato	0.498		
Irapuato	3	2769	1103	39.8	$35 < Tr \le 50$) Important	0.7	León	1.0		
León	13	1200	1200	100.0	$25 < Tr \le 35$	Slightly	0.5	Salamanca	1.0		
Salamanca Silao	2	120	170	85.0 89.5	$1 < Tr \le 25$	Very	0.25	Silao	1.0		

Table A1. Cont.

Reuse of water (Function 1; Graphic D)

 $Tr\approx 0$

Critical trated

volume

0

	Analyzed v	alues		Linguistic a	and numeric terms	Diffuse values			
		[()		Values (% reuse)	Linguistic terms				
	Values in I/	s [61]		$80 < Tr \le 100$	High reuse	1			
Municipality	Treated	Water	% of water		Extremely		Municipality	Value	
in an in participation of the	discharge	reused	reused	$65 < Tr \le 80$	important	0.9	Celaya	0.494	
Celaya	663	262	39.52	$50 < Tr \le 65$	Very important	0.8	Irapuato	0.101	
Irapuato	1103	89	8.07	$35 < T_r < 50$	Important	0.7	León	0.861	
León	1200	827	68.92	33 < 17 2 50	Important	0.7	Colomonoo	0.007	
0.1	170	1	0.50	$25 < Tr \le 35$	Slightly important	0.5	Salamanca	0.007	
Salamanca	170	1	0.59	$1 < T_{\rm r} < 25$	Voruminnortant	0.25	Silao	0.012	
Silao	107.4	1	0.93	1 < 17 ≤ 25	very uninportant	0.25			
				$Tr \approx 0$ Critical reused volume		0			

Appendix B

Analyzed Values Linguistic and Numeric Terms Diffuse Values Image: Construction of the constr									Drought	(Function	2; Graj	phic C))							
K Year Level B Level C <thc< th=""> <thc< th=""> <thc< th=""></thc<></thc<></thc<>		A	nalyz	ed Val	ues				Lin Nur	guistic and neric Term	d Is		Diffuse Values							
A Year Level B Level C Level C Value C Value Level N N Value Level N <th< th=""><th></th><th>L</th><th>evel c</th><th>of droug</th><th>ght</th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th></th><th>Varia</th><th>17.1</th><th></th><th>N. I.</th><th>6</th><th>N.</th></th<>		L	evel c	of droug	ght									Varia	17.1		N. I.	6	N.	
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	Α	Year	Level	В	Level	С	Level						A	Year 2005	Value 0.85	В	Value 0.85	C	Value	
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		05	30		30		25							2005	0.65	-	0.525		0.5	
Celaya 0 <td></td> <td>06</td> <td>70</td> <td>1</td> <td>95</td> <td></td> <td>100</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td>2007</td> <td>1</td> <td>-</td> <td>0.975</td> <td></td> <td>0.975</td>		06	70	1	95		100							2007	1	-	0.975		0.975	
08 85 90 70 95 10 25 10 25 10 95 20 10 25 10 0.875 0.875 0.875 0.875 0.875 0.99 1.1 0.625 0.99 1.1 0.60 0.875 0.875 0.875 0.99 1.1 0.625 0.99 1.1 0.625 0.99 1.1 0.625 0.99 1.1 0.625 0.99 1.1 0.625 0.99 1.1 0.625 0.99 1.1 0.625 0.99 1.1 0.625 0.99 1.1 0.625 0.99 1.1 0.625 0.99 1.1 0.625 0.99 1.1 0.625 0.99 1.1 0.625 0.99 1.1 0.68 0.875 0.99 1.1 0.68 0.875 0.875 0.875 0.875 0.875 0.875 0.9975 0.72 0.75 0.72 0.75 0.75 0.75 0.75 0.75 0.75 0.75		07	0	1	5		5							2008	0.575	-	0.55		0.65	
09 95 135 95 10 25 10 0 0 10 0 0 0 10 0 0 0 0 10 0		08	85	1	90		70							2009	0.525	1	0.325		0.525	
Celaya 10 25 Irapuato 30 León 25 11 165 170 5 170 5 10 <		09	95	1	135	· ·	95							2010	0.875	1	0.85		0.875	
Celaya 11 165 Irapuato 170 100		10	25		30	- ·	25			T in and stic		1	Celaya	2011	0.175	Irapuato	0.15	León	0.15	
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	Celaya	11	165	Irapuato	170	León	170		Values	terms	Index			2012	0.7	1	0.625		0.725	
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		12	60	-	75	· ·	55		D = 0	Without	1			2013	0.875		0.9		0.925	
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		13	25		20	- ·	15			Slightly		1		2014	0.825		1		0.95	
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		14	35		0	- ·	10		0 < <i>D</i> ≤ 10	important	0.75			2015	0.975		1		0.975	
16 25 15 15 15 15 16 20 0.5 0.5 05 30 25 1 15 15 16 20 0.723 0.753 0.753 0.755		15	5	1	0	5		10 < D < 20	Important	0.5	1		2016	0.875	-	0.925		0.925		
05 30 25 0 06 85 100 0<		16	25		15		15		10 < D 3 20	presence	0.0	-		Average	0.742		0.723		0.754	
06 85 00 0 07 0 5 0 08 95 0 0 85 0 09 130 115 0 0 Critical presence 0 10 30 50 0 0 0 0.35 0.425 0.455 0		05	30		25				20 < D ≤ 30	important	0.25			2005	0.85	-	0.875			
07 0		06	85	1	100					presence Extremely		-		2006	0.575	-	0.5			
08 95 09 130 115 10 2010 0.35 0.425 0.455 0.425 0.455		07	0		5				30 < <i>D</i> ≤ 40	important	0.1			2007	1	-	0.975			
10 30 5ilao 115 1170		08	95	1	85					presence Critical		-		2008	0.525	-	0.575			
Salamanca 10 30 Silao 50 1 10 30 Silao 50 1 11 160 170 1 201 0.05 12 70 65 1 13 20 25 1 15 0 0 0		09	130	1	115				40 < D	presence	0			2009	0.85	-	0.425			
Salamanca Silao 170 10 2012 0.65 0.675 0.		10	30	1	50								Salamanca	2010	0.2	Silao	0.15			
12 70 65 0 13 20 25 2014 0.925 14 15 10 10 2016 0.925 15 0 0 0 0.925	Salamanca	11	160	Silao	170									2012	0.65	-	0.675			
13 20 25 0.95 14 15 10 10 15 0 0 0		12	70		65									2013	0.9	1	0.875			
14 15 10 2015 1 1 15 0 0 2016 0.925 0.925		13	20	1	25									2014	0.925	1	0.95			
15 0 0 0.925 0.925 0.925		14	15		10									2015	1	1	1			
		15	0		0									2016	0.925	1	0.925			
16 15 15 Average 0.729 0.723		16	15	1	15									Average	0.729		0.723			

Table A2. Values used and results of FL.

Source: Drought Monitor of North America. SMN.

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