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Article

Evaluating Groundwater Management Sustainability under Limited Data Availability in Semiarid Zones

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Abstract: In recent years, many researchers have devoted their efforts to finding an objective measurement of sustainability by developing evaluation tools based on sustainability indices. These indexes not only reveal the current state of water resources in a given area but also contribute to the development and implementation of effective sustainable water management and decision-making. The great disadvantage of these indices is that for proper application, a number of variables are necessary and they are usually not available in data-scarce aquifers. This study was designed to evaluate sustainability in groundwater resource management in an aquifer in a semiarid zone, using readily available parameters and under a pressure-state-response framework. This methodology has been applied to an aquifer in Southeast Spain with satisfactory results, since the indicators that were evaluated reflect the two main problems that hinder sustainable resource management: the contamination of groundwater by intensive local farming; and the need for external inputs from other basins to alleviate water stress. Therefore, the methodology used can be replicated in other areas with similar characteristics to those of the case study.

Keywords: sustainability index; groundwater management; aquifer; semiarid; campo de Cartagena; pressure-state-response framework

1. Introduction

Since the publication of the Brundtland Report, where sustainable development is defined as that which "meets the needs of the present without compromising the ability of future generations to meet their own needs" [1], many institutions and organizations have dedicated much effort to the objective measurement of sustainability. A clear example of this effort is the development of evaluation tools based on sustainability indices. These indices are fundamental to the sustainable management of the resource [2] and when applied to water resources, they identify all the factors that contribute to better water resource management. Thus, this information can be used to present the current state of water resources in one area to all its users and to help Sustainable Water Management and Decision-Making (SWMaDM) [3].

Groundwater Management Sustainability was defined by Alley [4] as the development and use of the resource in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences. Therefore, to develop an index that ensures adequate measurement of sustainability in groundwater resource management, it is important to consider not only hydrogeological parameters, but also parameters related to Environment, Life and Policy. Accordingly, some attempts to develop water resources sustainability indices have already been proposed, for example, Canadian Water Sustainability Index [5], Watershed Sustainability Index [6], West Java Water Sustainability Index [7], Sustainability Index for Integrated Urban Water Management [8], Groundwater Sustainability Infrastructure Index (GSII) [9]. Of all the above, only the GSII has been developed specifically for groundwater management. Most of these indices require a large amount of data and therefore cannot be applied to areas under limited data availability [9]. In addition, the measures for the sustainable water resource management vary according to the geographical and economic conditions of where they are being evaluated [10]. Thus, the development of new methodologies that evaluate sustainability for more specific conditions becomes necessary.

This work aims to evaluate sustainable groundwater management through the development of a methodology that can be replicated in other places where conditions are similar to the case study presented here (intensive agriculture, semiarid climate and absence of permanent river courses) [11]. Accordingly, we propose the "aquifer sustainability index" (ASI) as a framework for measuring groundwater sustainability in order to evaluate progress in achieving sustainability. This index was developed under a Pressure-State-Response framework. This framework was proposed by Rapport and Friend [12] and has been widely used around the world [13–15] thanks to its implementation as a development model for environmental indicators by the Organisation for Economic Co-operation and Development (OECD) [16]. In order to demonstrate the applicability of the index, this paper discusses results from testing the index on Campo de Cartagena (CC) (SE Spain).

2. Case Study Area

In geographical terms, CC is a large plain of more than 1600 km^2 between the provinces of Alicante and Murcia. It is surrounded by mountain ridges around its entire perimeter, except for the coastline on the Mediterranean Sea and the seawater lake known as Mar Menor (Figure 1). It has no permanent surface water courses, but it does have abundant watercourses that collect the sparse but intense rainfall, most notably that of Fuente Álamo–El Albujón. The region is characterized by a semiarid climate with an average temperature of 18 °C and an annual average rainfall of 300 mm, which is distributed in few but very intense and short-lasting events [17]. CC is located in the Segura Basin, which has recently been selected by the Spanish Government as the Spanish Pilot River Basin within the European Expert Network on Water Scarcity and Droughts, since it currently presents water management problems that will be common in most Mediterranean regions in forthcoming decades [18].

Figure 1. General map of the study area.

From a geological point of view, CC is a postectonic depression with a strong backfill composed mainly of low-permeability detrital materials interspersed with highly permeable formations: Tortonian clusters, Andaluciense calcarenites and Pliocene sandstones. The most modern materials correspond to the quaternary and consist of silts, gravels and clays [19]. Accordingly, the hydrogeological system is a multilayer system consisting of deep, confined aquifers and an unconfined surface aquifer (quaternary). Groundwater makes a major contribution to the sustainability of local farming, along with the water provided by the Tagus-Segura Water Transfer Channel (TTS) and the recent surge of public desalinated seawater and the saltwater desalination plants from privately owned wells. The groundwater comes mainly from deep wells that occasionally collect the three or four productive aquifers without worrying about the isolation of crossed aquifers whose water is of poorer chemical quality.

In the past, resource management was private until the entry-into-force of the 1985 Water Act, which explains the almost universal situation of deposits controlled by new legislation, preventing the drilling of new wells, except in very special situations that involve repair or replacement to prevent loss of rights acquired in the situation before 1986. In 1980, the TTS was completed and provided CC with a maximum flow rate of 122 hm^3/year. From that moment on, more expensive groundwater became a complementary resource for the flow rate provided by the TTS, which varies in time, but is of better quality. The TTS has become the main supplier of water resources to the area, albeit with highly variable flow rates depending on those available in the Tagus headwaters. In recent years, the gradual reduction of the flow rates transferred from the TTS has led to increased pressure on groundwater [20]. The solution to the problem of overexploitation of aquifers in Southeast Spain is urgent and requires an effort from various administrations and water users [21].

The local economy is based on farming with crops that occupy approximately one third of the total area [22]. This space is distributed in similar proportions between arable crops (mainly lettuce, melon and artichoke) and woody crops (mainly citrus). Water scarcity has developed the use of drip irrigation and the need to make good use of water. In recent years, tourism has become an important development factor for water, favoured by good weather, the presence of large beaches on the coast and hotel infrastructures. The progressive increase in the demand for public supply water has set both uses in competition with each other.

3. Materials and Methods

The methodology presented here is based on the Watershed Sustainability Index proposed by Chaves and Alipaz in 2007 [6], and it has been adapted to the characteristics of basins which, under an arid or semiarid climate, withstand great human pressure on resources when there are hardly any surface resources. Accordingly, most of the water used comes from groundwater. It is considered that the sustainability of a basin with the above characteristics depends on its hydrogeology (H), environment (E), life (L) and the policies applied to water resources (P). These four indicators return a new index, called the Aquifer Sustainability Index (ASI), by applying the following equation:

$$ASI = \frac{H+E+L+P}{4} \quad (1)$$

where H indicates the hydrogeology (0–1); E indicates the environment (0–1); L indicates life (0–1); and P indicates Policies (0–1). Each of these indicators is analysed separately following a pressure-state-response model. It consists of analysing the relationship between human activities (pressure) and their impact on the state of the environment (state), causing a series of actions to be taken to solve the problems that are created (response). The advantage of using a model of this type is that, by incorporating relations of cause and effect, it informs users and decision-makers of the relationship between various parameters and therefore helps the establishment or reorientation of policies [23]. To do this, we have proposed a number of parameters that provide adequate representation of the individual processes in each indicator (Table 1). From the equation, it follows that the same weight is given to each indicator and, like the other indicators, the ASI will vary between 0 and 1. The weight of each indicator should be established by consensus among the various stakeholders in the basin, whereby they may vary in each case study. In this paper, we have assumed the same weight for each indicator to avoid bias in the results [24].

Table 1. Indicators and parameters of the Aquifer Sustainability Index.

Indicators	Parameters		
	Pressure	**State**	**Response**
(H) Hydrogeology	Variation in the groundwater depletion in the period studied, relative to the long-term average	Groundwater as a percentage of total use of irrigation water	Evolution in non-conventional water resources supply
	Variation in the Nitrate concentration in the period analysed	Sampling points that meet quality standards in the period analysed	Improvement in nitrate contamination in the period analysed
(E) Environment	Averaged variation of basin agricultural area and urban population in the period analysed	% of basin area with natural vegetation	Evolution in basin conservation in the period analysed
(L) Life	Variation in the basin per capita income in the period analysed	Basin HDI (weighed by county population)	Evolution in the basin HDI in the period analysed
(P) Policy	Variation in the basin HDI-Education in the period analysed	Basin institutional capacity in IWRM	Evolution in the basin's IWRM expenditures in the period analysed

The following develops the methodology used to calculate the parameters in each indicator and the source of the data used. After obtaining the score of each indicator, the above equation is applied. From the final ASI value, sustainability could be considered low if ASI < 0.5, intermediate if the range varies between 0.5 and 0.8, and high if ASI > 0.8. This follows a classification similar to that used by the United Nations in the classification of the Human Development Index (HDI) [25].

3.1. Hydrogeology

The objective of the hydrogeology indicators is to define specific aspects of the quantitative and qualitative state of groundwater to define the planning and sustainable management of available water resources [26]. The indicators used are calculated from data that are relatively easy to obtain, providing information about the state of the aquifer and the possible trends and impacts that occur in it.

3.1.1. Quantity

From a quantitative point of view, the sustainable management of groundwater depends on it not being extracted through overexploitation, which in turn is related to the fall in the piezometric levels of the aquifer. The piezometric evolution of the numerous wells has made it possible to select those in which it is possible to ensure that the three in existence collect from one single aquifer [22]. Figure 2a plots the piezometric variations of the different aquifers. The quaternary aquifer shows stabilized evolution, while the evolutions of the Messinian and Pliocene aquifers are very similar, with significant periods of falling piezometric levels that correspond to periods of drought in which the flow rates provided by the TTS decreased (Figure 2b).

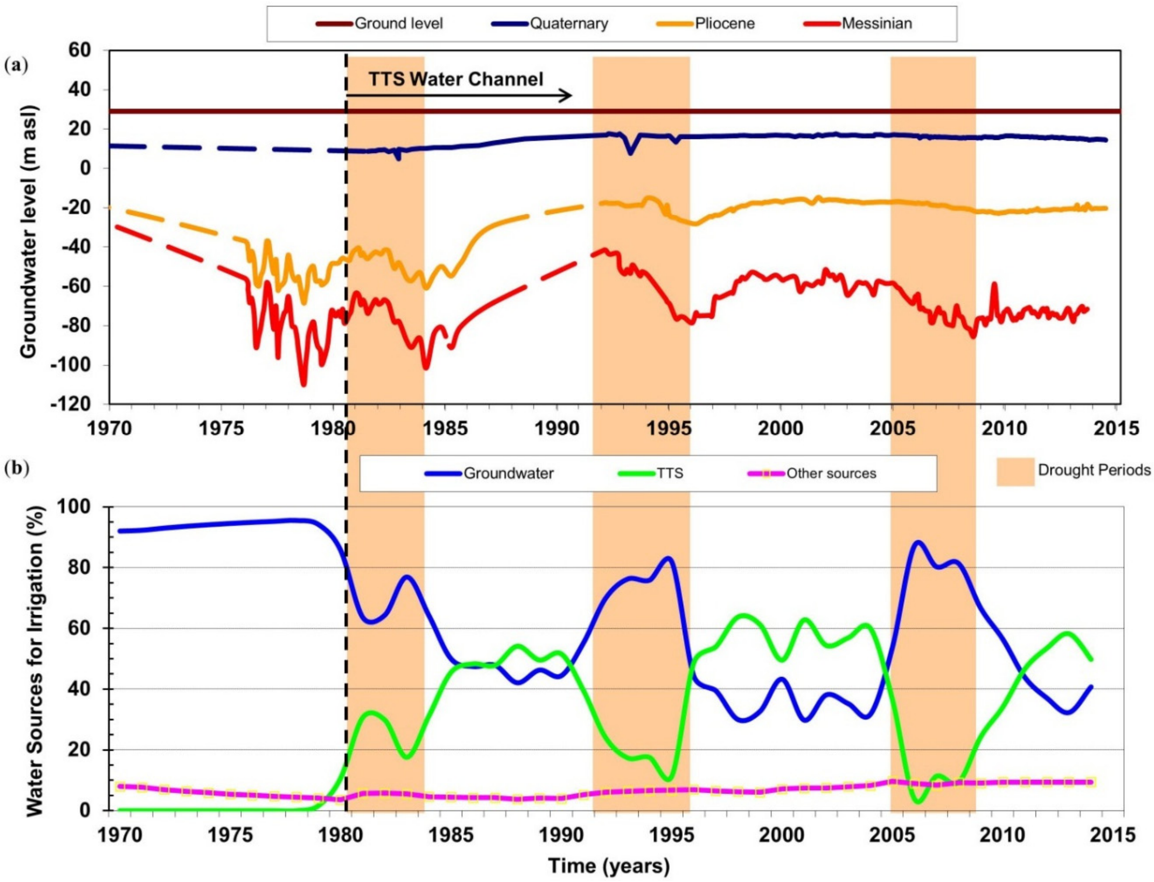

Figure 2. (**a**) Long-term variations of groundwater levels in the Campo de Cartagena aquifer. Dashed lines correspond to reconstructed evolution. Adapted from Baudron *et al.* [22]; (**b**) Water sources for irrigation in the Campo de Cartagena area. Adapted from García-Aróstegui *et al.* [27].

The above information has been used to evaluate the pressure parameter by comparing the average piezometric level in each aquifer during the study period with the average piezometric level throughout the period 1980–2006. A score of 0.5 has been considered when the average piezometric level in the aquifer during the study period was similar to the average piezometric level during the historical series. This score increases or decreases depending on the position of the average piezometric level during the study period with respect to the maximum and minimum levels of the historical series. Accordingly, the following equations are applied:

If $GL_{SP} < GL_{LP}$:

$$\Delta 1(\%) = \frac{GL_{SP} - GL_{LPmin}}{GL_{LP} - GL_{LPmin}} \times 100 \tag{2}$$

If $GL_{SP} \geq GL_{LP}$:

$$\Delta 2(\%) = \frac{GL_{SP} - GL_{LP}}{GL_{LPmax} - GL_{LP}} \times 100 \tag{3}$$

where GL_{SP} is the average groundwater level in the short period; GL_{LP} is the average groundwater level in the long period; GL_{LPmin} is the minimum groundwater level in the long period and GL_{LPmax} is the maximum groundwater level in the long period.

As shown in Figure 2, the sustainable exploitation of the CC aquifer is closely related to the percentage of groundwater used to meet demand. We can see how, in order to manage these waters sustainably, this percentage should be between 50% and 60%, while the rest of the demand must be satisfied by surface water resources from the TTS or by reusing wastewater and desalination water. Percentages above 60% compromise the sustainable management of groundwater in the aquifer. According to Table 2, this percentage must be calculated during the study period to evaluate the state parameter.

To analyse the response parameter, we calculated the non-conventional water resources obtained through the reuse of wastewater, desalination and transfers from other basins, assigning scores based on the percentage of non-conventional water resources obtained regarding the natural availability of water per capita.

Table 2. Description of Hydrogeology parameters, levels, and scores.

Stages	Parameters	Level	Score
Pressure	Δ1, Δ2 Variation in the groundwater depletion in the period studied, relative to the long-term average	Δ1 ≤ 40%	0.00
		40% < Δ1 < 80%	0.25
		Δ1 ≥ 80% Δ2 ≤ 20%	0.50
		20% < Δ2 < 60%	0.75
		Δ2 ≥ 60%	1.00
	Variation in the nitrate concentration in the period studied, relative to the long-term average	Δ ≥ 20%	0.00
		10% ≤ Δ < 20%	0.25
		−10% ≤ Δ < 10%	0.50
		−20% ≤ Δ < −10%	0.75
		Δ < −20%	1.00
State	Groundwater as a percentage of total use of irrigation water	Δ ≥ 80%	0.00
		70% ≤ Δ < 80%	0.25
		60% ≤ Δ < 70%	0.50
		50% ≤ Δ < 60%	0.75
		Δ < 50%	1.00
	Percentage of sampling points that meet quality standards in the period studied (nitrate concentration ≤50 mg/L)	Δ ≤ 20%	0.00
		20% < Δ ≤ 40%	0.25
		40% < Δ ≤ 60%	0.50
		60% < Δ ≤ 80%	0.75
		Δ > 80%	1.00
Response	Non-conventional water resources supply in the study area, relative to the conventional water resources in the period studied	Δ = 0%	0.00
		0% < Δ ≤ 5%	0.25
		5% < Δ ≤ 10%	0.50
		10% < Δ ≤ 20%	0.75
		Δ > 20%	1.00
	Improvement in nitrate concentration in the aquifer, in the period studied	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00

3.1.2. Quality

The contamination of groundwater by nitrates from farming sources is one of the most serious environmental and public health problems facing modern agriculture. This contamination is caused mainly by the excessive fertilization of crops and the inappropriate management of waste from livestock farms. It is particularly problematic in areas with low rainfall, as is the case with the semiarid areas examined in this paper [28]. This problem is widespread in many regions and countries. Thus, the European Union has stepped in, promoting legislation that prevents this kind of contamination. One of the most important aspects of this legislation has been the establishment of Codes of Good Agricultural Practice and the designation of the areas most affected by contamination (called Vulnerable Areas) and the corresponding Action Programmes for said areas in order to control and reduce contamination.

The pressure and state parameters have been calculated from nitrate concentration figures provided by the IGME and the CHS. To analyse pressure, the mean value of the nitrate content during the study period is compared with the historical average. The state has been evaluated by calculating the number of sampling points of the total that comply with the limit established by the European directive on the protection of groundwater (50 mg/L) [29]. Regarding the response to this serious contamination, the improvements made to reduce this problem must be analysed.

3.2. Environment

Pressure on the environment has been evaluated based on the variation in the area of the basin used for agriculture and the variation of the resident population throughout the study period, since, according to Hunsaker and Levine [30], the proportion of urban and agricultural areas correlates with the quality of the resources. Population growth is one of the crucial elements affecting long-term sustainability of water resources. The state of the environment has been defined from the percentage of basin area under natural vegetation (Av), whereas the response to these pressures has been evaluated based on the increase during the study period of the areas legally declared as protected natural areas (PNA) (Table 3).

Table 3. Description of environment parameters, levels, and scores.

Stages	Parameters	Level	Score
Pressure	Averaged variation of basin agricultural area and urban population in the period analysed	$\Delta \geq 20\%$	0.00
		$10\% \leq \Delta < 20\%$	0.25
		$5\% \leq \Delta < 10\%$	0.50
		$0\% \leq \Delta < 5\%$	0.75
		$\Delta < 0\%$	1.00
State	Percent of basin area under natural vegetation (Av)	$Av \leq 5\%$	0.00
		$5\% < Av \leq 10\%$	0.25
		$10\% < Av \leq 25\%$	0.50
		$25\% < Av \leq 40\%$	0.75
		$Av > 40\%$	1.00
Response	Evolution in protected natural areas (PNA) in the basin, in the period studied	$\Delta \leq -10\%$	0.00
		$-10\% < \Delta \leq 0\%$	0.25
		$0\% < \Delta \leq 10\%$	0.50
		$10\% < \Delta \leq 20\%$	0.75
		$\Delta > 20\%$	1.00

The municipal population data were obtained from the National Statistics Institute (INE) [31]. In the case of municipalities whose surface was part of areas other than those in CC, the approach taken has been to allocate the population of said area to the area where the main population centre of the municipality was geographically located. The evolution in land use is calculated using the maps for the Segura basin obtained by Alonso *et al.* in 2010 [32] using remote sensing. These recent data have also been used to determine the percentage of each of the sub-basins with natural vegetation. For the response parameter, we have used the data available from the EUROPARC-Spain Foundation [33].

3.3. Life

The purpose of this indicator is to evaluate the quality of life of human beings. Based on the idea of the low availability of data on which this work has been completed, we decided to use the Human Development Index (HDI). The HDI was developed by the United Nations Development Programme (UNDP) and has been used for ranking countries and regions all over the world since 1990 [25]. The HDI is a composite index that measures a region's average achievements in three basic aspects of human development: longevity, knowledge, and a decent standard of living. Longevity is measured by life expectancy at birth; knowledge is measured by a combination of the adult literacy rate and the combined primary, secondary and tertiary gross enrolment ratio; standard of living is measured by GDP per capita.

Following the methodology used by Chaves and Alipaz [6], we have selected the variation of HDI-Income as the pressure parameter during the study period, the HDI in the year prior to the period studied for Life State, and the evolution of the HDI in the period studied as the Life Pressure parameter (Table 4).

Table 4. Description of life parameters, levels, and scores.

Stages	Parameters	Level	Score
Pressure	Variation in the aquifer per capita HDI-Income in the period studied, relative to the previous period	$\Delta \leq -20\%$	0.00
		$-20\% < \Delta \leq -10\%$	0.25
		$-10\% < \Delta \leq 0\%$	0.50
		$0\% < \Delta \leq 10\%$	0.75
		$\Delta > 10\%$	1.00
State	Aquifer HDI (weighed by county population)	HDI ≤ 0.5	0.00
		0.5 < HDI ≤ 0.6	0.25
		0.6 < HDI ≤ 0.75	0.50
		0.75 < HDI ≤ 0.9	0.75
		HDI > 0.9	1.00
Response	Evolution in the aquifer HDI, in the period studied	$\Delta \leq -10\%$	0.00
		$-10\% < \Delta \leq 0\%$	0.25
		$0\% < \Delta \leq 10\%$	0.50
		$10\% < \Delta \leq 20\%$	0.75
		$\Delta > 20\%$	1.00

We have used the human development indices (HDI) published by Instituto Valenciano de Investigaciones Económicas [34]. These indices are calculated at provincial level. Thus, in order to obtain the indicators related to the study area, we have calculated a weighted average based on the population of each province in the study area.

3.4. Policy

For the pressure parameter, we use the variation of the human development index on education (HDI-education) during the study period (Table 5). This is determined in a similar way to the abovementioned life indicators. For the institutional capacity of the basin, we have used a quantitative classification ranging from poor (0.0) to excellent (1.0), accepting that if there are appropriate water resource management laws, but they have not yet been implemented or regulated, an intermediate score (0.5) could be assigned. In the case of CC, the study area is subject to the obligations provided in the Water Framework Directive (WFD) [35]. Thus, the starting point will be a medium level and the score will increase depending on legal capacity, the effectiveness of the institutional framework and public participation in the SWMaDM process. Legal and institutional capacity in the management of water resources is subject to different points of view. One of them corresponds to the administration's ability to perform its functions effectively, efficiently and sustainably. From this simplistic approach, it follows that the higher the capacity, the greater the possibility of progressing towards sustainable development. We have analysed the level of compliance with the provisions of the WFD, meetings between the different sectors involved and participation in said meetings by the players involved in the hydrological planning process.

To analyse the political response, we have used data provided by the agency responsible for the management of the basin in terms of investments in the management of aquifer water resources during the study period.

Table 5. Description of policy parameters, levels, and scores.

Stages	Parameters	Level	Score
Pressure	Variation in the aquifer HDI-Education in the period studied, relative to the previous period	$\Delta \leq -20\%$	0.00
		$-20\% < \Delta \leq -10\%$	0.25
		$-10\% < \Delta \leq 0\%$	0.50
		$0\% < \Delta \leq 10\%$	0.75
		$\Delta > 10\%$	1.00
State	Aquifer institutional capacity in IWRM (legal and organizational)	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00
Response	Evolution in the aquifer's WRM expenditures in the aquifer, in the period studied	$\Delta \leq -10\%$	0.00
		$-10\% < \Delta \leq 0\%$	0.25
		$0\% < \Delta \leq 10\%$	0.50
		$10\% < \Delta \leq 20\%$	0.75
		$\Delta > 20\%$	1.00

4. Results and Discussion

The methodology described above has been applied to CC, whose main features have been discussed earlier, during the period between 2006 and 2010, when data were available. Since ASI is formed by four indicators, each of them will be presented separately, and the overall sustainability index computed in the end. Finally, an uncertainty analysis has been done in order to analyze the uncertainty of the results attributable to the levels established in the methodology.

4.1. Hydrogeology Indicator

The hydrogeology indicator score was simply the average of the aquifer's quantity and quality parameters. The following offers a description of the results obtained for both indicators.

4.1.1. Quantity

Analysing the average piezometric level in the study period with regard to the average level for the historical period (1980–2010), we have observed that the levels in the Quaternary and Pliocene are above the historic average (Table 6). However, in the Messinian, the opposite is true. By applying Equations (2) and (3), and applying the levels specified in Table 2, a medium pressure parameter of 0.58 is obtained for the CC aquifer. This indicator gives us the possibility of evaluate not only drops in the piezometric level due to the excessive pumping of groundwater but also the ascent of piezometric level due to recharge produced as a consequence of the irrigation by means of external resources (TTS). We consider that this situation is not very frequent in semiarid zones, but these external resources can suppose a good tool to mitigate piezometric drops and guarantee the sustainability in the groundwater resources management.

Table 6. Groundwater quantity in the period analysed (2006–2010): Pressure parameter.

Layer	GL_{SP} (m asl)	GL_{LP} (m asl)	GL_{LPmin} (m asl)	GL_{LPmax} (m asl)	$\Delta 1$ (%)	$\Delta 2$ (%)	Pressure Score
Quaternary	15.93	15.11	4.79	17.64		32.41	0.75
Pliocene	−20.58	−24.91	−60.88	−14.73		42.53	0.75
Messinian	−74.88	−67.92	−101.56	−41.46	79.31		0.25
CC Aquifer							0.58

In the case of groundwater quantity state parameter, the average percentage of the total use of irrigation water in the five-year period was 74% due to the fact that during most of the study period, the area was under the effects of drought and contributions from the TTS fell drastically. According to Table 2, this results in a state score of 0.25.

As shown in Table 7, the use of non-conventional water resources has been one of the major commitments to reducing overexploitation of the CC aquifer. Throughout the study period resources from the TTS (49.01 hm^3/yr) were used, the number of Wastewater Treatment Plants increased from the 23 before 2006 to 27 in late 2010. Certain reuse treatments were improved and this has led to an increase in the quantity of reused wastewater to an average value of 17.73 hm^3/yr during the study period. In addition, five new desalination plants have been built capable of producing a total of

92 hm^3/yr. All these actions have led to the availability of more than 400 m^3/inhab/yr from non-conventional water resources. Moreover, the natural availability of water resources in CC in 2006 and 2010 was only just over 1000 m^3/inhab/yr, which, for the purposes of the Falkenmark index [36], ranks the study area in a situation of serious water stress. Finally, a ratio of 38.69% between the availability of unconventional and conventional water resources is obtained. This is equivalent to a response score of 1.0.

Table 7. Groundwater quantity in the period analysed (2006–2010): Response parameters.

Parameters	Response Score
Averaged Population (inhabitants)	361,745
Averaged Non-Conventional Water Resources (hm^3/yr)	158.74
Non-Conventional Water Resources Availability per capita (m^3/inhab/yr)	439
Conventional Water Resources Availability per capita (m^3/inhab/yr)	1134
Non-Conventional Water Resources/Conventional Water Resources Availability (%)	38.69
Response Score	1

4.1.2. Quality

In the case of the groundwater quality sub-indicator, pressure corresponds to the variation in the nitrate concentration in the period studied, relative to the long-term average (1980–2010), yielding, according to Table 8, a score of 0. As mentioned above, nitrate contamination is one of the major problems in CC. This can be seen in the fact that the average nitrate concentration obtained from 65 chemical analyses [37] conducted between 2006 and 2010 and distributed across 22 different sampling points is more than twice the average nitrate concentration obtained from all available analyses since 1980. To determine the state parameter, we analysed the number of sampling points over the total whose average nitrate concentration complies with current legislation (<50 mg/L).

Table 8. Groundwater quality: Pressure and state parameters.

Parameters	Value	Δ (%)	Pressure Score	State Score
Average nitrate concentration (mg/L) (1980–2010)	63.4	137.9	0.00	
Average nitrate concentration (mg/L) (2006–2010)	150.8			
Number of sampling points below 50 mg/L	5	22.7		0.25
Total sampling points	22			

During the last years and in compliance with EU specifications, some programmes have been approved in CC in order to control and reduce groundwater contamination. As reflected in the state parameter, these programmes have not yet borne fruit. The analysis of subsequent study periods will determine the effectiveness of the action programme that was proposed. Therefore, an average value of 0.5 is proposed for this response parameter.

4.2. Environment Indicator

The areas used for agriculture and the resident population have grown over the study period, yielding an EPI of 6.62% (Table 9). This corresponds to an environmental pressure score of 0.50.

Table 9. Environment. Pressure, state and response parameters.

Parameters		Value	Δ (%)	EPI	Pressure Score	State Score	Response Score
Total Area (km^2)		1602					
Agricultural Area (km^2)	2006	1101	5.90	6.62	0.50		
	2010	1166					
Population	2006	348893	7.33				
	2010	374466					
Av (%)	2006	18.13	17.08			0.50	
	2010	16.03					
PNA (km^2)	2006	105.99	0				0.25
	2010	105.99					

Regarding the percentage of aquifer area under natural vegetation (Av), very similar values have been obtained in 2006 and 2010, determining an average Av of 17.08% over the study period, equivalent to a score of 0.50. During the study period, there has been no increase to the PNA so the score is 0.25.

4.3. Life Indicator

Given that the data on the HDI are provincial, we have obtained the values for the aquifer by weighting the population of each province in the study area (Tables 10 and 11).

Table 10. Life: Pressure parameters.

Province	Population		HDI-Income		Weighted HDI-Income			Pressure Score
	2006	2010	2006	2010	2006	2010	Δ (%)	
Murcia	329,315	351,911	0.789	0.779	0.789	0.779	−1.27	0.50
Alicante	19,578	22,555	0.794	0.782				

Table 11. Life: State and Response parameters.

Province	HDI		Weighted HDI			State Score	Response Score
	2006	2010	2006	2010	Δ (%)		
Murcia	0.838	0.845	0.838	0.845	0.88	0.75	0.50
Alicante	0.839	0.853					

4.4. Policy Indicator

Like the previous section, the HDI-Education evolution throughout the study period (Table 12) returned an increase of 2.06%. This results in a pressure score of 0.75.

Table 12. Policy: Pressure parameters.

Province	HDI-Education		Weighted HDI-Education			Pressure Score
	2006	2010	2006	2010	Δ (%)	
Murcia	0.782	0.797	0.781	0.798	2.06	0.75
Alicante	0.772	0.806				

The WFD sets out clear deadlines for each of the requirements, which adds up to an ambitious overall timetable. During the period study, one of the key milestone was to finalize river basin management plan including the programme of measures in 2009. This target was not achieved since the river basin management plan was not approved until 2014. In terms of institutional capacity, during the study period, the Segura River Basin Authority (SRBA) set up territorial boards across the geography of the basin in order to design and implement the public participation process. One of these territorial boards was specific to CC and several meetings took place during the study period. With respect to public participation, several sectoral boards were also set up (Environment, Agriculture, Research and Socio-economic) and all stakeholders were invited to take part. The minutes of the meetings provided by the SRBA show that the level of participation exceeded 60% of those who were invited. As a consequence, the aquifer was ranked 'good' in this item, with a corresponding parameter level of 0.75. As shown in Table 13, WRM expenditures increased by 14.58% in CC, resulting in a parameter value of 0.75.

Table 13. Policy: Response parameters.

Population		WRM Expenditures (miles €)			Response Score
2006	2010	2006	2010	Δ (%)	
348893	374466	8366	9586	14.58	0.75

4.5. Overall Aquifer Sustainability

Applying Equation (1), an overall ASI score of 0.55 was obtained for the CC aquifer. Table 14 offers a summary of all the parameters obtained and the final value of the index, which for the purposes of the proposed scales would imply a medium sustainability index. If the results obtained are analysed based on indicator, the highest scores correspond to Life and Policy, while the worst results come from Hydrogeology and Environment. On the other hand, an analysis of the overall results of pressure, state and response returns no significant differences.

Table 14. Results from the application of the aquifer sustainability index (ASI) in Campo de Cartagena (2006–2010).

Indicators		Pressure	State	Response	Result
Hydrogeology	Quantity	0.58	0.25	1	0.43
	Quality	0.00	0.25	0.50	
	Overall	0.29	0.25	0.75	
Environment		0.50	0.50	0.25	0.42
Life		0.50	0.75	0.50	0.58
Policy		0.75	0.75	0.75	0.75
Result		0.51	0.56	0.56	**0.55**

However, an analysis of each of the indicators that have been calculated reveals the main problems that prevent more sustainable aquifer management. On the one hand, low results for the hydrogeological indicator for pressure and state, in terms of quantity and quality, highlight the two major problems facing the aquifer: groundwater contamination as a result of intensive local farming;

and severe water stress alleviated in part by contributions from the TTS, although as a result of droughts during much of the study period, said contributions were lower. However, the response parameters can be considered good and water users, stakeholders, and decision-makers should maintain the measures that have been taken. Future periods subsequent to that analysed in this work should involve an improvement of the pressure and state parameters.

On the other hand, the response to the environment indicator is low, which should be solved in the future with measures related to compliance with EU environmental legislation and the creation of PNA. It is also important to note the decline of HDI-Income over the study period, which makes sense if we consider the severe economic crisis that affected Spain during the study period under analysis.

4.6. Uncertainty Analysis

Many subjective judgements have to be made in the development of a composite indicator. The uncertainty analysis aims to quantify the overall uncertainty of the composite index here presented as a result of the uncertainties associated with the modelling process and the subjective choices taken [13,38]. A Monte Carlo method was used to evaluate those uncertainties varying ±10% levels established to obtain a score per each parameter; running times is 1344. Then, the mean and 95% confidence interval of the ASI is obtained. The results of the uncertainty analysis can be seen in Table 15. From those results, it is easy to find that the actual and simulated results are similar and both above a final score of 0.50, so it can be still considered an intermediate level of sustainability during the period studied and the uncertainty of the results is reasonable.

Table 15. Results from the uncertainty analysis.

Statistics	Hydrogeology (H)	Environment (E)	Life (L)	Policy (P)	ASI
Average	0.5276	0.4156	0.5832	0.7512	0.5694
Standard Deviation	0.0197	0.1217	0.1161	0.0948	0.0488
Minimum	0.5000	0.1667	0.3334	0.5834	0.4167
Maximum	0.5416	0.6667	0.8334	0.9167	0.7083
Significance Level	0.05	0.05	0.05	0.05	0.05
Width Confidence Intervals	0.0011	0.0065	0.0062	0.0051	0.0026

5. Conclusions

In this work, we have developed a compound index called the aquifer sustainability index, which considers not only hydrogeological aspects but also social, economic and environmental aspects. This index could be applied in aquifers other than the one studied, we used a small number of parameters based on commonly available variables so that they could be calculated in areas under limited data availability.

The case study is very similar to other aquifers in Mediterranean countries: the absence of permanent courses, intensive farming and close competition on groundwater resources, which makes it possible for the methodology presented here to be applied elsewhere.

In the case of Campo de Cartagena, the results obtained show the main problems in the aquifer: groundwater contamination as a result of intensive farming, and the dependence on external inputs from the Tagus-Segura Water Transfer Channel to avoid overexploitation of groundwater resources. Applied to successive periods of time, this methodology contributes to the development and implementation of effective sustainable water management and contributes to the decision-making process.

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Author Contributions

Javier Senent-Aparicio, Julio Pérez-Sánchez and José Luis García-Aróstegui developed the study. Alicia Bielsa-Artero and Juan Carlos Domingo-Pinillos were involved in the data collection. Javier Senent-Aparicio prepared the manuscript and all authors discussed the results and implications and commented on the manuscript at all stages.

Conflicts of Interest

The authors declare no conflict of interest.

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