Desalination and Water Treatment
www.deswater.com

doi: 10.1080/19443994.2013.848331

52 (2014) 2102–2113
February

Taylor & Francis
Taylor & Francis Group

A new conceptual water integrated model for the Seybouse basin, Annaba region

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Received 29 November 2012; Accepted 12 September 2013

ABSTRACT

A new conceptual water integrated management model is proposed for the Annaba region water management. The effective variables of water sector management are characterized and the geographical areas under water stress within AR are defined. The aim of the study is to find out how to establish the prediction relationships to be used as decision support tools. The Conceptual Water Integrated Model in Semi-Arid Mediterranean (CWIMSAM model) concept integrates socioeconomic, pollution pressures, water quality, public health and ecological impacts, and institutional responses. It shifts water resources from supply management side to demand management side. The integrated, preventive, and ecosystem approaches have been introduced. We apply the research methodology development and the validation of CWIMSAM to achieve sustainable water resources management. We discuss on the driver-pressure-state-impact-response (DPSIR) framework to develop the possible variables based on cause–effect relationship. We analyze the expert opinion and judgment methods for the development and validation of model and variables and we make the comparison with well-established water management models.

Keywords: ANN; Annaba region; Integrated water management model; Pollution pressures; Public health and ecological impacts; Socioeconomic driving forces; State of water quality

1. Introduction

Water resources management in semi-arid Mediterranean countries with scarce water resources is a complex challenge [1–3]. It requires new concepts and techniques if management should be based on sound scientific findings in order to optimize and conserve the precious water resources.

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Presented at the 6th International Conference on Water Resources in Mediterranean Basin (WATMED6), 10–12 October 2012, Sousse, Tunisia

In regards to integrated water resources management (IWRM), no systematic and comprehensive multidisciplinary works have been developed so far and even they seem to have shortcomings. Therefore, many scholars [4–6] explicitly have called for additional work to substantiate this aspect.

The Mediterranean water resources especially in the southern countries are characterized by vulnerable, scarce, intensively exploited, and threatened water resources. Water availability is about 100 m^3/inhabitant/year [7]. There are severe water imbalances particularly in summer months due to low precipitation and uneven distribution and high temperature. Water resources are vulnerable to global change, such as climate change and sensitive to drought. The consequences of droughts are severe on soils and sub-soils drying up, agriculture production, food security, and socioeconomic aspects where they lead to water deficit.

Water resources are also vulnerable to the fast-growing demand of urban and rural populations, demand of economic sectors including agriculture and industry. The predicted water demand either exceeds or will exceed the sustainable supply within a short time since the water demand is high and on an upward trend.

Increasingly, water quality degradation from land use conflicts, destruction of wetlands and ecosystems, and anthropogenic effects is undermining the sustainable management of water resources and threatening water resource base as part of nature. Anthropogenic effects are caused by local and diffuse sources. The pollution sources are: urban sewage, solid waste, hazardous waste, industrial waste, overuse of fertilizers, and pesticides. In addition, over-exploitation of coastal aquifers has already led to many cases of irreversible saltwater intrusion [8]. If the pollution sources remain unrestrained, then it is likely to further exacerbate water scarcity in a region that has already a limited inheritance of water.

The main objectives of the research were to:

- characterize the effective variables of water sector management and define the geographical areas within Annaba region under water stresses;
- establish prediction relationships between the water abstraction from the coastal aquifer and socioeconomic driving forces;
- classify municipalities into clusters associated with their related water variables; and
- formulate recommendations for change including new concepts to sustain the natural water resources as sources of supply for both the present and future generations [9].

In semi-arid Mediterranean countries, water is not only an essential resource, but also a limited and scarce resource. The situation of water resources is described by supply-oriented management, resources under pressure and exploited, environmental degradation and low coverage of water supply and sanitation facilities for both rural and urban areas.

One of the lessons learned over the years conclude that technical engineering solutions alone cannot provide the increasing populations with adequate quantities to the required qualities and, in parallel, maintain the integrity of hydrological and ecosystems [10].

It is certain that water management today cannot be made with the methods and mentality of the past.

Hence, there is a need for careful and wise management of water resources. Accordingly, transition from a water supply-driven approach, where water resources development was the major focus, to an IWRM is essential [11]. A holistic multidisciplinary integrated approach is crucial as a feasible answer to the accumulated water problems and a way to avoid further water crises [12].

In this research, a relation between groundwater abstraction and socioeconomic variables in the Annaba coastal aquifer has been developed based on a cause–effect relationship tackling the life cycle of water resources management. The driver-pressure-state-impact-response (DPSIR), EEA, was selected as a well-established framework to develop the possible socioeconomic variables.

The effective variables have been characterized and prioritized using multicriteria analysis with artificial neural networks (ANN) and expert opinion and judgment. The selected variables have been classified and organized using multivariate techniques which are cluster analysis, factor analysis, and principal component and classification analysis.

This research work was intended to contribute to those efforts through developing a new conceptual water integrated model for semi-arid mediterranean region (CWIMSAM). It has been the first experience that tackled the big picture of IWRM with emphasis on sustainability concepts and continuous interactions between the institutional system and the human and natural systems. The integrated, preventive, and ecosystem approaches have been introduced in the CWIMSAM. Besides, effective and useful sets of variables (indicators) were characterized for water sector analysis and monitoring. CWIMSAM supports water planners and managers to gain adequate knowledge and understanding of the actual water problems. It causes changes in the decision-makers' subjective views and enables them to devise proper interventions with the objective of achieving sustainable use and management of Annaba aquifer as part of the nature conservation.

2. Materials and methods

2.1. Study area

Annaba, in Algeria, is currently facing an acute shortage of freshwater supply and water is seen as one of the most critically stressed resources.

The regional aquifer system is limited in the west by the Edough metamorphic complex, in the south by Fetzara Lake and the eastern extension of the Cheffia Numidian mountains, in the north by the Mediterranean Sea, and finally in the east by the Bouteldja Numidian massifs, as shown in Fig. 1. The total area of the Annaba region is 760 km^2. The study area is divided into 21 main sectors: Besbes, Zerizer, Ben M'hidi, Drean, Chbaita, Sidi Amar, Hdj eddiss, Mouaissia, Sebaa, Daroussa, El Kous, Ben Amar, Denden, El Hadjar, El Kerma, El Gantra, Fetzara and Taref, Salines, Bouteldja, and Pont Bouchet.

The population of Annaba is expected to double by 2020 to reach 2 millions [13]. This will worsen the already precarious situation. However, the current withdrawals are very far from meeting demand in terms of quantity and quality: domestic water supply is only 100 liters per capita per day ($L\,c^{-1}\,d^{-1}$), compared with 150 $L\,c^{-1}\,d^{-1}$ recommended by the World Health Organization (WHO) standards [14]. Over-exploitation of the aquifer has led to falling groundwater levels and deteriorating water quality due to seawater intrusion. Furthermore, groundwater quality is made worse through the infiltration of sewage, polluted surface water, solid waste leachates, and agricultural chemicals. Chloride and nitrate contents of the water are very high, at many locations exceeding maximum levels established by the WHO for drinking water. During recent years, water resource shortages and water pollution have severely hindered the socio-economic development in many parts of Annaba. Considering the potential doubling of population by year 2020, water demand will increase to reach 300 $hm^3\,year^{-1}$ by that time. This projected value will definitely exceed the sustainable capacity of the aquifer [15].

2.2. Methods

The most important elements and sciences related to water have been depicted in the form of lence

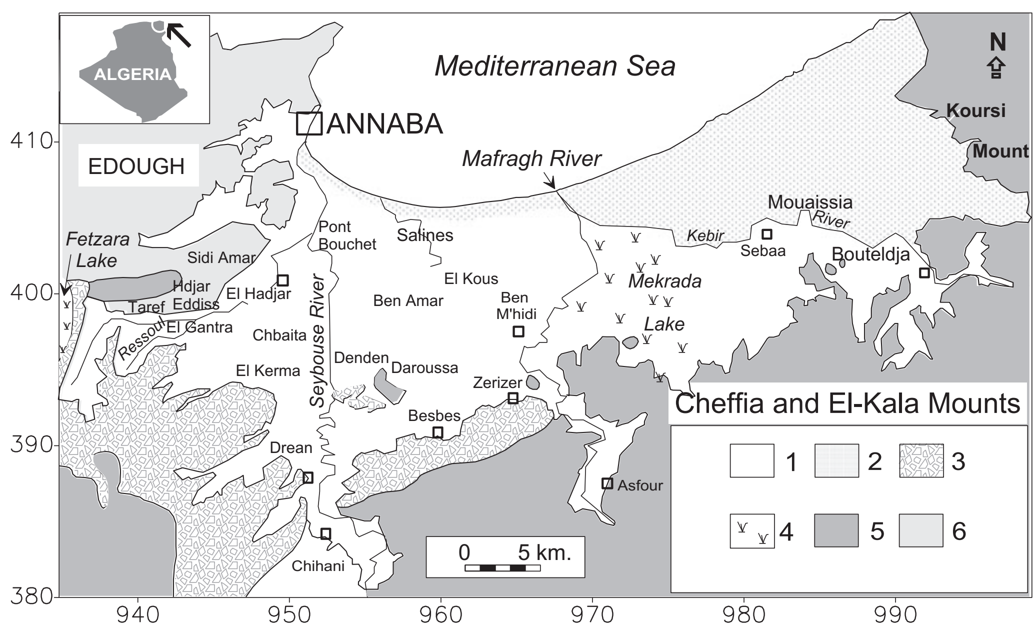

Fig. 1. Geological sketch map of the plain of the Annaba region: (1) recent and present alluvium; (2) dunes; (3) ancient alluvium; (4) lake or swamp; (5) Numidian sandstone or clay; and (6) Metamorphic formation (micaschists, gneiss, marbles).

(Fig. 2(a)) as a new conceptual model [16–19]. Fig. 2(a) indicates that water resources development and management must be within the ecological sustaining limits of available natural water resources. The new conceptual model is based mainly on three decisive categories: (1) the natural system, which is of critical significance for the water available quantities and qualities, (2) the human system, which determines the use of water and the pollution of the resource, and (3) the institutional and management system must balance consideration of the natural and human systems and their interdependencies. In Figs. 2(a) and (b), the three systems are divided into five categories based on cause–effect DPSIR framework for development of water-related variables. The variables reflect and translate the water sustainability concepts, preventive and ecosystem approaches. The five categories are: socioeconomic aspects, anthropogenic pollution pressures, state of water quality, public health and ecological impacts, and the institutional responses. The human system is explained by socioeconomic aspects, anthropogenic pressures, and public health variables. The natural water system is represented by the state of water, and ecological impacts and the institutional system is reflected by the institutional responses.

Fig. 2(b) highlights the involvement of water sector stakeholders and the experts' opinion and judgment [20–24].

The tools chosen for this research were ANN, expert opinion and judgment, health risk assessment, basic statistics, and multivariate techniques [25]. The software selected were the STATISTICA package version 6.0, STATISTICA Neural Networks (SNN) Release 4.0 E and RISC WorkBench [26]. There are five

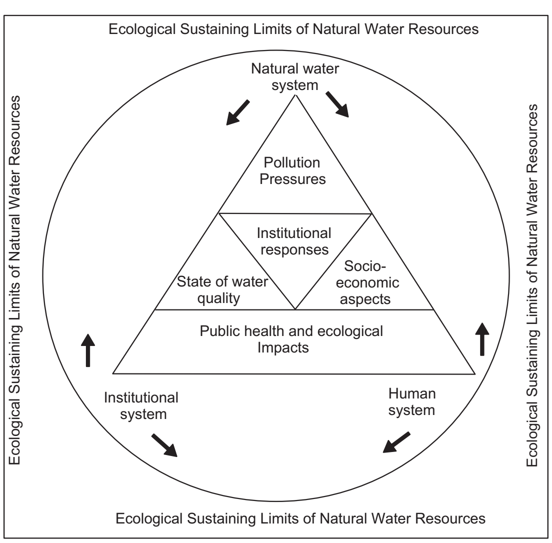

Fig. 2(a). Lence of CWIMSAM.

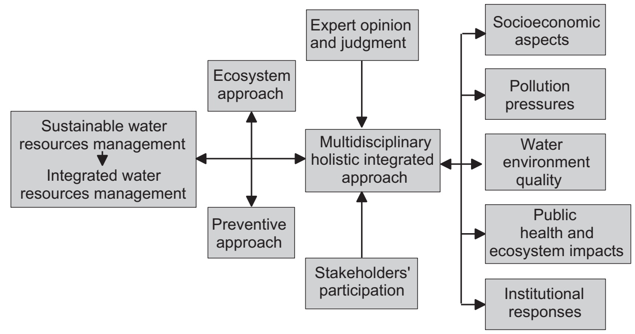

Fig. 2(b). Diagram of the conceptual integrated water model for the semi-arid Mediterranean.

steps in the proposed methodology for developing a conceptual integrated water model:

- Step 1: This first step expresses the creation of the ANN model, the characterization and prioritization of the effective variables, and the establishment of the modeling prediction relationships.
- Step 2: This indicates the analysis of the questionnaire undertaken to explore the expert opinion and judgment of various stakeholders using descriptive statistics. The results of Step (2) were compared with the results of the ANN in Step (1) to examine the understanding and knowledge of the local experts about the actual baseline conditions of water sector.
- Step 3: Transformation of data variables that were not normally distributed, and calculation of the correlation matrix, were carried out in Step (3) for the variables selected from Step (1).
- Step 4: Three techniques of multivariate analysis were undertaken in Step (4) for the selected variables, to classify them with the relevant municipalities.
- Step 5: This final step explains the health risk assessment of the Annaba Wastewater Treatment Plant as a contaminated hotspot. It assessed the health risks associated with the current disposal of wastewater on the sea shore close to the bathing areas. The chemicals identified as carcinogenic risks were fed back into the CWIMSAM model.

The results of Steps (1) and (4) were also fed back to complement the CWIMSAM with the selected priority variables and geographical areas under water stress. The full results will be a basis for and an input to evaluating the water plan through a Strategic

Environmental Assessment study which is beyond the scope of this research work.

Here, we present the main results obtained from analysis of socioeconomic data in addition to the synthesis of the results of the five categories analysis: socioeconomic aspects, anthropogenic pollution pressures, state of water quality, public health and ecological impacts, and the institutional responses.

The expert opinion and judgment was undertaken for comparison purposes to examine the level of understanding and knowledge of the selected group about the actual baseline conditions of water sector. The formation of the group judgment was facilitated by means of a questionnaire interspersed with controlled opinion feedback. Knowledge about the ranking of variables in the five categories was collected from 25 experts based in Annaba region. The group included the minister of environment, senior staff from the water, environment, industrial, and agricultural authorities, managers of water services in municipalities, agencies and specialized staff from non-governmental organizations representing the civil society.

3. Results

3.1. Application of ANN

The variables representing the socioeconomic driving forces: population in numbers (POP), income per capita in Euro year (ICP), land use measures the ratio of urban to agricultural areas (LDU), tourism, number of guest days (TRS), access to safe water supply in percentage (WSP), wastewater system coverage (WWC), storm water system coverage in percentage (SWC), water consumption per capita in percentage (WCC), water price in Euro m^{-3} (WPC), efficiency in revenue collection in percentage (ERC), agriculture water consumption in hm^3 $year^{-1}$ (AWC), gender empowerment in percentage (GEE), and water that is unaccounted in percentage (UFW), were considered as the possible input variables, whilst the target output variable was the water abstraction in hm^3 $year^{-1}$ (WAB). A schematic diagram of this network is given in Fig. 3.

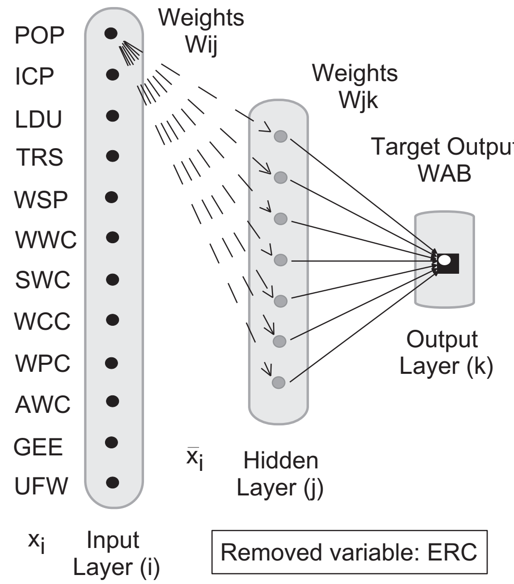

Fig. 3. MLP Network (three layers), socioeconomic variables.

It shows a typical feed forward structure with signals flow from input nodes, forward through hidden nodes, eventually reaching the output node. The input layer is not really neural at all: these nodes simply serve to introduce the standardized values of the input variables to the neighboring hidden layer without any transformation. The hidden and output layer nodes are each connected to all of the nodes in the preceding layer. However, the nodes in each layer are not connected to each other. A numeric weight is associated with each of the inter-node connections. A numeric weight of W_{ij} represents the strength of connections of nodes between input and hidden layer while W_{jk} represents the strength of connections of nodes between hidden and output layers.

Each hidden node (j) receives signals from every input node (i) which carries scaled values ($\overline{X}_i$) of an input variable where various input variables have different measurement units and span different ranges. $\overline{X}_i$ is expressed as:

$$\overline{X}_i = \frac{Xi - X\min(i)}{X\max(i) - X\min(i)} \tag{1}$$

Each signal comes via a connection that has a weight (W_{ij}). The net integral incoming signals to a receiving hidden node (Net_j) is the weighted sum of the entering signals, $\overline{X}_i$, and the corresponding weights, W_{ij} plus a constant reflecting the node threshold value (TH_j):

$$\text{Net}_j = \sum_{i=1}^{n} \overline{X_i} W_{ij} + \text{TH}_j \tag{2}$$

The net incoming signals of a hidden node (Net_j) is transformed to an output (O_j) from the hidden node by using a non-linear function (f) of sigmoid type, given by the following equation from:

$$O_j = f(\mathrm{Net}_j) = \frac{1}{1 + e^{-\mathrm{Net}_j}} \quad (3)$$

O_j passes as a signal to the output node (Net_k) is transformed using the sigmoid-type function to a standardized or scaled output ($\overline{O}_k$) that is:

$$\overline{O}_k = f(\mathrm{Net}_k) = \frac{1}{1 + e^{-Net_k}} \quad (4)$$

Then, $\overline{O}_k$ is de-scaled to produce the target output:

$$Ok = \overline{O}k(O\max(k) - O\min(k)) + 0\min(k) \quad (5)$$

During the analysis, 500 networks were tested. The best optimal ANN model found was MLP (3 layers) with seven hidden nodes and a minimal error of 0.089 compared with the other types of ANN networks. The model has very good performance in verification with a regression ratio (SD ratio) of 0.045. The root-mean-square errors (RMSE) for training, verification, and testing are small (Table 1). In addition, the correlation coefficient is greater than 99% for training, verification, and testing, which shows an excellent agreement between the actual observed and predicted water abstraction.

The ANN sensitivity analysis of socioeconomic variables in the verification phase (Table 2) indicates that income per capita is the most important socioeconomic driving force, followed by Tourism. The remaining effective socioeconomic driving forces according to their rank in theverification phase are: agricultural water consumption, water consumption per capita, population, gender empowerment, water supply, wastewater coverage, water price, and storm water coverage, unaccounted for water and land use. The ANN model removed one input variable—efficiency in revenue collection—because of its low sensitivity. The results of the ANN model and expert opinion shown in Table 3 are similar only in ranking the fifth variable, which is water supply, whilst they differ in ranking the remaining variables.

3.2. Application of the correlation matrix

An analysis of the correlation matrix was undertaken to explore the direction, strength, and significance of relationship between any two variables in the same category of data-set. Transformation of any specified variable that is not normally distributed is a prerequisite, and a transformation to natural logs (base e), worked reasonably well for all intended variables. As an example, the water abstraction variable is transformed to ln(water abstraction) with an approximately normal distribution.

Table 4 shows that ln(water abstraction) has significant and positive linear relationships with ln(storm water coverage), income per capita, ln(agriculture water consumption), ln(population), ln(unaccounted for water), and ln(tourism). The positive correlation is greatest between water abstraction and storm water coverage, and the lowest with tourism. Increase in income per capita, intensification of agriculture water consumption, growth of population, and rise in the number of tourists are important factors influencing the water demand and abstraction of groundwater as the only available resource. Water abstraction increases with the amount of water that is unaccounted for. ln(water abstraction) also has a negative linear relationship with safe access to water supply. If water abstraction increases, then the salinity increases resulting in less opportunity for users to access acceptable water quality. There are positive linear relationships between ln(population) and, ln(tourism), ln(storm water coverage), income per capita, ln(unaccounted for water), and ln(land use). The income per capita has positive linear relationships with ln(storm water coverage), ln(tourism), ln(agriculture water

Table 1
Statistical regression parameters for the target output (WAB)—socioeconomic variables

	Tr. WAB	Ve. WAB	Te. WAB
Data mean	3.9907	2.83	7.96
Data S.D.	5.5632	2.1527	13.402
Error mean	0.0356	–0.0159	–0.2827
Error S.D.	0.2494	0.0969	0.59364
Abs. error mean	0.1884	0.0799	0.3847
RMS error	0.2436	0.0881	0.6015
S.D. ratio	0.0448	0.045	0.0443
Correlation	0.9990	0.9997	0.99909

Note: Tr: Training, Ve: Verification, Te: Testing.

Table 2
Sensitivity analysis of independent input variables—socioeconomic variables

	POP	ICP	LDU	TRS	WSP	WWC	SWC	WCC	WPC	AWC	GEE	UFW
Rank	6	2	5	1	3	8	7	11	10	4	12	9
Error	0.837	1.2166	1.1024	1.7644	1.152	0.5103	0.764	0.3512	0.3805	1.115	0.3365	0.4361
Ratio	3.435	4.9945	4.5257	7.2434	4.7293	2.095	3.138	1.4417	1.5619	4.578	1.3814	1.7904
Rank	5	1	12	2	7	8	10	4	9	3	6	11
Error	0.466	0.5538	0.0507	0.5534	0.2289	0.2253	0.106	0.5273	0.1191	0.5431	0.4118	0.0619
Ratio	5.293	6.2871	0.5749	6.2816	2.5985	2.5577	1.1991	5.986	1.3516	6.162	4.6751	0.703

Note: The lower sets in Table 2 are unaccounted for water and landuse.

Table 3
Ranking of input variables via expert opinion and judgment—socioeconomic variables

	POP	ICP	LDU	TRS	WSP	WWC	SWC	WCC	WPC	ERC	AWC	GEE	UFW
Rank	1	6	8	12	7	5	11	3	4	9	2	13	10

Table 4
Correlation matrix of study variables

	ln(WAB)	ln(POP)	ICP	ln(LDU)	ln(TRS)	WSP	ln(WWC)	ln(SWC)	WCC	WPC	ln(AWC)	GEE	ln(UFW)
ln(WAB)	1.00												
ln(POP)	**0.81**	1.00											
ICP	**0.89**	**0.81**	1.00										
ln(LDU)	–0.05	**0.50**	0.09	1.00									
ln(TRS)	**0.7**	**0.87**	**0.68**	**0.47**	1.00								
WSP	**–0.41**	–0.27	–0.20	–0.05	–0.3	1.00							
ln(WWC)	0.21	**0.49**	0.22	**0.56**	**0.51**	0.05	1.00						
ln(SWC)	**0.91**	**0.85**	**0.96**	0.3	**0.7**	–0.25	0.28	1.00					
WCC	0.21	0.20	0.12	–0.03	0.14	–0.06	0.39	0.17	1.00				
WPC	–0.06	–0.05	–0.13	–0.20	0.04	0.11	–0.14	–0.12	**–0.69**	1.00			
ln(AWC)	**0.80**	0.33	**0.69**	**–0.5**	0.2	–0.16	–0.04	**0.67**	0.06	0.11	1.00		
GEE	0.10	0.21	–0.01	0.11	0.13	0.01	0.33	0.02	–0.02	0.12	0.11	1.00	
ln(UFW)	**0.71**	**0.69**	**0.58**	0.1	**0.61**	**–0.51**	0.28	**0.57**	0.16	–0.14	**0.54**	0.1	1.00

Note: Significant values (at $p < 0.05$) are in bold.

consumption), and ln(unaccounted for water). ln(land use) has significant and positive linear relationships with ln(wastewater coverage) and ln(tourism), and a negative linear relationship with ln(agriculture water consumption). Ln(tourism) has positive linear relationships with ln(storm water coverage), ln(unaccounted for water), and ln(wastewater coverage).

Access to safe water supply has a negative linear relationship with ln(unaccounted for water). ln(storm water system coverage) has positive linear relationships with ln(agriculture water consumption) and ln (water that is unaccounted for). Water consumption per capita has a negative correlation with water price. ln(agriculture water consumption) has a positive linear relationship with ln(unaccounted for water).

3.3. Application of multivariate exploratory techniques

3.3.1. Cluster analysis

Cluster analysis was selected to organize observations and variables in the same category of the data-set, into more meaningful groups so that each group is more-or-less homogeneous (sharing properties in common) and distinct from other clusters. Transformed variables were standardized;

complete linkage of tree clustering was selected so that Euclidean distance between two clusters is determined by the distance of the furthest cases of these two clusters.

Fig. 4(a) shows two distinct groups of variables. The first group of variables contains income per capita, storm water coverage, water abstraction, population, tourism, water that is unaccounted, agriculture water consumption, and water consumption per capita. It can be labeled as *water abstraction*. The second group of variables has land use, wastewater coverage, gender empowerment, access to safe water supply, and water price. It can be labeled as *land use*.

Fig. 4(b) indicates two dissimilar clusters of municipalities. The first cluster (right) consists of Besbes, Zerizer1, Zerizer2, Ben M'hidi1, Ben M'hidi2, Drean1, Drean2, Chbaita1, Chbaita2, Sidi Amar, Hdj eddiss, Mouaissia, Sebaa, Daroussa, El Kous, Ben Amar, Denden, El Hadjar, El Kerma, El Gantra, Fetzara, and Taref. The second cluster of municipalities contains Salines, Bouteldja, and Pont Bouchet.

The first cluster of sectors can be identified as the *land use* cluster whilst the second cluster of municipalities is labeled the *water abstraction* cluster.

3.3.2. *Principal component and classification analysis (PCCA)*

The purpose of applying the PCCA module is to reduce the number of variables into a smaller number of dimensions (factors) and to classify variables and clusters of observations with similar characteristics with respect to these factors. In addition, variables removed from the ANN analysis were mapped into those factors as supplementary variables.

PCCA was carried out for the categories of socioeconomic, pollution pressure, state of water quality, impact and management responses variables.

Table 5 shows that there are 13 variables in the analysis, and thus the sum of all eigenvalues is equal to 13. The number of factors was chosen in accordance with Kaiser's criterion and Cattell's scree test. It shows that the point where the continuous drop in eigenvalues levels off is at Factor 3. Therefore, three factors were chosen for analysis with a cumulative variance of 71%. The remaining eigenvalues each account for less than 10% of the total variance.

Table 6 presents variances of factors and their loadings from variables. The first factor corresponds to the largest eigenvalue (5.49) and accounts for approx. 42.24% of the total variance. It is most correlated with the variables water abstraction, storm water harvesting, population, income per capita, tourism, and flow that is unaccounted for (with negative correlations). The second factor, corresponding to the second eigenvalue (2.1), accounts for 16.2% of the total variance. It is highly correlated with wastewater coverage and land use (negative correlation) and water price (positive correlation). The third factor, corresponding to the eigenvalue 1.65, accounts for 13%. It is significantly correlated with water price (negative correlation) and water consumption per capita (positive correlation). Water price has significant opposition to water consumption per capita. If water price increases, then water consumption per capita decreases and vice versa.

Based on the magnitudes of the factor coordinates for the variables in the analysis, the first factor can be labeled as water abstraction (see Fig. 5(a)). Factor two can be labeled as land use and factor three can be labeled as water consumption vs. water price. The corresponding. Fig. 5(b) for the two factors shows that sectors of Besbes and Bouteldja are analogous in terms of water abstraction, storm water coverage, and agriculture water consumption. Zerizer2, Chbaita2,

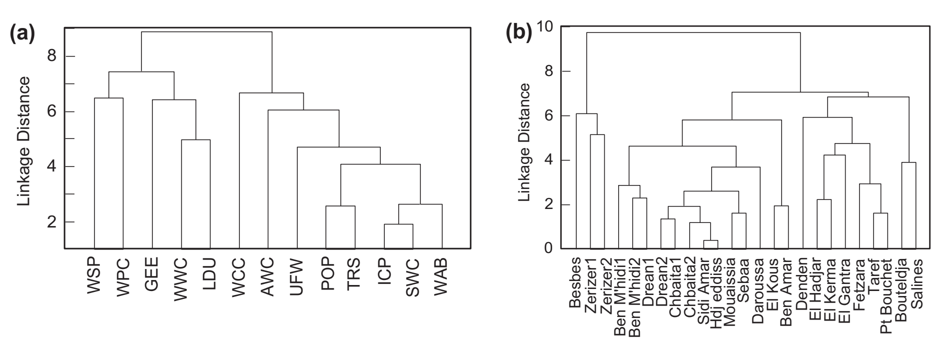

Fig. 4. (a) Cluster analysis results for variables—socioeconomic driving forces and (b) hierarchical tree for cases—socioeconomic driving forces.

Table 5
Eigenvalues of the correlation matrix: active socioeconomic variables only

	Eigenvalue	% Total variance	Cumulative eigenvalue	Cumulative %
1	5.492	42.244	5.492	42.244
2	2.101	16.160	7.592	58.403
3	1.647	12.667	9.239	71.070
4	1.145	8.806	10.384	79.876
5	0.970	7.463	11.354	87.339
6	0.519	3.989	11.873	91.328
7	0.393	3.020	12.265	94.348
8	0.300	2.311	12.566	96.659
9	0.208	1.601	12.774	98.260
10	0.085	0.654	12.859	98.915
11	0.082	0.627	12.940	99.542
12	0.045	0.343	12.985	99.885
13	0.015	0.115	13.000	100.000

Table 6
Factor-variable correlations (factor loadings), socioeconomic variables

	Factor 1	Factor 2	Factor 3		Factor 1	Factor 2	Factor 3
WAB	**–0.923**	–0.338	0.026	SWC	**–0.915**	–0.129	0.029
POP	**–0.913**	0.214	–0.208	WCC	–0.281	0.351	**0.762**
ICP	**–0.880**	–0.180	0.033	WPC	0.133	–0.327	**–0.838**
LDU	–0.255	**0.765**	–0.315	AWC	–0.609	–0.658	0.054
TRS	**–0.818**	0.251	–0.249	GEE	–0.143	0.262	–0.365
WSP	0.440	0.129	–0.123	UFW	**–0.767**	–0.049	0.065
WWC	–0.436	**0.702**	–0.036				

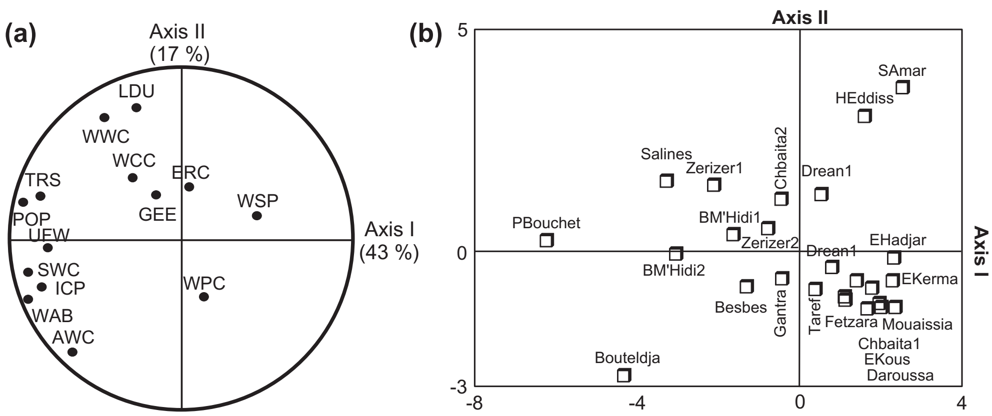

Fig. 5. (a) Projection of the variables on the factor-plane (I–II); and (b) projection of the cases on the factor-plane (I–II).

and Ben M'hidi1 are similar in the areas of population, land use, tourism, wastewater coverage, and gender empowerment. Drean2, El Kous, Ben Amar, Taref, Chbaita1, El Kerma, and Denden are distinguished by the water price variable. El Gantra is differentiated with income per capita and water that is unaccounted for. Drean1 is distinguished by safe access to water supply and efficiency of revenue collection as a supplementary variable. Pont Bouchet, Zerizer1, and Salines are similar in terms of water consumption per capita.

The results of the PCCA analysis and cluster analysis have similarities and differences for the five categories of variables. Characteristics of the identified groups of variables in the cluster analysis are similar to the corresponding factors in the PCCA analysis. However, the PCCA identified an additional factor per category (i.e. socioeconomic, pollution, and management response). The PCCA gives more details about the groups of variables (factors) and the association of cases (sectors) with the corresponding variables. It gives the weight of each group of variables (factor) reflected by the variance value and presents the variables' loadings on factors reflecting their significance and priority.

Hence, the results of the PCCA analysis can be applied to formulating priority strategy programs to handle the water stress in specific geographical areas. However, the cluster analysis can be used as an early exploratory tool to investigate the hierarchy and shapes of possible groups of cases and corresponding variables.

3.3.3. Factor analysis

Factor analysis was used for the purpose of comparison with PCCA results. It reduces the number of observed variables per category to a smaller number of unobserved latent factors which are uncorrelated with each other, and classifies variables within these factors.

The number of significant factors resulted from the PCCA analysis for the five categories of variables were used for the factor analysis. The varimax normalized rotation strategy was adopted to maximize the variance of factors on the new axes and to obtain a pattern of variable loadings on each factor. The factor analysis was carried out for the categories of socioeconomic, pollution pressure, state of water quality, impact and management responses variables.

Table 7 presents the two-factor rotated solution with the cross-loadings of their classified variables. The first factor represents 38.9% of the total variance. It contains inter-correlated observed variables which are: water abstraction, storm water coverage, income per capita, agriculture water consumption, population, and water that is unaccounted for. This underlying factor explains the determinants of the groundwater abstraction from the coastal aquifer.

Table 7
Factor loadings socioeconomic variables (varimax normalized) extraction: principal components (underlined loadings are >700 000)

	Factor 1	Factor 2	Factor 3
WAB	**0.983**	0.012	0.008
POP	**0.771**	0.573	0.014
ICP	**0.887**	0.128	0.072
LDU	−0.043	**0.863**	0.052
TRS	0.668	0.589	−0.020
WSP	−0.460	0.013	−0.117
WWC	0.156	**0.753**	0.303
SWC	**0.901**	0.185	0.093
WCC	0.155	0.072	**0.868**
WPC	−0.028	0.030	**−0.909**
AWC	**0.805**	−0.380	−0.135
GEE	0.031	0.422	−0.209
UFW	**0.735**	0.188	0.138
Proportion of the total variance	0.389	0.185	0.137

The second factor represents 18.5% of total variance and has two variables, which are land use and wastewater coverage. This latent factor represents the land use as a driver to improve the sanitation services.

The third factor has 13.7% of total variance and includes two inter-correlated and inverse variables which are water consumption per capita and water price. If one increases, then the other decreases. The third factor refers to the water price as a determinant of the water consumption per capita.

In comparison with the PCCA results for the socioeconomic variables, the factor analysis introduced an important new determinant of water abstraction, namely agricultural water consumption, and dropped tourism. The remaining variables are similar but have different factor loadings.

4. Discussion

In this research, a new conceptual water integrated model has been developed based on cause–effect relationships (Table 8). The new model depicts the most important elements and science related to water, and indicates that water resource development and management must be within the ecological sustaining limits of the available natural water resources. The new conceptual water integrated model was applied to the life cycle of water resources management in the Annaba region.

Table 8
Significant variables for conceptual water integrated model for Annaba

Socioeconomic variables	Pollution pressures	Water environment quality	Public health and ecosystem impacts	Institutional responses
• Population • Income per capita • Land use • Tourism • Access to safe water supply • Wastewater system coverage • Storm water system coverage • Water consumption per capita • Water price • Agricultural water consumption • Gender empowerment	• Hazardous wastes • Generation of domestic wastewater • Organic fertilizers • Domestic solid waste • Industrial wastewater • Carbon dioxide • Seawater intrusion or upcoming reflecting over pumping	• Nitrate • Chloride • Cadmium	• Morbidity • Loss of productivity • Loss of wetland	• Brackish water desalination • Storm water harvesting • Importation of water and regional water conveyance • Treated/partially treated wastewater • Efficiency in urban water supply networks • Efficiency of water information system • Water awareness and education campaigns

The effective variables have been characterized and prioritized using multi-criteria analysis with ANN, risk assessment techniques, and expert opinion and judgment. The selected variables have been classified and organized using the multivariate techniques of cluster analysis, principal component and classification analysis, and factor analysis (Table 8).

The conclusions of data analysis using the techniques of ANN, basic statistics, multivariate, health risk assessment, and expert opinion and judgment can be summarized as follows:

- All water policy and management responses are significant. Sustainable coastal aquifer management must take into consideration technical engineering as well as managerial interventions such that top priority should be given to the reuse of treated wastewater in agriculture followed by desalination of water.
- Cadmium is the only chemical that has carcinogenic risk for both adults and children and its concentration has to be reduced by 20%. The total carcinogenic risk of cadmium for both adults and children is close to two cases per million. Cadmium has the highest total hazard.
- Index, followed by Chromium VI, whilst copper has the lowest for both adults and children. The total hazard index resulting from all chemicals in the two exposure routes is higher in the case of adults than for children. The dermal contact exposure route has a higher total hazard index compared with the ingestion exposure route.
- The municipalities of Bouteldja and Pont Bouchet are characterized by high water abstraction and their need for additional water resources, including desalination and regional conveyance of water. They are distinguished also by the significant anthropogenic pollution generated from the socioeconomic activities of their large populations.
- Sidi Amar, Hdj eddiss, Ben M'hidi2, Bouteldja, and Pont Bouchet are classified by the significant morbidity there, originating from water borne diseases.
- Sectors of Besbes, Zerizer2, Pont Bouchet, Ben M'hidi1, and Mouaissia are characterized by ecosystem due to the existence of wadis within their boundaries.
- The municipalities of Ben M'hidi2, Pont Bouchet, and Zerizer1 have high NO_3 concentrations, due to the overloading of treatment facilities within their boundaries and disposal of effluent into an open environment.
- Coastal municipalities as well as municipalities located close to the northern border of Annaba region are characterized with high Cl concentration. This is due to seawater intrusion in coastal municipalities.

- The water plan should be reformulated to take account of the priority water problems and the geographical areas under stresses.

5. Conclusions

This research was intended to contribute to the advancement of water resources management through the development of new conceptual water model based on systematic and multidisciplinary approach. The new conceptual integrated water model can be applied in the semi-arid Mediterranean region. It has been the first experience that tackled the big picture of IWRM including sustainability concepts. Besides, it has been based on integrated, preventive, and ecosystem approaches with the view to optimize water resources management whilst sustaining the ecological limits and carrying capacity of the natural water resources.

The research defined for the first time, the effective multicriteria parameters for water sector analysis and monitoring besides the geographical areas under water stresses on objective scientific basis. It concludes also the potential interventions needed to ensure water availability; suitability and supply–demand balance. The new model addressed a key objective on the levels of Mediterranean region in general and Annaba in particular "to achieve sustainable use and management of natural water resources and effective protection of the environment." Protection ensures that the water resources base is utilized wisely so that it can continue to provide benefits for improving people's livelihoods and fostering economic development on sustainable basis.

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