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Presenting a conceptual model of data collection to manage the groundwater quality

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Abstract

A conceptual model was proposed in the present study, which highlighted important independent and dependent variables in order to managing the groundwater quality. Furthermore, the methods of selection of variable and collection of related data were explained. The study was carried out in the Tajan Plain, north of Iran; 50 drinking wells were considered as sampling points. In this model the Analytical Hierarchy Process (AHP) was proposed to select the indicator water quality parameters. According to expert opinions and characteristics of the study area ten factors were chosen as variables influencing the quality of groundwater (land use types, lithology units, geology units, distance of wells to the outlet, distance to the residential areas, direction toward the residential areas, depth of the groundwater table, the type of aquifer, transmissivity and population). Geographic Information System (AecGIS 9.3) was used to manage the spatial-based variables and the data of non-spatial-based variables were obtained from relevant references. A database, which contains all collected data related to groundwater quality management in the studied area, was created as the output of the model. The output of this conceptual model can be used as an input for quantitative and mathematical models. Results show that 6 parameters (sulphate, iron, nitrate, electrical conductivity, calcium, and total dissolved solids (TDS) were the best indicators for groundwater quality analysis in the area. More than 50% of the wells were drilled in the depth of groundwater table about 5 meters, in this low depth pollutants can load into the wells and also 78% of the wells are located within 5 km from the urban area; it can be concluded from this result that the intensive urban activities could affect groundwater quality.

Key words: *Analytical Hierarchy Process (AHP), conceptual model, database, Geographic Information System (GIS), the Tajan Plain*

INTRODUCTION

Nowadays, because of population growth in many developing countries, water demand is increasing. Among different resources, groundwater is the most usable source for drinking in many countries [HAMMOURI *et al.* 2016; HOSSAIN, BAHAUDDIN 2013; LJUBENKOV 2012] such as Iran. Groundwater accounts for 26% of global renewable fresh water resources [ELBEIH 2015] but despite of low amount has become an essential commodity due to its increasing usage for drinking, irrigation and industrialization [SINGH *et al.* 2011]. Groundwater pollutions are usually diagnosed after contamination of wells, when aquifers contamination removal is almost impossible; therefor identification of the pollution sources and managing of them seem very important. Groundwater quality is usually subject to contamination especially in agriculture-dominated areas having intensive activity involving the use of fertilisers and pesticides [ERSOY, GÜLTEKIN 2013] such as the study area.

Sufficient information and an overview of the groundwater condition have significant role in the early stages of preparing a sustainable groundwater development plan [SHIRAZI *et al.* 2015]. Appropriate measures should urgently be undertaken for water resources development due to fast decline of groundwater table and increasing water demand [ZARDARI *et al.* 2014]. Also in order to manage the pollution sources, the linkage between water quality parameters (dependent variables) and affecting factors on quality (independent variables) should be analysed. The aim of this study is; providing a conceptual model in order to select and collect the required data for managing the quality of drinking groundwater.

Conceptual models are models that support understanding and reasoning about problem and solution space by abstracting in many directions [MULLER 2014]. A conceptual model is the first step in developing a more quantitative geologic, water-quality, groundwater flow, or water management model [USGS 2015].

There are many methods for water quality assessment; different parameters are analysed as indicators of water quality by each method. One of the most common methods in groundwater assessment is Groundwater Quality Index which was used in different researches [ADHIKARI *et al.* 2012; GORAI, KUMAR 2013]. In the present study, AHP method was proposed to rank and select the most appropriate water quality parameters, which properly reflect the status of groundwater contamination in the area of study. AHP introduced by SAATY [1977] is a popular MCDM method and is widely used to calculate the weights of evaluation criteria [NOURBAKHSH *et al.* 2015a]. This method uses pair-wise comparison for obtaining the relative weights of criteria [SHARIATI *et al.* 2013].

Since most of the independent variables in the present study were capable of spatial analysis, the Geographical information system was used as a spatial-base managing tool in order to acquisition the data of independent variables. Geographical Information System is an applicable tool in different research fields of water resources, including water pollution [ZUSHI, MASU-NAGA 2011], vulnerability assessment [NESHAT *et al.* 2014], modelling and simulation [RIOS *et al.* 2013] and water resources management [PACHRI *et al.* 2013]. This study was carried out in the Tajan Plain, located in the north of Iran and drinking water quality is considered. It is worth noting that in all Caspian countries including northern Iran, groundwater is the most drinking supply in coastal zones [MEHRDADI *et al.* 2007].

Literature review revealed that the proposed variables in the model of this study were also pointed in other articles. An article was released by VICTORINE NEH *et al.* [2015], which in seven independent variables were involved in groundwater vulnerability assessment. The variables were included depth of groundwater table, the type of aquifer, discharge ratio, soil type, topography, the upstream effects and electrical conductivity [VICTORINE NEH *et al.* 2015]. These variables also examined by Gorai and Kumar for modelling the ground water quality management in a plain in India [GORAI, KUMAR 2013]. Osibanjo and Majolagbe examined the physicochemical quality of groundwater in terms of land use and through correlation analysis in a region of Nigeria; Industrial area, coastal area, dryland farming, waste disposal site and residential area were studied. The results showed that the amount of calcium and magnesium in the area of dryland farming was higher than other land use types and the amount of chlorine and sodium in industrial lands was higher [OSIBANJO, MAJOLAGBE 2012]. LI *et al.* evaluated the groundwater of the Pyongyang area in northern China using the Groundwater Quality Index (*GWQI*). TDS, sulphate, fluoride, nitrite and TH were considered as qualitative parameters that are almost similar to dependent variables of the present study [LI *et al.* 2010].

MATERIALS AND METHODS

STUDY AREA

The area of study (the Tajan Plain) is located in Iran – the province of Mazandaran, in the northern Alborz range [MASHARI *et al.* 2012], the Tajan Plain geographically lies between 35°56′31.35″ and 36°48′50.672″ N latitude, and 52°55′30.967″ and 53°17′53.793″ E longitude [NOURBAKHSH *et al.* 2015b]. Tajan River is a major river in the Caspian Sea water basin and it is about 170 km long [YOUSEFI *et al.* 2013]. Tajan Basin has an area of 4372.33 km^2 and includes the Tajan Plain at 631.1 km^2 located in the highlands of the basin (Fig. 1).

THE CONCEPTUAL MODEL

In the present study, a conceptual model was presented and a database was developed which indicates the required information for modelling the effects of different factors on the quality of groundwater resources. This conceptual model includes procedures and methods of data collection and data analysis also indicates processes and outputs of the study in each step. This model can be used as a pattern for similar researches. Presented model consists of three main sections; first the sampling wells, second the quality parameters (dependent variables) and third the influencing factors (independent variables). Different methods to select and collect data related to each of sectors were offered in the above-mentioned model. The value in preparing a conceptual model is that it facilitates and expedites developing a credible quantitative model [STIGTER *et al.* 2006]. In this regard; the output of presented conceptual model (Tab. 1) is usable as the input of quantitative and mathematical models. The conceptual model presented in this paper is schematically shown in Figure 2 and different sections were defined as follow.

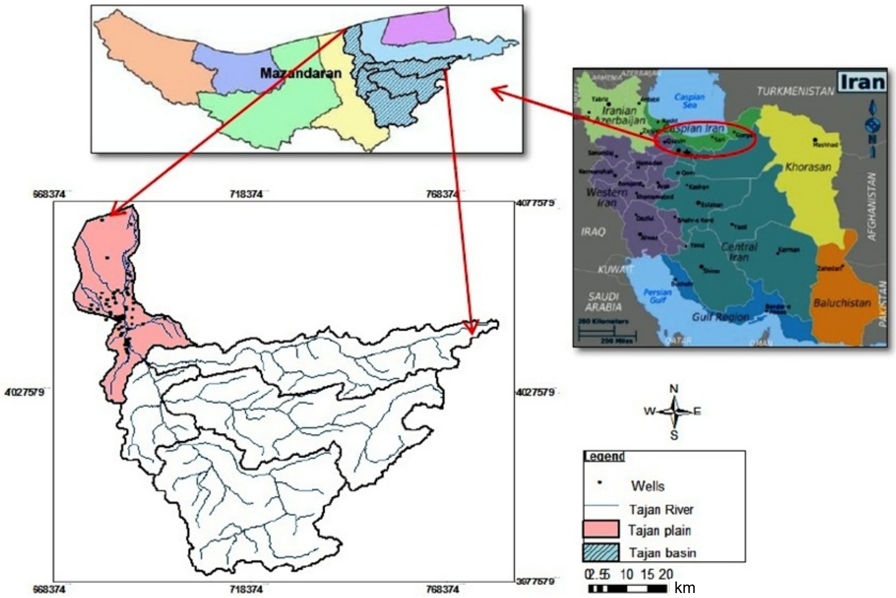


Fig. 1. Location of the study area; source: LAR Consulting Engineers [2001]

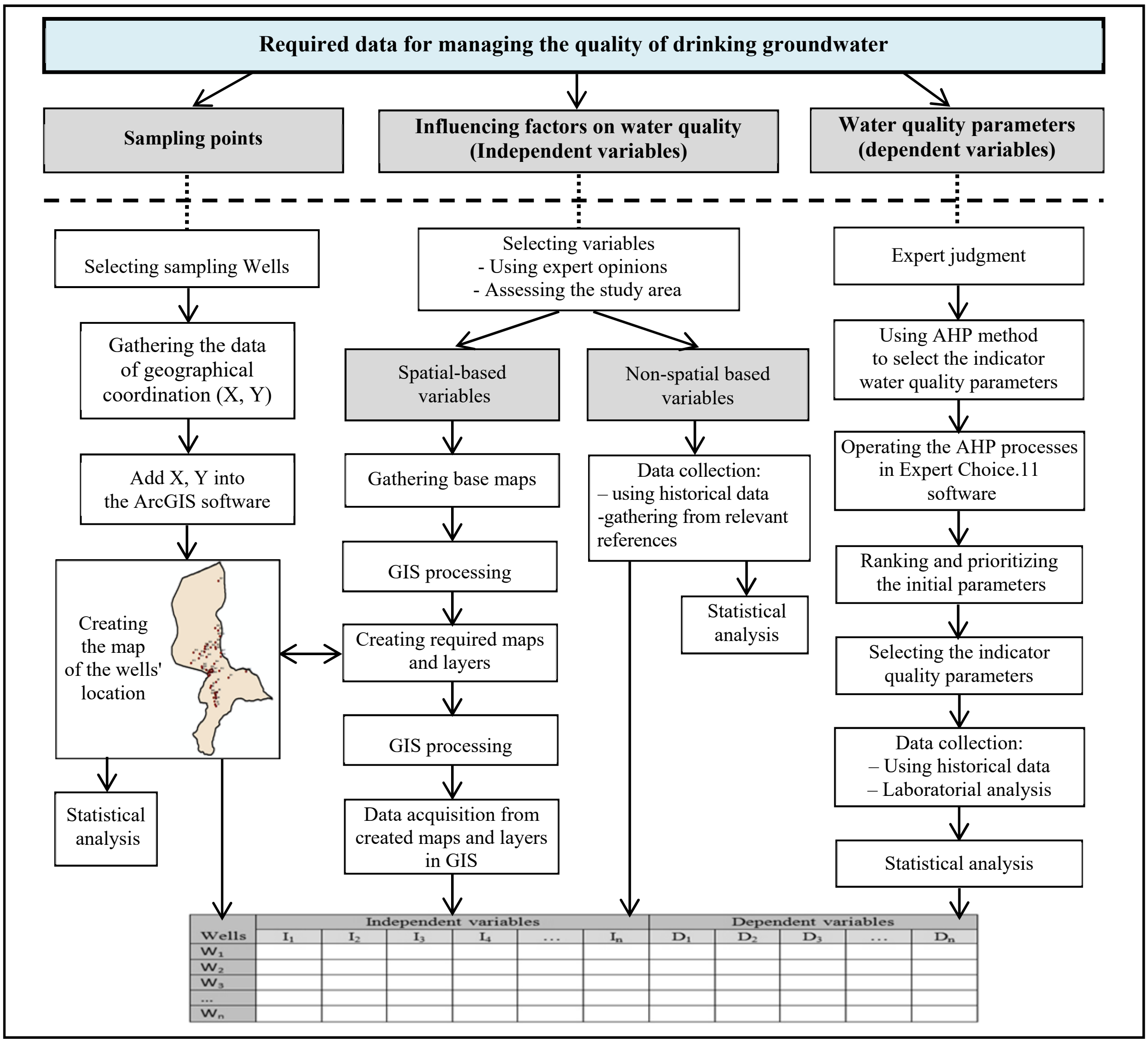


Fig. 2. Schematic form of conceptual model of the research; source: own elaboration

Sampling points. Since the objective of the study was managing the quality of drinking water, the drinking wells of the study area were be involved as sampling points. The number of sampling points is depends on project objectives, methods of data analysis and prediction of the **s**patial variation of groundwater quality, for these reasons specially for statistical analysis, US Geological Survey suggested that at least 30 sampling points should be considered [FRANKE 1997]. In present research all of the 50 existing drinking wells in the area were studied. The samples are selected according to urbanization, land use in the area of study to identify the main interest of drinking water vulnerability according to some elements [BENRABAH *et al.* 2016]. The locations of wells are shown in Figure 3 and the characteristic of wells are presented in Table 1.

Water quality parameters (dependent variables). Since all parameters that may exist in a groundwater system, could not be evaluated, some parameters must be selected as indicator. Indicators can be used to monitor ecosystem status and trends; therefor the careful selection of a group of indicators is a crucial exercise [JAMES *et al.* 2012]. In present study the AHP technique was used to select indicator parameters. Different steps of selecting parameters are shown in Figure 4.

The first step in the AHP method is to decompose the problem into a hierarchy. The elements of hierarchy levels are compared in pairs to assess the irrelative preference with respect to each of the elements at the next higher level [SINGH, BENYOUCEF 2011].

The research hierarchy in the present study comprised three main levels; main goal, criteria and subcriteria (Fig. 5). Expert opinion was used to perform paired comparisons in this research, so a questionnaire was designed and all experts were asked to compare the parameters. Twenty experts were chosen to form the group, they were familiar with the study area and had expertise in knowledge of groundwater quality. The experts compared parameters with each other by scores between 1 to 9. 1 indicates the equal preference of two criteria, 9 indicates the full preference of one criterion over the other [SAATY 1997].

In order to accelerate the AHP analysis (steps 4, 5, 6 and 7 in Fig. 4) "Expert Choice. 11" software was used. Operations related to weighting and ranking were performed in the software; at last the parameters were prioritized according to their final weights.

When the indicator parameters were selected, the related data were obtained from Mazandaran Water and

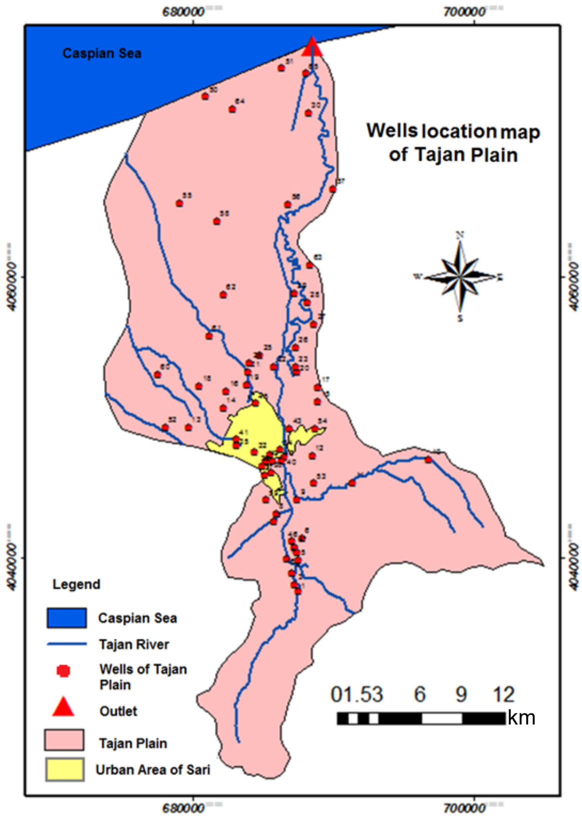


Fig. 3. The map of wells location in the Tajan Plain; source: own elaboration

Wastewater Company. The mean of the water quality data in a 10 years period (2004–2014) was calculated using seasonal measurements and the result values were used as indicative value of each parameter in each well. This period is an acceptable period for analysing the groundwater quality [ATTOUI *et al.* 2016].

Influencing factors on groundwater quality (independent variable). Given the objectives of the study, different factors were involved in the water quality modelling process. Based on expert's opinion, literature review and surveying the study area, the following factors were taken into consideration as the influencing factors on groundwater quality: land use types, lithology units (the type of surface soil), geology units (stratigraphic type), distance of the wells from the outlet, distance from the residential areas, direction toward the residential areas, depth of the groundwater table, aquifer kinds, transmissivity and population density.

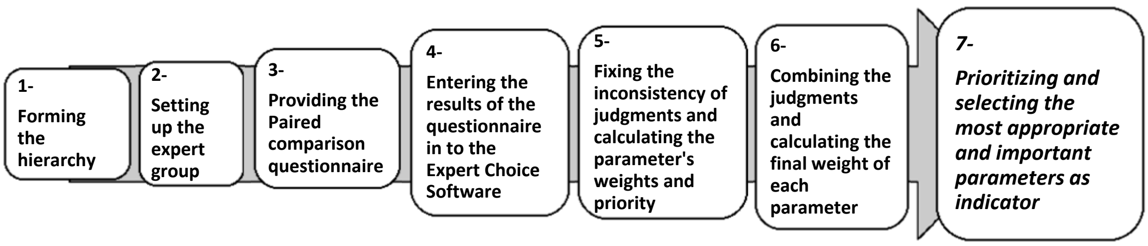


Fig. 4. Process of selecting appropriate water quality parameters via AHP technique;source: own elaboration

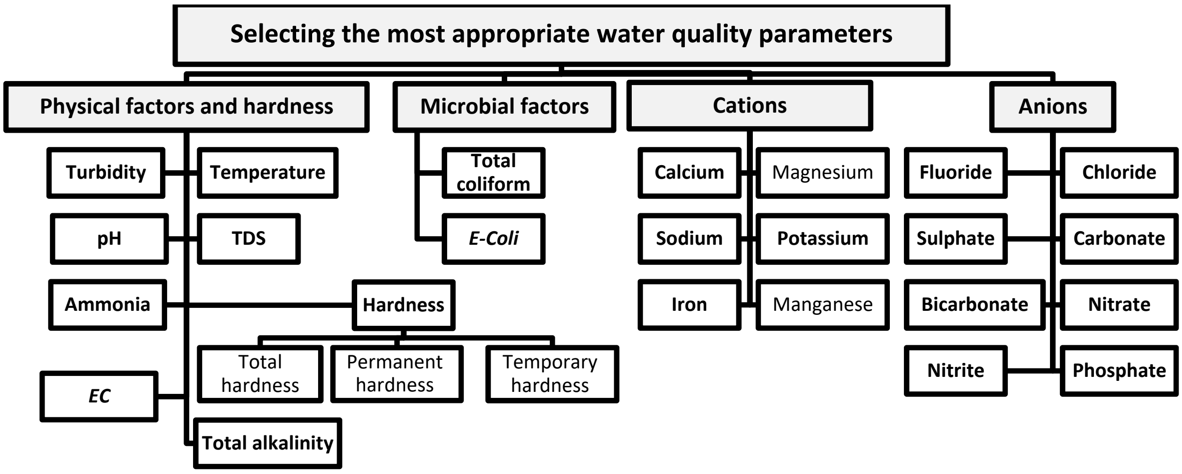


Fig. 5. The hierarchy of the research; source: own elaboration

Geographical information system was used for managing the spatial-base data related to the most of independent variables. The GIS analysis was carried out by using ArcGIS 9.3. Geographic information system (GIS) has different applications in analyzing and modelling of point and non-point water pollution sources [MAINARDI FAN *et al.* 2015; SHEN *et al.* 2013].

To obtain the required data, at first the boundary of study area were digitized on the 1:50 000 topographic quadrangle maps (related sheets to the Tajan Plain) and the boundary layer plus the geographic coordinates (X, Y) of wells were added to other digital maps of area (geology, land use, lithology, depth and the other maps). All databases were projected onto a common coordinate system, Universal Transverse Mercator (UTM) (zone 39N). The required information about independent variables was gathered in four types of data.

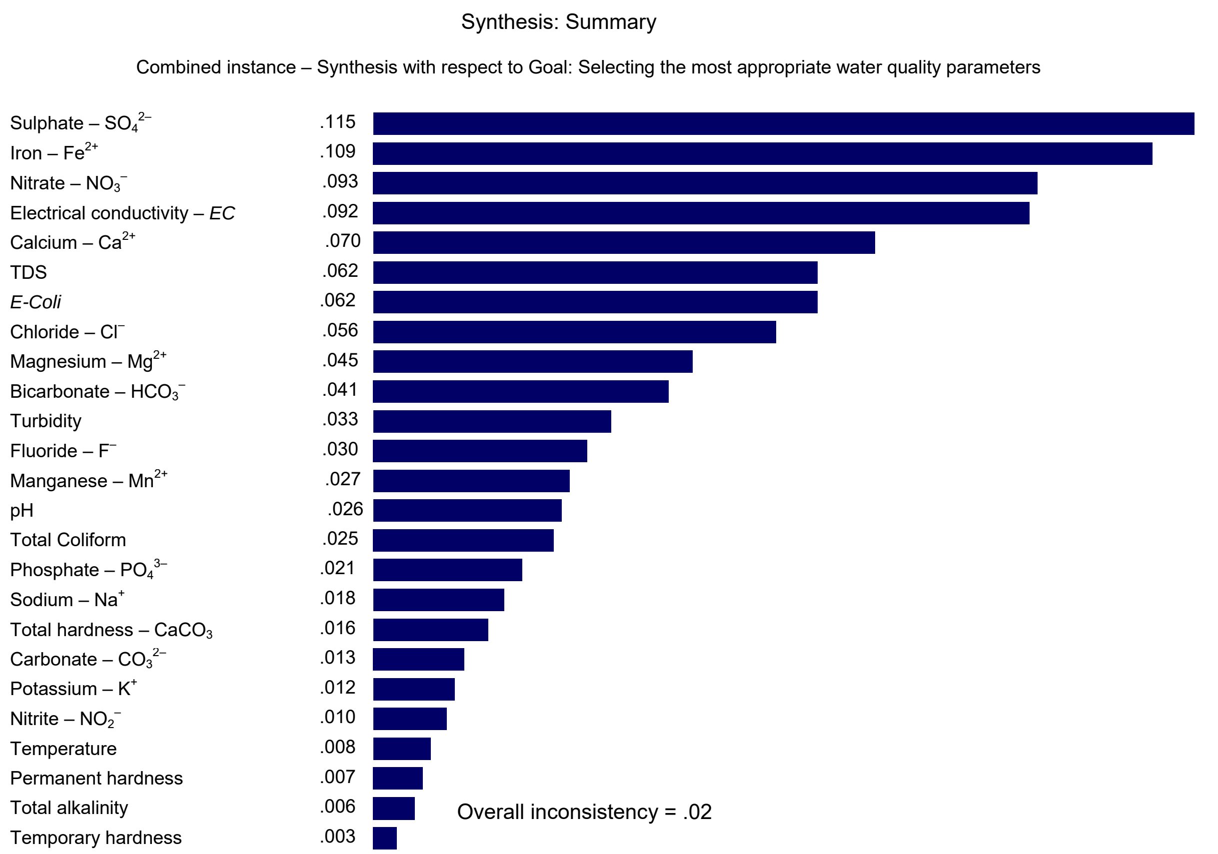
A. To determine the land use types around each well, the 1:100 000 land use map of Sari were cropped in the Tajan Plain. All layers of land use types were digitized as polygon vector layer in Arc map, then the point layer of wells were added and the wells were identified in different land use types. This stage was also passed to determine the geological units (mean stratigraphic types which are twenty three units in the Tajan Plain) and lithological units (means the type of surface soil which were divided to five units in the Tajan Plain).
B. According to the expert's opinion, the distance of wells up to the residential areas and distance up to the outlet of watershed were considered as two important independent variables. To determine these distances the layers of the Caspian Sea (outlet of the watershed) was added to land use map and the layer of residential areas (urban and rural areas in the Tajan Plain) were digitized on land use map and then distances were calculated with metric unit in GIS. The directions of the wells toward the residential areas were measured on the maps too.
C. For determining the depth of groundwater table, the raster layer of groundwater table was made using the map of depth contour and then the point layer of wells were added to final depth map.
D. The transmissivity map of aquifer formations in the Tajan Plain were received from Mazandaran Company of rural water and sewer. The vector layer of transmissivity classes were built based on the raster map, then the transmissivity classes related to different wells were determined in $m^2 \cdot day^{-1}$ [GHOLAMY 2014].

Population centers within a radius of 1000 meters upstream the well were considered as effective population [GHOLAMY 2014]. Since the total slope of the study area is south to north, population centers in south of the wells (upstream) were involved in population analysis. To calculate the effective population on some wells which were located in the urban area; the area was zoning out and the average population of upper zones of each well was calculated as effective population on that well. The population's data were putted in the first column of Table 1. Population data was based on the 2011 population census, which was carried out by Iran Statistic Centre [The Governor of Mazandaran 2011]. It is worth noting that general slope of the area is lower than 5% according to experts opinions the layer of slope was not considered as an effective factor.

RESULTS AND DISCUSSIONS

AHP ANALYSIS

As previously mentioned, dependent variables (indicator water quality parameters) were selected by AHP technique using Expert Choice software. After completion of the process, the weight graphs of all the criteria were plotted separately and at the end, the graph of synthesis of parameter's weight were composed (Fig. 6). In this graph, the quality parameters were ranked and prioritized based on relative weights from most to least important). The first six parameters mean the high priority ones (sulphate-iron-nitrate-*EC*-calcium and TDS) were determined as indicator parameters.



– The value before each chart shows the weight of relative parameter in comparison with the others.
– The sign of "combined" is the indication of collective group opinion.
– Inconsistency: Less than 0.1 is negligible and acceptable in the AHP method.

Fig. 6. Ranking graph of all the water quality parameters of the study; source: own study

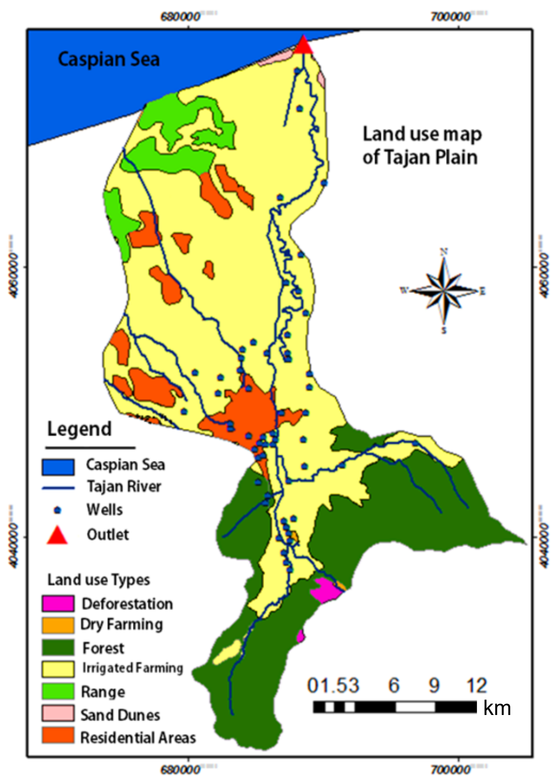


Fig. 7. The land use map of the Tajan Plain; source: own elaboration

The overall inconsistency was less than 0.1 which is negligible and acceptable in AHP technique, it was showed the high degree of homogeneity in judgments and synthesis. The closer the inconsistency ratio to zero shows the greater consistency [TORFI *et al.* 2010].

GIS ANALYSIS

Land use analysis. Based on the prepared land use map in Arc map, these results were obtained that the study area includes seven main types of land uses (Fig. 7), but there are no well in two land use types (range and deforestation). However, since the land use map was not represented all details, satellite images of Google Earth was used as an auxiliary tool, finally 5 main land use types were identified upstream and around the wells. According to the spatial analysis, gardens and irrigated farms are the dominant land use types in the study area, statistical analysis was indicated that garden lands were exist upstream of 37.2% of wells, also about 28% of wells were located in irrigated farms and the same amount in the urban areas (Fig. 8). The second column in Table 1 allocated to the land use type related to each well. The land use types were putted in output table by five codes: garden (Lg), irrigated farming (Li), residential areas (Lr), dry farming (Ld), forest (Lf).

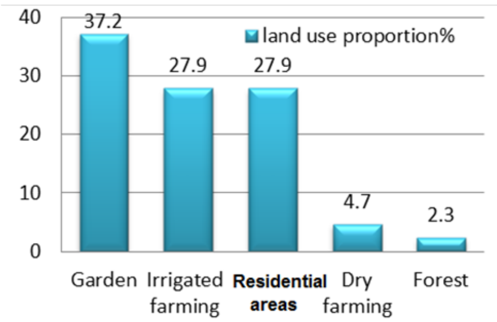


Fig. 8. The proportion of land use types around the wells; source: own study

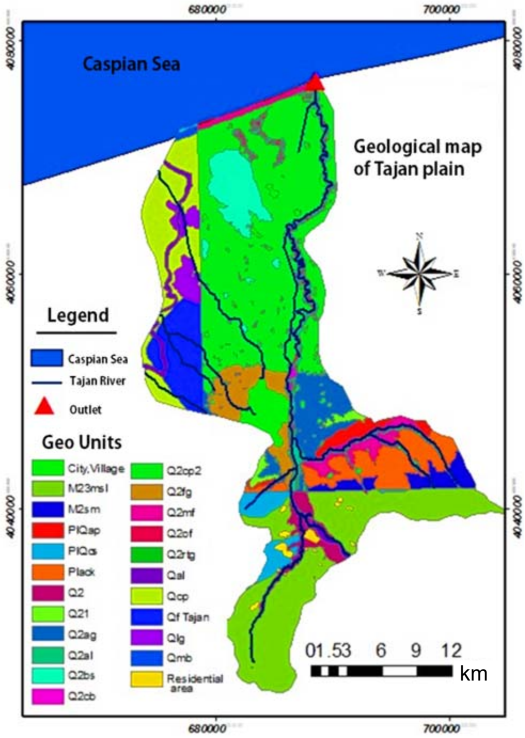


Fig. 9. The geological map of the Tajan Plain; source: own elaboration

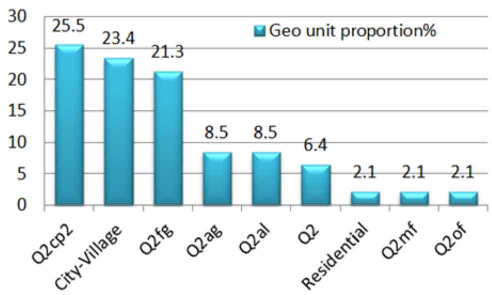


Fig. 10. The proportion of geo units around the wells; source: own study

Geological units analysis. The results of the geological map's study (Fig. 9) indicated that there are 23 geo units in the Tajan Plain but the wells have been drilled just in nine geo units. According to the statistical analysis (Fig. 10) almost half of the wells have been drilled in two geo units: 1 – Q2cp2 (Coastal plain deposits: gravel and sand), 2 – city village.

Lithological units analysis. The lithological analysis showed that the Tajan Plain consists of five lithological types (Fig. 11) but more than 90% of wells are located in "Qt2c" (Los agro-covered areas**)** unit and almost 10% of wells are located in "Plcm" (Conglomerate, marl, silty marl) and "Qal" (Fluvial sediments) units. Columns 3 and 4 of Table 1 are related to geological and lithological data.

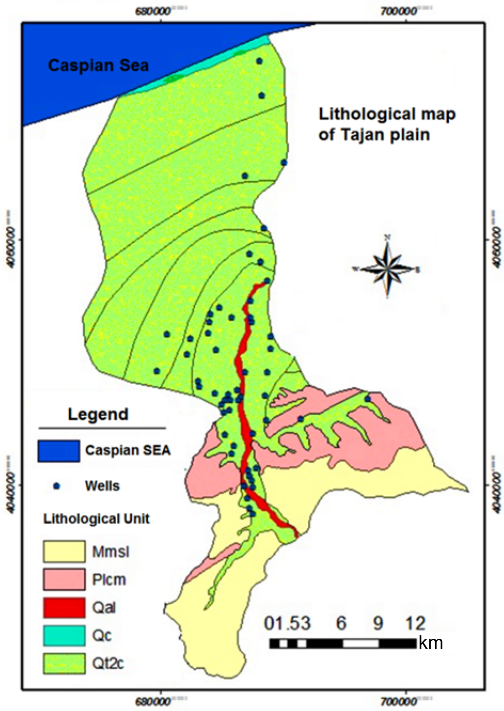


Fig. 11. The lithological map of the Tajan Plain; source: own elaboration

Analyzing the distances. After spatial examining of maps and statistical analysis, the results showed that all 50 wells were scattered between 4.5 and 38.2 km from the outlet of basin (means Caspian Sea**)**, 90% of the wells have been drilled at a distance of more than 20 km from the sea. On the other hand, all of the wells were located at a distance of 0 to 15 km from residential areas, but 78% of the wells are located within 5 km from the urban area, it can included from this result that the intensive urban activities could affect groundwater quality in the area [TU 2011]. Further related details of distances are shown in Figures 12 and 13.

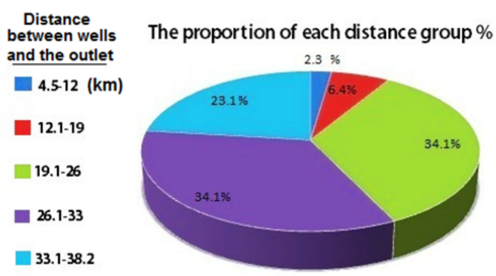


Fig. 12. Distances of the wells up to the outlet; source: own study

Table 1. The database of required data for managing the quality of groundwater in Tajan Plain

Wells	Independent variables										Dependent variables					
	upstream population person	land use type	geology unit	lithology unit	distance to outlet km	distance to city km	direction toward the city	depth of groundwater table m	transmissivity $m^2 \cdot day^{-1}$	aquifer kind	sulphate	iron	nitrate	electrical conductivity *EC*	calcium	Total dissolved solids (TDS)
1	3 506	Ld	Residential	Qt2c	38.2	7.0	South	12.5	300	alluvial deposits	57.4	0.57	9.5	775.9	109.5	429.6
2	1 012	Li-Lg-Lr	Q2ag	Qt2c	31.4	1.5	South	17.5	2 000	unconfined	38.1	0.01	8.3	695.5	115.0	448.0
3	907	Lf	Q2	Qt2c	38.0	6.0	South	12.5	2 000	alluvial deposits	46.0	0.14	12.0	608.3	116.6	445.4
4	1 191	Li-Ld	Q2	Qt2c	36.2	5.5	South	12.5	2 000	alluvial deposits	72.2	0.12	8.1	710.0	118.7	438.7
5	402	Li	Q2	Qt2c	37.0	4.5	South	12.5	2 000	alluvial deposits	88.8	0.20	7.1	647.9	105.4	426.0
6	573	Lf	Q2al	Qal	35.0	3.5	South	7.5	300	alluvial deposits	72.0	0.04	9.5	869.2	122.1	627.3
7	1 753	Li-Lg-Lr	Q2al	Qal	36.5	4.5	South	12.5	2 000	alluvial deposits	63.8	0.39	18.6	714.3	114.5	370.0
8	4 580	Li-Lg-Lr	Q2fg	Qt2c	31.6	1.2	South	17.5	2 000	unconfined	82.8	0.01	9.9	679.9	105.3	378.3
9	1 824	Li-Lg-Lr	Q2al	Qt2c	33.2	2.0	South	7.5	100	alluvial deposits	28.4	0.62	7.3	752.1	119.8	395.1
10	1 932	Lf	Q2mf	Plcm	32.0	9.0	South	7.5	100	alluvial deposits	34.0	0.07	6.3	830.3	132.1	529.8
11	754	Ld-Li	C-V	Qt2c	33.0	6.0	South	7.5	2 000	alluvial deposits	30.1	0.08	6.0	686.1	113.7	434.0
12	1 904	Li-Lg	Q2ag	Qt2c	30.0	1.5	South	7.5	75	unconfined	92.0	0.34	2.5	905.0	85.1	517.3
13	95	Li-Lg-Lr	C-V	Qt2c	24.0	2.5	North	2.5	1 500	confined	84.7	0.15	18.1	836.0	106.6	467.9
14	1 045	Li-Lg-Lr	Q2fg	Qt2c	23.3	1.0	North	2.5	2 000	confined	109.6	0.46	12.0	883.9	106.6	537.0
15	1 099	Li-Lg	Q2ag	Qt2c	25.0	3.0	North	7.5	2 000	confined	90.8	0.15	16.9	740.8	106.1	451.8
16	304	Lg	Q2fg	Qt2c	22.0	2.0	North	7.5	2 000	confined	67.4	1.12	12.5	634.8	95.8	411.0
17	1 464	Li-Lg	Q2cp2	Qt2c	22.8	3.7	North	7.5	2 000	confined	92.0	0.05	17.8	1 027.0	137.0	616.0
18	563	Lg	Q2fg	Qt2c	20.7	3.5	North	2.5	750	confined	82.0	0.61	10.0	1 089.8	141.0	795.0
19	706	Lg-Lr	Q2cp2	Qt2c	21.5	1.0	North	2.5	2 000	confined	80.0	0.10	19.6	710.7	101.1	455.2
20	628	Li-Lg	Q2cp2	Qt2c	22.5	3.4	North	7.5	2 000	confined	69.0	0.99	18.2	631.5	81.8	402.5
21	369	Lg	Q2cp2	Qt2c	20.5	2.5	North	7.5	2 000	confined	77.0	0.24	7.5	770.0	101.4	440.0
22	368	Lg-Lr	Q2cp2	Qt2c	20.0	3.0	North	2.5	2 000	confined	86.0	0.21	14.2	810.8	90.6	493.0
23	432	Lg-Lr	C-V	Qt2c	21.0	4.0	North	2.5	2 000	confined	66.3	0.65	8.5	806.7	84.4	513.0
24	412	Lg	Q2cp2	Qt2c	19.0	2.0	North	7.5	2 000	confined	83.1	0.31	9.5	764.6	103.3	505.4
25	91	Lr	Q2cp2	Qt2c	19.0	3.0	North	7.5	2 000	confined	87.6	0.19	13.0	714.1	98.4	486.9
26	712	Li-Lg	Q2cp2	Qt2c	21.0	5.0	North	2.5	2 000	confined	36.0	0.46	5.5	576.6	73.1	361.3
27	604	Li-Lg	Q2cp2	Qt2c	20.5	8.0	North	2.5	2 000	confined	36.0	0.57	13.7	656.1	83.2	379.6
28	320	Li-Lg	Q2cp2	Qt2c	15.6	10.0	North	2.5	2 000	confined	42.8	0.49	11.0	660.0	65.2	402.2
29	380	Li-Lg	Q2of	Qt2c	18.8	10.0	North	2.5	2 000	confined	36.3	0.42	5.8	641.8	65.8	378.5
30	235	Lg-Lr	Q2cp2	Qt2c	17.0	7.0	North	7.5	100	confined	68.5	0.62	6.5	682.5	79.8	443.5
31	1 468	Lg	Q2cp2	Qt2c	4.5	15.0	North	2.5	2 000	unconfined	75.0	0.21	1.4	897.5	101.2	539.0
32	10 645	Lr	C-V	Qt2c	27.3	0	inside	2.5	2 000	unconfined	124.3	0.02	38.7	1 036.0	151.2	695.8
33	10 550	Lr	C-V	Qt2c	27.0	0	inside	2.5	2 000	unconfined	111.2	0.02	51.9	1 438.7	125.8	922.0
34	6 890	Li-Lg-Lr	Q2fg	Qt2c	28.8	0.3	North	2.5	2 000	unconfined	127.4	0.17	29.9	944.4	108.0	619.3
35	4 780	Lr	Q2fg	Qt2c	28.6	0	inside	7.5	2 000	unconfined	114.5	0.20	26.8	947.0	97.1	619.2
36	14 740	Lr	C-V	Qt2c	26.0	0	inside	2.5	2 000	unconfined	113.8	0.02	35.6	1 237.2	125.2	836.6
37	11 205	Lr	C-V	Qt2c	28.3	0	inside	2.5	2 000	unconfined	120.7	0.15	34.3	1 139.1	119.4	779.5
38	7 680	Lr	C-V	Qt2c	29.5	0	inside	2.5	2 000	unconfined	124.3	0.20	35.5	982.1	112.3	640.9
39	6 580	Lr	C-V	Qt2c	28.2	0	inside	12.5	2 000	alluvial deposits	126.8	0.03	28.0	964.7	111.1	610.6
40	3 568	Li	Q2fg	Qt2c	35.0	3.5	North	2.5	2 000	unconfined	118.6	0.14	15.7	1 376.5	136.3	926.6
41	8 300	Lg-Lr	Q2al	Qal	28.5	0	inside	7.5	2 000	unconfined	95.0	0.32	22.9	945.4	105.9	624.5
42	18 635	Li	C-V	Qt2c	25.6	0	inside	7.5	2 000	unconfined	108.3	0.12	42.2	1 224.0	125.0	817.7
43	6 700	Li-Lg-Lr	Q2al	Qt2c	28.0	0.3	South	2.5	2 000	unconfined	89.0	0.30	23.8	936.1	112.2	618.6
44	8 320	Lg-Lr	Q2ag	Qt2c	26.0	0	inside	7.5	2 000	unconfined	116.4	0.02	28.6	930.1	104.9	621.1
45	10 360	Lg-Lr	Q2fg	Qt2c	26.7	1.0	inside	2.5	2 000	confined	112.3	0.04	17.3	1 046.0	112.9	709.6
46	15 970	Lr	Q2fg	Qt2c	25.0	0	inside	7.5	2 000	alluvial deposits	111.2	0.20	40.5	1 187.1	128.5	795.7
47	2 440	Li-Lg	Q2fg	Qt2c	36.0	3.0	South	12.5	2 000	alluvial deposits	128.1	0.03	20.7	948.4	108.6	644.4
48	2 315	Li-Lg	Q2fg	Qt2c	37.0	3.5	North	12.5	2 000	alluvial deposits	125.0	0.02	20.4	973.7	105.9	647.5
49	1 980	Li-Lg	Q2fg	Qt2c	38.0	4.0	South	2.5	2 000	unconfined	126.9	0.02	12.5	906.4	104.4	606.7
50	10 320	Lr	C-V	Qt2c	29.5	0	inside	7.5	100	confined	138.5	0.03	26.8	1 760.4	118.8	1 218.0

Explanations: **codes of land use types** are given in page 154; **geology units:** Q2ag = alluvial apron deposits: boulder gravel and coarse-grained sand with some fine-grained materials; Q2 = young alluvial fans and terraces, river terraces, mainly cultivated; Q2al = recent alluvium: coarse to fine grained alluvium which from in river based and channels; Q2fg = alluvial fan deposits: boulder gravel, gravel with sand unconsolidated; Q2mf = inter mountainous fan deposits: boulder gravel and gravel, poorly sorted; C-V = city, village; Q2cp2 = coastal plain deposits: gravel and sand, becomes fine grained to seaward; **lithology units:** Plcm = conglomerate, marl, silty marl; Qal = fluvial sediments; Qt2c = los agro-covered areas; Mmsl = marl, calcareous sandstone, sandy limestone, conglomerate, QC = coastline sand.
Source: own study.

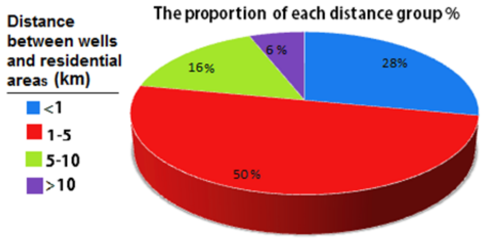


Fig. 13. Distances of wells up to the residential areas; source: own study

Analysing the depth of groundwater table. To evaluate the effect of the groundwater table depth on the water quality, the depth raster map was created at this stage (Fig. 14). According to the study; average depth of groundwater in the Tajan Plain is lower than 17.5 m. This result shows the high probability of pollution discharge into the aquifer. The analyses showed that 42% of the wells have been drilled in the area with groundwater depth of 2.3 m, 38% of wells have been drilled in groundwater depth of 7.5 m, 16% of the wells are in 12.5 m depth and 4% are in 17.5 m depth of groundwater table in Tajan plain.

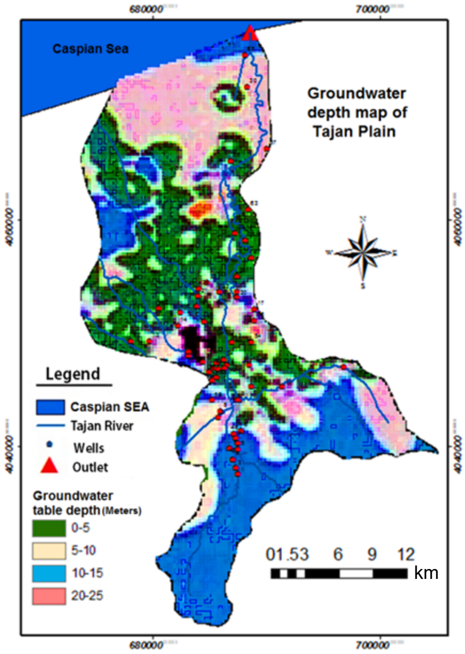


Fig. 14. The map of groundwater table depth in the Tajan Plain; source: own elaboration

Analysing the transmissivity of aquifer formation. The map of transmissivity was prepared to examine this issue; whether the difference in the transmissivity of aquifer formation could affect groundwater quality. As can be seen in the map (Fig. 15), the transmissivity of the Tajan Plain is divided in nine classes with almost equal area. The lowest transmissivity in the Tajan Plain is 75 $m^2 \cdot day^{-1}$ and the highest one is 2000 $m^2 \cdot day^{-1}$. The most wells are located in high transmissivity rate, so despite the high discharge capacity, they have a high potential in surface contaminants reception.

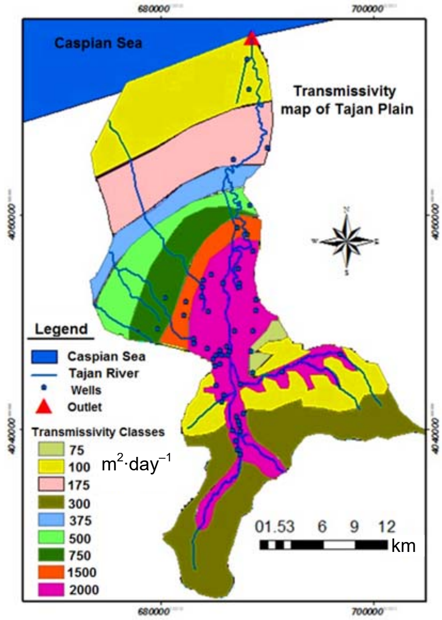


Fig. 15. The transmissivity map of the Tajan Plain; source: own elaboration

Analysing the aquifer kinds. The aquifer map was prepared for determining the difference of groundwater quality in different aquifer kinds of the area (Fig. 16). According to the map it can be seen that there are two kinds of aquifers in the Tajan Plain: confined aquifer and unconfined aquifer. Almost half of the area covered by confined aquifer and because of its large area about half of the wells have been drilled in this aquifer. Unconfined aquifer has covered 6% of the area but many of wells are located in this small area. Alluvial deposits of Tajan River have formed about 15% of the area; in this part of the region because of the high discharge of sediments, some drinking wells were drilled.

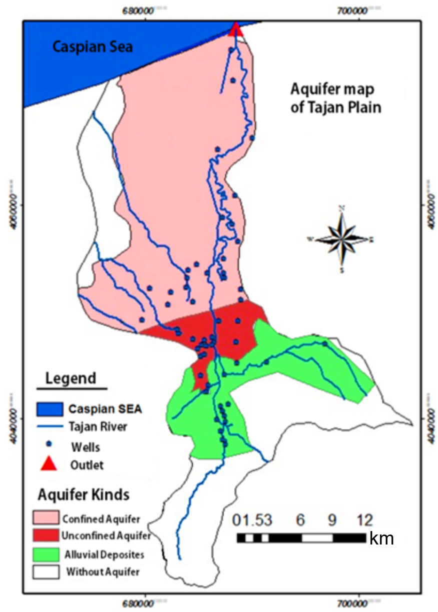


Fig. 16. The map of aquifer kinds in the Tajan Plain; source: own elaboration

CREATING THE FINAL DATABASE

At the end of the study, means after selecting variables and gathering the related data by using different methods, a database in the form of a table was created as the final output of presented conceptual model. This database contains the necessary information which is needed to manage drinking water quality in the Tajan Plain.

CONCLUSIONS

As previously maintained a conceptual model was presented in this study to select and collect the required data for managing the quality of drinking groundwater. Four main questions were examined via proposed conceptual model.

1. What quality parameters (dependent variables) are more suitable to manage the quality of drinking groundwater in the study area?
2. What environmental factors (independent variables) have the greatest impact on groundwater quality?
3. What methods are appropriate to select different variables?
4. How the relevant data can be collect?

The output of this conceptual model is Table 1 which is a database for groundwater quality management in study area. Through this database the relationship between independent and dependent variables can be modelled and the main affecting factors can be identified so appropriate management strategies can be offered according to the results. The proposed conceptual model has six main advantages.

1. This model shows the required data and the processes of data gathering for managing the quality of groundwater.
2. This conceptual model can be used as a pattern for different studies such as other plains and watersheds and also surface waters, even in other fields of study such as air and soil pollution management.
3. The output of this model can operate as input of quantitative and mathematical models.
4. A full identification source of the studied wells has been provided through the output table.
5. One of the other advantages of this model is flexibility, which based on the objectives of the study; different fields can be added or removed.
6. Another advantage of the model is using the expert's opinion in different steps. Two important factors were highlighted to select the experts, being familiar with the characteristics of study area and being a specialist in water quality sciences.

In addition to the above items, different conclusions were obtained from different levels of study; one of the conclusions was that; different quality parameters do not impose the same pollution load on the groundwater resources, so they should be involved in the analysis according to their weights, also it was concluded that the Analytic Hierarchy Process is an appropriate method for weighting and a logical way for prioritizing and selecting the indicator groundwater quality parameters. One of the other important conclusions that obtained from this level was that: the background of pollution is an essential issue that should be focused in selecting parameters. For example, expert opinion stated that microbial agents had rarely observed in wells of the Tajan Plain, thus, despite the importance of this factor, is not a priority for analysis.

Another point which is concluded was that: the most affecting factors on water quality were spatial based so Geographical Information System was used as an applicable tool to collect the related data, in this regard the data of the most of independent variables were extract via GIS direct or indirect, also the efficiency of the GIS has ensured. After data gathering, some preliminary statistical analyses were performed on them. These analyses are the introduction of more advanced ones.

Another considerable point was that; the characteristics of study area were important for selecting significant factors and different managing variables. For example, since the study area was not very expanded and there was just one climatologic station, the climatologic factors (rain, evaporation, temperature…) were not involved in the model. In addition because of rare topographic variation in the Tajan Plain and by agreement of the expert group, the layer of topography was removed from the analysis.

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Przedstawienie koncepcyjnego modelu gromadzenia danych na potrzeby zarządzania jakością wód gruntowych

STRESZCZENIE

W przedstawionym badaniu zaproponowano model koncepcyjny, który uwydatnia niezależne i zależne zmienne ważne dla zarządzania jakością wód gruntowych. Wyjaśniono ponadto metody doboru zmiennych i gromadzenia stosownych danych. Badania prowadzono na Równinie Tajan na północy Iranu. Próby pobierano w 50 studniach. W wybranym modelu zaproponowano proces analitycznej hierarchii (AHP) do wyboru wskaźnikowych parametrów jakości wody. Zgodnie z opiniami ekspertów i charakterystyką obszaru badań wybrano dziesięć czynników stanowiących zmienne wpływające na jakość wód gruntowych (typ użytkowania ziemi, jednostki litologiczne, jednostki geologiczne, odległość studni od odpływu, odległość od terenów zamieszkanych przez ludzi, głębokość zwierciadła wód gruntowych, typ warstwy wodonośnej, przepuszczalność i liczba ludności). Wykorzystano system informacji geograficznej (AecGIS 9.3) do zarządzania zmiennymi przestrzennymi, a dane o zmiennych niezwiązanych z rozmieszczeniem przestrzennym pozyskano z literatury. Jako wyjście z modelu stworzono bazę danych, która zawiera wszystkie zebrane dane odnoszące się do zarządzania jakością wód gruntowych. Wyjście tego koncepcyjnego modelu może być użyte jako wejście do modeli ilościowych i matematycznych. Uzyskane wyniki świadczą, że najlepsze wskaźniki do analizy jakości wód gruntowych na badanym obszarze stanowiło 6 parametrów (siarczany, żelazo, azotany, przewodnictwo elektrolityczne, wapń i suma substancji rozpuszczonych). Ponad 50% studni wiercono do poziomu zwierciadła ok. 5 m. W warunkach tak małych głębokości można spodziewać się znacznej dostawy ładunku zanieczyszczeń. Spośród badanych studni 78% było usytuowanych w promieniu 5 km od terenów miejskich. Uzyskane wyniki pozwalają sądzić, że aktywność miejska może wpływać na jakość wód gruntowych.

Słowa kluczowe: *metoda hierarchicznej analizy problemów decyzyjnych (AHP), model koncepcyjny, Równina Tajan, system informacji geograficznej (GIS)*