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A FUZZY LOGIC APPROACH TO ASSESS GROUNDWATER POLLUTION LEVELS BELOW AGRICULTURAL FIELDS

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Abstract. A fuzzy logic approach has been developed to assess the groundwater pollution levels below agricultural fields. The data collected for Kumluca Plain of Turkey have been utilized to develop the approach. The plain is known with its intensive agricultural activities, which imply excessive application of fertilizers. The characteristics of the soils and underlying groundwater for this plain were monitored during the years 1999 and 2000. Additionally, an extensive field survey related to the types and yields of crops, fertilizer application and irrigation water was carried out. Both the soil and groundwater have exhibited high levels of nitrogen, phosphorus and salinity with considerable spatial and temporal variations. The pollution level of groundwater at several established stations within the plain were assessed using Fuzzy Logic. Water Pollution Index (WPI) values are calculated by Fuzzy Logic utilizing the most significant groundwater pollutants in the area namely nitrite, nitrate and orthophosphate together with the groundwater vulnerability to pollution. The results of the calculated WPI and the monitoring study have yielded good agreement. WPI indicated high to moderate water pollution levels at Kumluca plain depending on factors such as agricultural age, depth to groundwater, soil characteristics and vulnerability of groundwater to pollution. Fuzzy Logic approach has shown to be a practical, simple and useful tool to assess groundwater pollution levels.

Keywords: agriculture, fertilizers, Fuzzy Logic, groundwater, nitrate, nitrite, orthophosphate, pollution, Seepage Index Number, Water Pollution Index

1. Introduction

Non-point source pollutants, irrespective of their origin, are transported overland and through the soil by precipitation and excess irrigation water. These pollutants ultimately find their way into groundwater, wetlands, rivers, lakes and oceans. The ecological impacts of these pollutants range from simple nuisance substances to severe ecological impacts on fish, birds, mammals, and human health. Diffuse pollution, the most pervasive type of pollution, is difficult to manage and control, being local, regional and transboundary (Novotny, 2005). Surface and groundwater quality degradation due to agricultural practices and conversion of land to agriculture have been well described by Novotny (Novotny, 1999, 2002). Since the 1970s there has been growing concern in Europe over the increases in nitrogen, phosphorus and pesticide residues in surface waters and groundwater fields. Intense cultivation and "factory" livestock operations led to the conclusion, that agriculture is a significant non-point source contributor to surface and groundwater pollution (Heinz *et al.*, 2002; Boers, 1996; Ignazi, 1993).

The European Community has responded with Directive (91/676/EEC) on "Protection of waters against pollution by nitrates from agricultural sources". Agriculture is also cited as a leading cause of groundwater pollution in the United States. In 1992, fully forty-nine of fifty states identified that nitrate was the principal groundwater contaminant, followed closely by the pesticide category. The US EPA (1994) concluded that "more than 75% of the states reported that agricultural activities posed a significant threat to groundwater quality". It is becoming apparent that, it may take longer for the watersheds to recover after nutrient loads to surface and groundwater are reduced if remedial measures are gradually implemented (Novotny, 2005). Abatement of agricultural diffuse sources of pollution can and must be conducted in the context of moving towards sustainable agriculture where agricultural best management practices are to be implemented (Novotny, 1999; Cook *et al.*, 1996). Additionally, vulnerability of groundwater to agricultural chemicals has been studied to develop new strategies (Burkart and Feher, 1996; Burkart and Stener, 2002; Meinardi *et al.*, 1995).

Kumluca is a coastal plain in the Western Mediterranean Region of Turkey as shown in Figure 1. The plain is 93 km away from Antalya city. The plain is an economically viable area with its intensive agriculture of vegetables, mainly in greenhouses, and citrus gardens. Groundwater was one of the main water resources for drinking and irrigation within the immediate vicinity. However, due to the

Figure 1. Location of Antalya City and Kumluca region in Turkey.

deterioration of groundwater quality, a new water supply project has been recently realized to meet the drinking water demand from spring water that is 50 km away from the town and about 800 m high in the mountains. Since the groundwater level in Kumluca is very near to the surface, almost all the farmers have their own private wells for irrigation. Irrigation water from a nearby rainwater reservoir is also available seasonally during summers at some locations.

In recent years, the applications of artificial intelligence techniques have been used to convert human experience into a form understandable by computers. Intelligent systems are usually described by analogies with biological systems by, for example, looking at how human beings perform control tasks, recognize patterns, or make decision. Fuzzy logic provides a powerful and convenient formalism for classifying environmental conditions and for describing both natural and anthropogenic changes. Whereas traditional indices are based either on crisp sets with discontinuous boundaries between them, or on continuous variables whose values are only meaningful to experts, fuzzy sets make it possible to combine these approaches. In addition, fuzzy logic can be used to classify and quantify environmental effects of a subjective nature and it even provides formalism for dealing with missing data. The fuzzy membership can be used as environmental indices, but it is also possible to "defuzzify" them and to obtain a more traditional type of index (Silvert, 2000). One well-known assessment methodology is the Water Quality Index (WQI), developed by the National Sanitation Foundation (Ott, 1978). WQI was originally designed to make an integrated assessment of water quality conditions to meet utilization goals. Considerable advances have since been made on WQI using slightly modified concepts (Heinonen and Herve, 1994; Dojlido *et al.*, 1994; Suvarna and Somashekar, 1997; Chang *et al.,* 2001). In the study of Woldt (Woldt *et al.*, 1996), a new groundwater modeling technique was developed in which fuzzy set theory is combined with finite difference modeling methods. Additionally, a rule based fuzzy-set approach to risk analysis of nitrate contaminated groundwater was presented in the study of Dahab (Dahab *et al.*, 1994). Recently, neuro-fuzzy techniques have been applied to predict groundwater vulnerability using GIS (Dixon *et al.*, 2002; Dixon, 2004, 2005), and for integrated water management (IHE, 2000).

In this study, a fuzzy logic system was developed to assess the groundwater pollution of Kumluca plain at previously selected nine sampling stations. The applied water pollution evaluation system involves the selection of water quality parameters and index values to form Water Pollution Index (WPI). Ranges of values are assigned to these parameters to form the input Membership Functions (MBF). In this application, four input variables, namely as nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), orthophosphate (PO_4-P) and Seepage Index Number (SIN) are used to describe WPI. The input membership functions of the selected parameters have three linguistic terms defined as high pollution, moderate pollution and low pollution levels of groundwater.

2. Methods

2.1. SAMPLING, MEASUREMENT AND ANALYSIS PROGRAM

The monitoring program was initiated in 1999 and finalized within the year 2000. A total of nine monitoring stations were established: seven of them represented groundwater conditions while the other two stations were operated to determine the water characteristics of the irrigation reservoir. The groundwater stations had different depths to groundwater: five stations were for unconfined shallow groundwater (6–8 m); one station was for unconfined medium (24 m), and one station was for deep (80 m) confined aquifer. Furthermore, the stations were located in such a way that they represent different soil types and agricultural activities. The locations of all the stations are shown in Figure 2 while description of the stations is given in Table I. Station 2 and 3 are shown to be at the same location. However, Station 2 represents groundwater while Station 3 represents the irrigation reservoir channel.

A total of seven separate water quality monitoring sessions were realized during the study period: the dates were June, August, October and November of the year 1999; and March, June and October of the year 2000. Two different sessions of soil analysis were carried out in addition to the water quality survey: one was in October 1999 and the other one was in March 2000. Water quality parameters such as temperature, salinity, and conductivity were measured in the field utilizing YSI Model 30 SCT-Meter. Moreover, collected water samples were analyzed for nitrate, nitrite, ammonia and orthophosphate parameters using HACH DR/2010 spectrophotometer, which has been approved by the U.S. Environmental Protection Agency as stated in the users' manual. Fecal coliform analyses were carried out

TABLE I
Characteristics of the monitoring stations

Station no.	Water source	Depth of well (m)	Water use	Land use activity	Agricultural age (year)
1	Groundwater	6	Irrigation	Greenhouse	15
2	Groundwater	7	Irrigation	Greenhouse	10
3	Surface	–	Irrigation		
4	Groundwater	8	Irrigation	Greenhouse /Citrus	3
5	Groundwater	6	Irrigation	Greenhouse	12
6	Groundwater	5	Irrigation	Summer house	3
7	Groundwater (Confined)	80	Drinking/Irrigation	Greenhouse	15
8	Groundwater	24	Drinking/Irrigation	Greenhouse/Citrus	10
9	Surface	–	Irrigation	Greenhouse/ Citrus	7

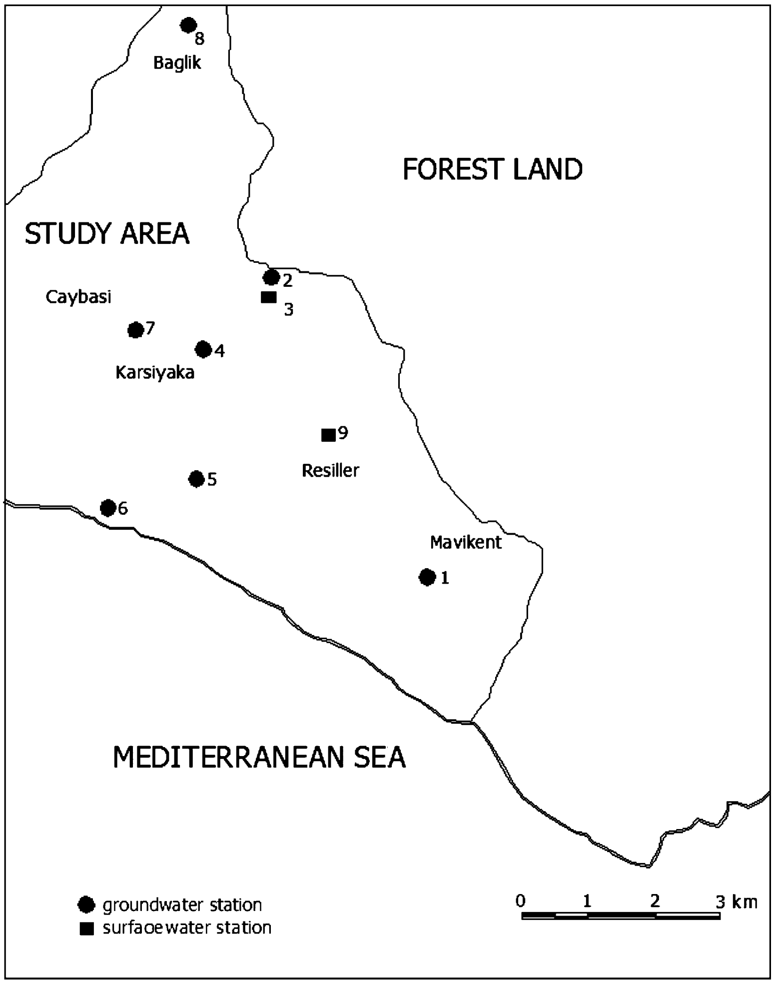


Figure 2. Location of the measurement and sampling stations in the study area.

for some samples in October and November of 1999 using the membrane-filter technique. The soil samples were collected at each station both from surface and 60 cm depth and analyzed for several parameters such as pH, salinity, texture, organic matter, total nitrogen and total phosphorus.

2.2. FIELD SURVEY

A field survey related to the determination of the amounts and types of fertilizer utilization, crop types and densities, amounts of irrigation water and crop yields were conducted at all the stations, parallel to the monitoring program. The types of crops were tomato, cucumber, melon, watermelon, eggplant, pepper and citrus trees. Drip irrigation was used for all the crops except for citrus. Citrus was irrigated by rainwater in the wet season while flood irrigation was used in the dry season. Different types of chemical fertilizers such as ammonium sulfate, potassium nitrate, and compounds with known nitrogen content were applied in the time period from November to April. Local farmers applied different amounts of chemical fertilizers for the same crop. All the farmers in the study area applied nearly the same yearly amounts of organic fertilizers. Details related to the field survey are given elsewhere (Muhammetoglu *et al.*, 2005).

2.3. ASSESSMENT OF GROUNDWATER VULNERABILITY TO POLLUTION

Groundwater vulnerability to pollution is assessed using the System for Early Evaluation of Pollution potential of Agricultural Groundwater Environments called as SEEPAGE model (Navulur and Engel, 2005). This numerical ranking model considers contamination from both concentrated and dispersed sources. SEEPAGE considers various hydrological settings and physical properties of the soil that affect groundwater vulnerability to pollution potential as follows: (i) soil slope, (ii) depth to water table, (iii) vadose zone material, (iv) aquifer material, (v) soil depth and (vi) attenuation potential. The attenuation potential further considers the following factors: (i) texture of surface soil, (ii) texture of sub soil, (iii) surface layer pH, (iv) organic matter content of the surface, (v) soil drainage class, (vi) soil permeability (least permeable layer). Each factor is assigned a numerical weight ranging from 1–50 based on its relative significance, with the most significant parameter affecting the water quality assigned a weight of 50 and the least significant assigned a weight of 1. The weights are different for concentrated sources and dispersed sources (Navulur and Engel, 2005). The ratings of the aquifer media and vadose zone are subjective and can be changed for a particular region. Once the scores of the six factors are obtained, these are summed to get the SEEPAGE Index Number (SIN). High SIN value implies relatively more vulnerability of the groundwater to contamination. The SIN values are arranged into four categories of pollution potential: low, moderate, high, and very high, as given in Table II. A high or very high SIN category indicates that the site has significant constraints for groundwater quality management (Moore and John, 1990). The quantification of the parameters of SEEPAGE is given elsewhere (Muhammetoglu *et al.*, 2002), while the obtained SIN values for Kumluca study area are given in Table III.

TABLE II
Classification of SEEPAGE Index Number (SIN) for pollution potential

SIN	Low	Moderate	High	Very high
Value	1–89	90–144	145–209	>210

TABLE III
Results of SEEPAGE Index Numbers for the study area

Station no.	Soil slope	Depth to water table	Vadose material	Aquifer material	Soil depth	Attenuation	SIN
1	30	30	22	24	30	36	172 – High
2	28	30	17	24	30	33	162 – High
4	21	25	17	24	25	31	143 – Moderate
5	27	30	27	24	30	37	175 – High
6	30	30	30	24	30	36	180 – High
7	30	05	24	24	05	34	122 – Moderate
8	21	15	22	24	15	32	129 – Moderate

2.4. ASSESSMENT OF GROUNDWATER POLLUTION

2.4.1. *Fuzzy Logic System*

A fuzzy control system is commonly defined as a system which emulates a human expert. A fuzzy controller consists of three operations: fuzzification, inference and defuzzification as shown in Figure 3. In fuzzy logic system, the knowledge of the human is put in the form of a set of fuzzy linguistic rules. These rules would produce approximate decisions, just as a human would. The human expert observes quantities by observing the inputs, and leads to a decision or output using his judgment. The human expert can be replaced by a combination of a fuzzy rule-based system (FRBS) and a block called a defuzzifier. The inputs are fed into the FRBS, where physical quantities are represented into linguistic variables with appropriate membership functions. These linguistic variables are then used in a set of fuzzy rules within an inference engine, resulting in a new set of fuzzy linguistic

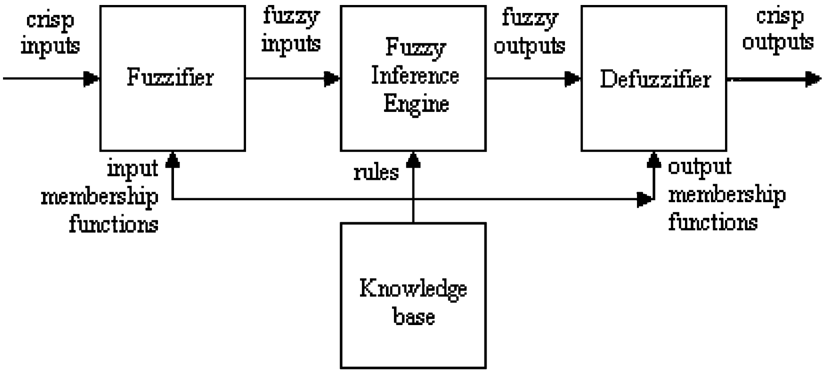


Figure 3. Conceptual definition of a fuzzy control system.

variables. In defuzzification stage, the variables are combined and changed to a crisp output which represents an approximation to actual output (Jamshidi, 2003).

2.4.2. *Fuzzy Sets*

A fuzzy set is represented by a membership function defined on the universe of discourse. The universe of discourse is the space where the fuzzy variables are defined. The membership function gives the grade, or degree, of membership (μ) within the set, of any element of the universe of discourse. The membership function maps the elements of the universe onto numerical values in the interval [0, 1]. A membership function value of zero implies that the corresponding element is definitely not an element of the fuzzy set, while a value of unit means that the element fully belongs to the set. A grade of membership in between corresponds to the fuzzy membership to set (Zrilic *et al.*, 2000).

2.4.3. *Fuzzification*

Fuzzification is the process of decomposing a system input and/or output into one or more fuzzy sets. Many types of curves can be used, but triangular or trapezoidal shaped membership functions are the most common. Fuzzy sets span a region of input (or output) value graphed with the membership. Any particular input is interpreted from this fuzzy set and a degree of membership is interpreted. The membership functions should overlap to allow smooth mapping of the system. The process of fuzzification allows the system inputs and outputs to be expressed in linguistic terms so that rules can be applied in a simple manner to express a complex system.

2.4.4. *Defuzzification*

After fuzzy reasoning we have a linguistic output variable which needs to be translated into a crisp value. The objective is to derive a single crisp numeric value that best represents the inferred fuzzy values of the linguistic output variable. Defuzzification is such inverse transformation which maps the output from the fuzzy domain back into the crisp domain. Some defuzzification methods tend to produce an integral output considering all the elements of the resulting fuzzy set with the corresponding weights. Other methods take into account just the elements corresponding to the maximum points of the resulting membership functions (Rondeau *et al.*, 1997). The Mean of Maximum (MoM) method is used only in some cases where the Center of Maximum (CoM) approach does not work. In the CoM method, only the peaks of the membership functions are used. The defuzzified crisp compromise value is determined by finding the place where the weights are balanced. Thus the areas of the membership functions play no role and only the maxima are used. The crisp output is computed as a weighted mean of the term membership maxima, weighted by the inference results. But whenever the maxima of the membership functions are not unique and the question is as to which one of the equal choices one should take, the MoM method should be used.

2.4.5. *Application to Kumluca Plain*

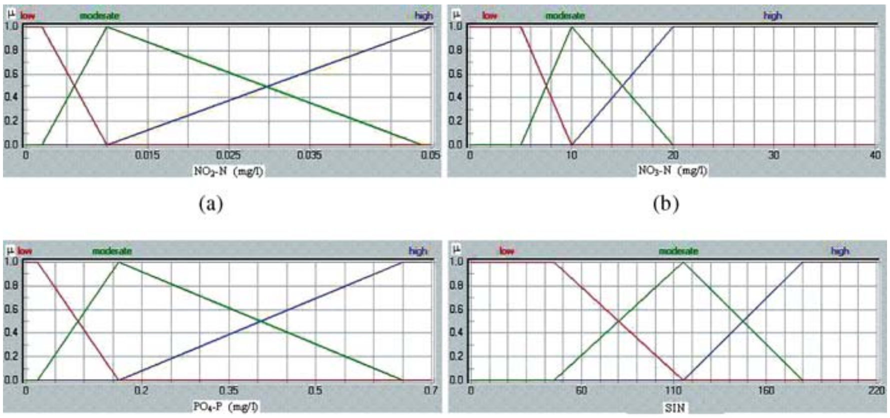
The results of the sampling, measurement and analyses program have shown that the significant groundwater pollutants of Kumluca are nitrite, nitrate and orthophosphate. High pollution levels of these parameters led to the abandoned usage of water for drinking purposes in the area. Additionally, the potential of groundwater pollution depends on the vulnerability of groundwater to pollution indicated by the SEEPAGE Index Number (SIN). High SIN implies high potential to pollution while the reverse is correct. Therefore, assessment of groundwater pollution in this case of study is considered to depend on four parameters namely observed concentrations of nitrate, nitrite, and orthophosphate and the calculated values of SIN. The Water Pollution Index (WPI) is determined depending on these four parameters using the fuzzy logic system.

The input membership functions (MBF) of the selected water quality parameters are chosen to have three linguistic terms being High, Moderate and Low based on the Groundwater Quality Classifications of the Turkish regulations of Water Pollution Control (TÇV, 2002), as given in Table IV. High water quality (Class I) implies low pollution level and therefore it has the linguistic term *Low*. On the other hand, low water quality (Class III) implies high pollution level which is given the linguistic term *High*.

The MBF of the selected parameters are presented in Figure 4 while the MBF for the resultant WPI is shown in Figure 5. The described membership functions are used to retranslate the fuzzy output into a crisp value. This translation is known as defuzzification and can be performed using several methods. In this application, two different defuzzification methods, namely, Mean of Maximum (MoM) and Center of Maximum (CoM) were adopted. A list of the compressed rule data base is given in Table V. In the table, low pollution levels of nitrite, nitrate, orthophosphate associated with low vulnerability to pollution give low WPI while the reverse is correct.

TABLE IV
Groundwater quality classification levels

	Water quality classes		
Water quality parameters	I – High	II – Moderate	III – Low
NO_2-N (mg/L)	0.002	0.01	>0.01
NO_3-N (mg/L)	5	10	>10
PO_4-P (mg/L)	0.02	0.16	>0.16



(a) (b)

(c) (d)

Figure 4. Membership functions of nitrite nitrogen (NO_2-N), nitrate nitrogen (NO_3-N), orthophosphate (PO_4-P) and Seepage Index Values (SIN) in (a), (b), (c) and (d) respectively.

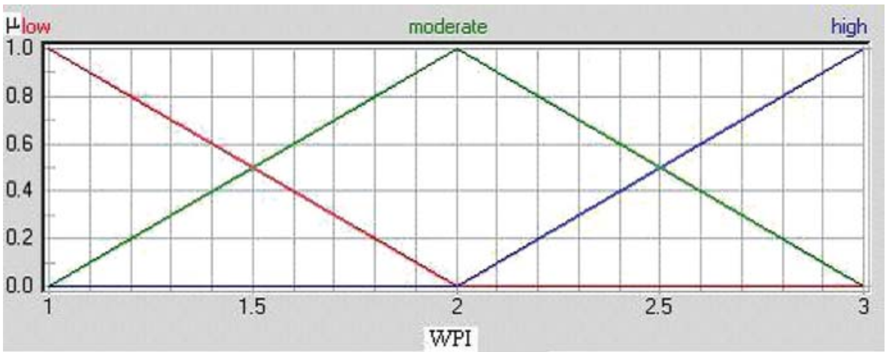


Figure 5. Membership function of Water Pollution Index (WPI).

3. Results and Discussion

3.1. RESULTS OF THE MEASUREMENT AND ANALYSIS PROGRAM

Figure 6 depicts the results of measurement and analyses in all the groundwater stations for all the measurement sessions. Table VI gives the average values of the measured and analyzed parameters. It can be seen that the levels of all the parameters are high in general and that nitrate nitrogen concentration highly exceed 11.3 mg NO_3-N/L at many stations that is the defined limit by the WHO drinking water quality guidelines. Station 1 and 2 exhibited the highest concentrations for all the parameters among all the groundwater stations. The observed levels of nitrogen concentrations at these stations were similar to the nitrogen

TABLE V
Compressed rule base data and the resultant WPI values

No	NO_2-N	NO_3-N	PO_4-P	SIN	WPI
1	Low/moderate	Low	Low	Low	Low
2	Low	Low	Moderate/high	Low	Low
3	Low	Moderate	Low	Low	Low
4	Low/moderate/high	Moderate/high	Moderate	Low	Moderate
5	Low/moderate/high	Moderate	High	Low	Moderate
6	Low/moderate/high	High	Low	Low/moderate	Moderate
7	Low/moderate	High	High	Low	Moderate
8	Moderate/high	Low	Moderate/high	Low/moderate	Moderate
9	Moderate/high	Moderate	Low	Low/moderate/high	Moderate
10	High	Low	Low	Low/moderate/high	Moderate
11	High	High	High	Low/moderate/high	High
12	Low	Low	Low	Moderate	Low
13	Low	Low/moderate/high	Moderate/high	Moderate	Moderate
14	Low	Moderate	Low	Moderate/high	Moderate
15	Moderate	Low	Low	Moderate/high	Moderate
16	Moderate/high	Moderate	Moderate	Moderate	Moderate
17	Moderate	Moderate	High	Moderate	Moderate
18	Moderate	High	Moderate	Moderate	Moderate
19	Moderate	High	High	Moderate/high	High
20	High	Moderate	High	Moderate/high	High
21	High	High	Moderate	Moderate/high	High
22	Low	Low/high	Low/moderate	High	Moderate
23	Low/moderate	Low	High	High	Moderate
24	Low/moderate	Moderate	Moderate	High	Moderate
25	Low	Moderate	High	High	Moderate
26	Low	High	High	High	High
27	Moderate/high	Low	Moderate	High	Moderate
28	Moderate	Moderate	High	High	High
29	Moderate	High	Low	High	Moderate
30	Moderate	High	Moderate	High	High
31	High	Low	High	High	High
32	High	Moderate	Moderate	High	High
33	High	High	Low	High	High

concentrations expected for medium strength raw domestic wastewater of 40 mg N/l (Tchobanoglous *et al.*, 2002). Additionally, the measured values of specific conductivity are much higher than the stated admissible Turkish drinking water quality standard value of 600 μs/cm. Station 3 and 9 represent the irrigation reservoir

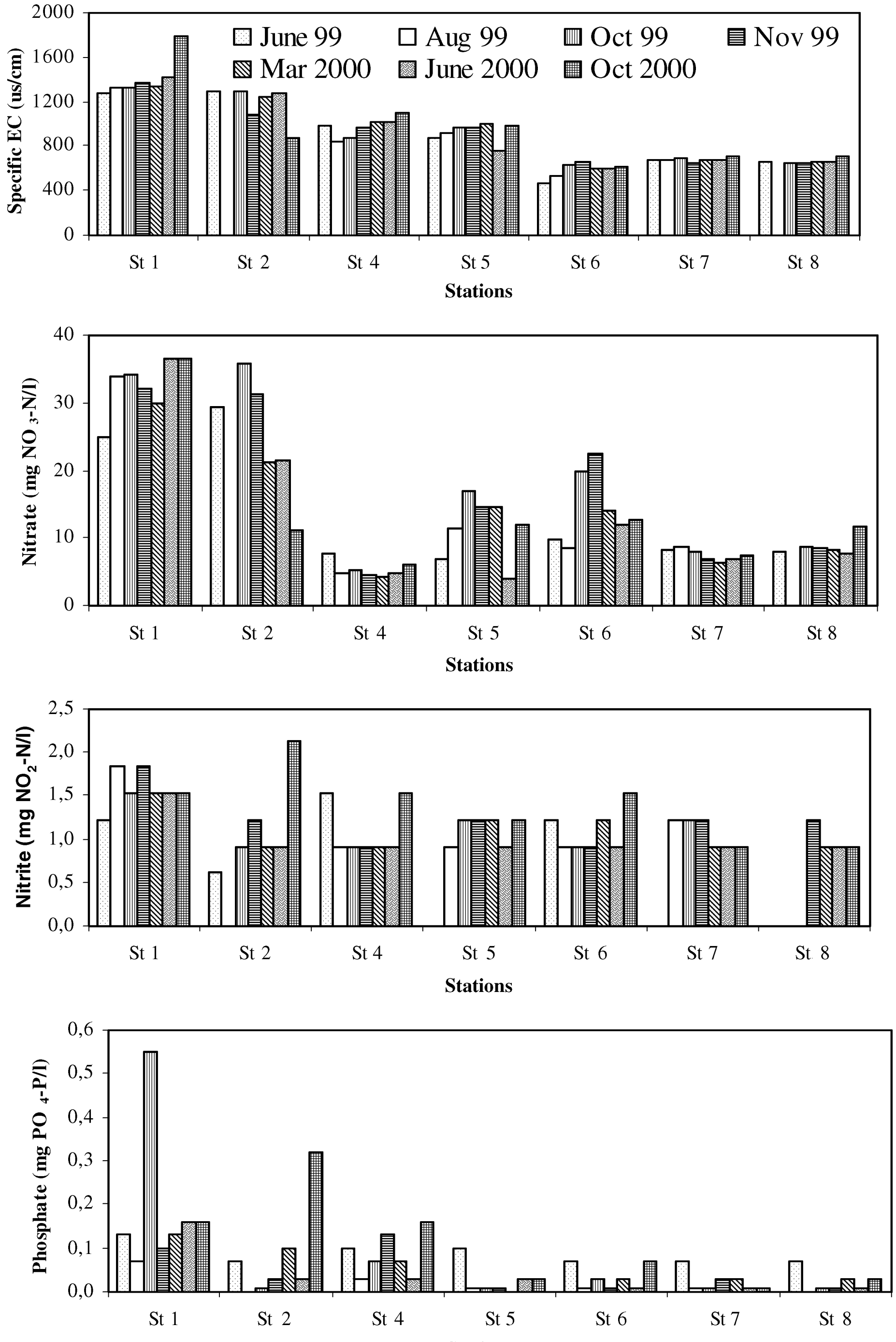


Figure 6. The measurement and analyses results for specific conductivity, nitrate nitrogen, nitrite nitrogen and orthophosphate.

TABLE VI
Mean values of some selected parameters in the study area

	Stations								
Parameter	1	2	3	4	5	6	7	8	9
NO_2-N, mg/L	1.56	1.11	0.91	1.08	1.11	1.08	1.06	0.91	0.81
NO_3-N, mg/L	32.6	24.9	2.86	5.37	11.4	14.2	7.5	8.8	0.6
PO_4-P, mg/L	0.18	0.09	0.19	0.08	0.03	0.03	0.02	0.03	0.09
Salinity, ppt	0.71	0.57	0.30	0.47	0.46	0.29	0.30	0.30	0.27
SpecificEC, μS/cm	1406	1175	602	970	926	588	679	667	558

channel which was polluted with solid wastes. Still, these stations showed the lowest pollution concentrations except for orthophosphate.

The groundwater quality parameters showed considerable spatial variations depending on factors such as depth to groundwater, soil characteristics, type and age of agriculture, nitrogen application in irrigation water. For example, Stations 1 and 2 showed the highest pollution levels due to their low depth to groundwater, long agricultural age, high nitrogen application rates with irrigation waters and high vulnerability to pollution. On the other hand, Station 7 showed relatively low pollution level due to its high depth to groundwater, low nitrogen application rates with irrigation waters and low vulnerability to pollution.

The levels of the examined water quality parameters in the groundwater showed considerable temporal variations mostly at the stations that have high vulnerability to pollution, low depth to groundwater and long agricultural age such as Stations 1 and 2. On the other hand, the water quality parameters at Station 7 showed low temporal variations due to its low vulnerability to pollution and high depth to groundwater.

Figure 6 shows that the results of October and November months have the highest N levels. It is appropriate to mention here that most of the farmers flood their agricultural land with plenty of water in September to reduce the salinity of the soil before the new agricultural season. This leads to carry the excess nitrogen to the groundwater, which is the main reason beyond the noticeable increase in N levels in October and November. Also, these two months coincide with the end of the dry summer season.

The results of the soil analyses also indicate high levels of nitrogen and salinity in general. The levels of these parameters in the groundwater and in the agricultural soil at each station are correlated. High levels of nitrogen and salinity in the groundwater are associated with high levels of these parameters in the agricultural soil. This correlation is clear in the stations that have low vulnerability to pollution and long agricultural age. Details are given by Muhammetoglu *et al.* (2003).

TABLE VII

Comparison of Water Pollution Index values obtained from different defuzzification methods ('CoM' denotes Center of Mean and 'MoM' denotes Mean of Maximum)

Station no	Method	June 1999	August 1999	October 1999	November 1999	March 2000	June 2000	October 2000	Average
1	CoM	2.8645	2.8393	2.9895	2.8228	2.8645	2.9905	2.9905	2.9088
	MoM	3	3	3	3	3	3	3	–
2	CoM	2.6989	2.7231	2.7231	2.7231	2.6736	2.7231	2.7086	2.7105
	MoM	3	3	3	3	3	3	3	–
4	CoM	2.4530	2.0000	2.0655	2.0000	2.0000	2.0000	2.2965	2.1164
	MoM	2	2	2	2	2	2	2	–
5	CoM	2.3864	2.1399	2.6900	2.4699	2.4499	2.0000	2.1899	2.3322
	MoM	2	2	3	2	2	2	2	–
6	CoM	2.3572	2.0000	2.9790	2.9916	2.3999	2.1799	2.3572	2.4664
	MoM	2	2	3	3	2	2	2	–
7	CoM	2.1480	2.0000	2.0000	2.1064	2.0902	2.0000	2.0000	2.0492
	MoM	2	2	2	2	2	2	2	–
8	CoM	2.2641	2.1779	2.0000	2.0000	2.1033	2.0000	2.1693	2.1021
	MoM	2	2	2	2	2	2	2	–
Average	CoM	2.4532	2.2686	2.4924	2.4448	2.3688	2.2705	2.3874	2.3837

3.2. RESULTS OF FUZZY LOGIC APPLICATION

The results of WPI values obtained from two different defuzzification methods are given in Table VII. Figure 7 depicts the results of WPI obtained from Center of Maximum (CoM) defuzzification method for all the measurement and analyses sessions. It can be seen that the WPI values obtained from the two different defuzzification methods have good agreement. Also, it can be seen that the WPI is mostly described between 2 and 3 being moderate and high levels of pollution. Station 1 and 2 exhibited the highest WPI which agrees well with the field and lab investigations which show the highest pollution levels of nitrate, nitrite and orthophosphate associated with high SIN. Similarly, Station 7 exhibited the lowest WPI which also agrees with the field and lab investigations.

Additionally, Table VIII presents the results of degree of support analyses where the fractional weight out of unity of each quality class can be distinguished. For this analysis, the running cases have been described by using the mean values of the selected parameters, namely; NO_3-N, NO_2-N and PO_4-P given in Table VI and the values of SIN given in Table III. The results of degree of support (DoS) analyses have been obtained from Center of Maximum (CoM) defuzzification method.

TABLE VIII

Membership degrees (μ) of the considered parameters and the degree of support (DoS) of the Water Pollution Index (WPI) obtained from Center of Maximum (CoM) defuzzification method

Station no	Class	μ for NO_3-N	μ for NO_2-N	μ for PO_4-P	μ for SIN	DoS for WPI
1	High	1.00	1.00	0.04	0.88	0.88
	Moderate	0.00	0.00	0.96	0.12	0.00
	Low	0.00	0.00	0.00	0.00	0.00
2	High	1.00	1.00	0.00	0.72	0.50
	Moderate	0.00	0.00	0.50	0.28	0.28
	Low	0.00	0.00	0.50	0.00	0.00
4	High	0.00	1.00	0.00	0.43	0.07
	Moderate	0.07	0.00	0.43	0.57	0.57
	Low	0.93	0.00	0.57	0.00	0.00
5	High	0.14	1.00	0.00	0.92	0.14
	Moderate	0.86	0.00	0.07	0.08	0.86
	Low	0.00	0.00	0.93	0.00	0.00
6	High	0.42	1.00	0.00	1.00	0.42
	Moderate	0.58	0.00	0.07	0.00	0.58
	Low	0.00	0.00	0.93	000	0.00
7	High	0.00	1.00	0.00	0.11	0.00
	Moderate	0.50	0.00	0.00	0.89	0.50
	Low	0.50	0.00	1.00	0.00	0.00
8	High	0.00	1.00	0.00	0.22	0.07
	Moderate	0.76	0.00	0.07	0.78	0.76
	Low	0.24	0.00	0.93	0.00	0.00

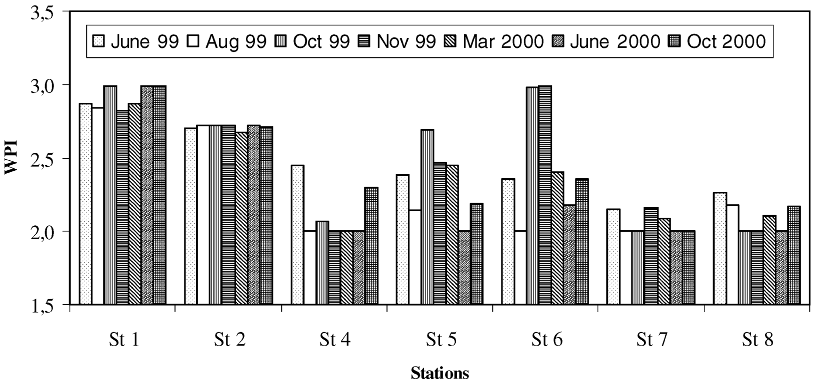


Figure 7. Results of WPI values obtained by Center of Maximum (CoM) defuzzification method.

As it can be seen from Table VIII, the described running cases end up with different values of degree of support (DoS) for different stations. According to the values of DoS, the WPI at Station 1 is high with a DoS of 0.88 while the WPI at Station 2 is shared between high with a DoS of 0.50 and moderate with a DoS of 0.28. It can be seen that Station 1 and 2 are the worst while Station 7 is the best in terms of their pollution level classes and DoS for WPI. For all the other stations, WPI values are much closer to moderate levels with higher fractions of moderate term.

4. Conclusion

The quality of groundwater in Kumluca is highly deteriorated mainly with nitrogen and phosphorus due to the excess use of agrochemicals. The monitored levels of water quality parameters showed wide spatial and temporal variations in the groundwater. The variations in the groundwater are due to factors such as the age of agriculture, amount of nitrogen application in irrigation water, soil characteristics, depth to groundwater and vulnerability of groundwater to pollution expressed by the SEEPAGE Index Number (SIN). Fuzzy Logic approach has been utilized to assess groundwater pollution levels in the area by developing Water Pollution Index (WPI) values. The observed levels of nitrite, nitrate, orthophosphate and SIN values were used to determine WPI values in the light of the Turkish water pollution regulations. Values of WPI are calculated using two different methods namely CoM and MoM. The fuzzy results are produced from the evaluation of fuzzy rules and passed *defuzzication stage*, using out *membership function*, to retranslate the fuzzy output into a crisp value. There was a good agreement between the fuzzy results and the monitoring study of the water quality parameters in the area. The fuzzy results indicate high to moderate water pollution level for Kumluca plain with different degree of supports. This study was conducted using the data gathered during the years 1999 and 2000. It is recommended that sampling and experimentation should be repeated at least every five years to observe the existing situation of groundwater resources. The new data may be assessed again by using the fuzzy logic approach. As a result, fuzzy logic approach presents a more understandable and objective way of water quality classification and this approach can be used as a practical tool to assess the pollution of water and groundwater for the optimum management of water resources.

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