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Use of water quality index and geographical information system to assess groundwater quality

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ABSTRACT

There are several factors influencing the water quality based on its usage. An attempt has been made to understand the ground water quality near the some industrial parts of Marvdasht city. the following 8 parameters have been considered: pH, dissolved oxygen, BOD (biochemical oxygen demand), Fecal coliform, temperature, total phosphate, nitrates and total solids, in the groundwater of three Marvdasht, Kharameh and Zarghan plains, during spring and fall(June-2012 and December-2013), to determine spatial distribution of groundwater quality and to identify places with the best quality for drinking, based on Water Quality Index calculation and Geographical Information System, due to industrialization, urbanization and agricultural activity. Groundwater samples were collected from 120 wells. The values of WQI for all samples were found in the range of 43.3 to 80.5 in the spring season while it was 44.7 to 82.3 in the fall season. In spring 10% and in fall season 7.5% of the water samples in Zaraghan and Dashtbal–Lanetavosi and Kharameh plains fall within the bad categories based on National Sanitation Foundation (NSF). The analysis reveals that the groundwater of these plains needs some degree of treatment before consumption, and it also needs to be protected from the perils of contamination.

1. Introduction

The access to "closer and cleaner drinking water" is still a distant dream for about one-sixth of humanity on this planet (Harvey, et al. 2002; Smedley and Kinniburgh 2002). It is predicted that this increasing scarcity, and competition over water resources in the first quarter of the 21st century will dramatically change the way we value and use water (Mroczek, 2005; Maqbool, et al. 2011). The requirement of water in all forms of lives, from micro-organisms to man, is a serious problem today because many water resources have been reached to a point of crisis due to unplanned urbanization and industrialization (Singh et al. 2004; Dixit and Tiwari, 2008). Contamination of the groundwater by domestic, industrial effluents and agricultural activity is a serious problem faced by developing countries. The industrial waste water, sewage sludge and solid waste materials are currently being discharged into the environment indiscriminately. These materials enter subsurface aquifers, resulting in the pollution of irrigation and drinking water (Forstner and Wittman, 1981).

It is estimated that approximately one third of the world's population use groundwater for drinking (Nickson et al, 2005). Hydrogeochemical studies of groundwater provide a better understanding of possible changes in quality as development progressed. Several authors have reported about the presence of contaminants in groundwater and surface waters in various part of the globe (Ali et al. 2004; Nakane and Haidary, 2010; Bhatnagar and Sangwan, 2009; Jeong et al. 2010; Taseli, 2009; Najafpour, 2008; Rene and Saidutta, 2008; Monavari and Guieysse, 2007; Qishlaqi and Moore, 2007; Elango et al. 2003; Srinivasa Rao et al. 1997; Subba Rao et al. 1998).

Risk assessment involves identifying the hazard associated with a particular occurrence, action, or circumstance and determination the probability for the occurrence of such hazards (Smith, 2001). Hence, evaluation of groundwater quantity and quality and establishing data base are important for the development of further civilization and for future water resources development strategies.

According to WHO organization, about 80% of all the diseases in human beings are caused by water. Once the groundwater is contaminated, its quality cannot be restored by stopping the pollutants from the source. It therefore becomes imperative to regularly monitor the quality of groundwater and to devise ways and means to protect it. Groundwater chemistry has been utilized as a tool to outlook water quality for various purposes (Rao, 2006; Edmunds et al. 2002). Water quality index is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers. It, thus, becomes an important parameter for the assessment and management of groundwater. In 1970 Brown et al., used the Delphe technique to formulate a water quality index (WQI) for the National Sanitation Foundation (NSF) of the United States.

WQI is an important technique for demarcating groundwater quality and its suitability for drinking purposes (Tiwari and Mishra, 1985; Singh, 1992; Rao, 1997; Mishra and Patel, 2001) and it is a mathematical equation used to transform a large number of water quality data into a single number (Mitra, 1998; Stambuk-Giljanovic, 1999). It is simple and easy to understandable for decision makers about quality and possible uses of any water body (Bordalo et al. 2001). It serves the understanding of the water quality issues by integrating complex data and generating a score that describes water quality status.

Till recently, groundwater assessment has been based on laboratory investigation, but the advent of Satellite Technology and Geographical Information System (GIS) has made it very easy to integrate various databases. GIS can be a powerful tool for developing solutions for water resources problems, assessing water quality, determining water availability, preventing flooding, understanding the natural environment and for managing water resources on a local or regional scale (Ferry et al. 2003).

The objective of the present work is to discuss the suitability of groundwater for human consumption based on computed water quality index values near the some industrial parts of Marvdasht city, including: Shiraz Refinery and petrochemical, Abbaric industrial town, Sina and Fars chemical industries, Pars oil companies, Marvdasht wastewater treatment plant, food-processing factories and etc. An interpolation technique, ordinary Inverse Distance Weighted (IDW), was used to obtain the spatial distribution of groundwater quality.

2. Materials and methods

2.1. Study Area

Marvdasht, Kharameh and Zarghan plains are located about 45km northeast of the Shiraz city in the Shiraz–Esfahan way between X=1206712-1312999 and Y=3263231-3395448 in UTM scale. Main rivers in the study area are Kor and Sivand, they pass through the region and drain into Bakhtegan Lake. Based on the geographical location the study area is divided into three Marvdasht, Kharameh and Zarghan plains. Marvdasht plain consists of four plains: Dashtak-Doroodzan, Maiyn-Bidgol, Dashtbal-Lanetavosi and Marvdasht–Korbal(figure 1).

Average annual rainfall in the study area is 300 mm, which mainly takes place between November and May. Thus the climate is classified as semi-arid climate type. Mean annual maximum and minimum temperatures are 42°C and 3°C, respectively. Temperature can rise in the summer to 49°C. This situation of dryness provokes the loss of water resource, especially during the last decade because the renewal of this resource is very weak.

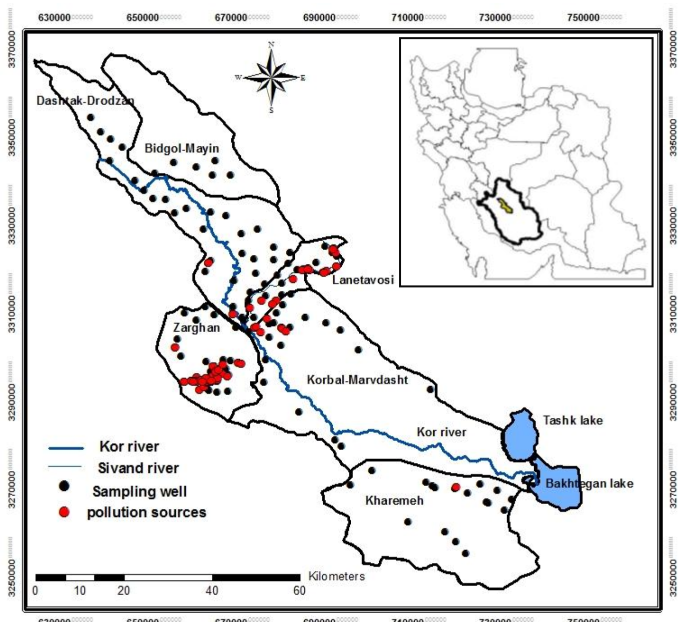

Fig. 1. The location of study area, sampling well and pollution sources.

2.2. Geology

The geologic formations surrounding the study area comprise Sarvak formation(about 9% of the total study area), Tarbour formation(about 6.8%), Dariyan - Fahliyan formation (about 6.3%), Bangestan formation (about 4.1%), Asmari-Jahrom formation (about 3.1%), Kazhdumi Formation (about 2.7%), Bakhtiyari formation (about 1.1%), Sachon formation (about 1%), Sormeh formation (about 0.9%), Razak formation (about 0.7%), Aghajari formation (about 0.6%), Gurpi formation (about 0.3%), Gadvan formation (about 0.2%) and Hormuz salt dome (about 0.18%). Quaternary alluvium with a surface area of 2741.7km2 is covered 62.9% of total study area. Alluvial sediments are consisting of sand, silt, clay coarse sediments, in some cases, with the rubble of coarse sand.

2.3. Sample collection

For the assessment of groundwater quality 120 water samples were collected during spring and fall (June-2012 and December-2013). Sampling points were selected according to the following criteria: accessibility of well for sampling in different seasons and in the difficult weather conditions, Absence of random pollution or contamination caused by unknown factors in the sampling place and according to the foci of contamination such as industrial and places that are entering wastewater into the study area .The samples were collected in polyethylene bottles (1.5 liters capacity) which had been thoroughly washed and filled with distilled water, and then taken to the sampling site. The bottles were emptied and rinsed several times with the water to be collected. In order to establish quality parameters of nitrate, nitrite, and phosphate, dark glass containers were used. The samples were kept at 4°C prior to analysis. Electrical conductivity (EC) and pH were measured in situ at each sampling point. Chemical analyses were carried out in the hydrochemistry Zagrous Laboratory in Shiraz. The Winkler's method was followed for the analysis of the DO and BOD. Nitrate was determined by colorimetric procedure (APHA 1989). The fecal coliform population was analyzed by MPN/100ml method, by growing on M-FC medium at temperature 44.5° ± 1°C and counted after 48 hrs. The samples were analyzed using standard procedure (APHA) [18, 19].

2.4. Calculation of WQI

There are four steps for computing WQI. In the first step, each of the 8 parameters (pH, dissolved oxygen, BOD (biochemical oxygen demand), Fecal coliform, temperature, total phosphate, nitrates and total solids) has been assigned a weight (W) according to its relative importance in the overall quality of water for drinking purposes (Table 1).

Table1
Weighting Factor of parameters.

Parameter	Weighting Factor
pH	0.12
Change in temp	0.11
DO	0.18
BOD	0.12
Turbidity	0.09
Total Phosphorus	0.11
Nitrate Nitrogen	0.10
E. coli*	0.17

Second, the calculation of the quality is rating for each of the water quality parameters. Third, the summation of these sub-indices in the overall index, forth, Classification criteria standards based on NSF- WQI(Table 2,3).

Wi of each parameter is obtained depending upon its weightage, by adopting the following formula

$WQI = (\Sigma q_i W_i) / (\Sigma W_i)$

$Q_i = 100(V_i/S_i)$

$W_i = K/S_i$

Where

W_i: the unit weightage

Q_i = quality rating for the ith water quality parameters (i=1, 2, 3,….N)

V_i = the measured value of the ith parameter at a given sampling location

S_i = the standard permissible value for the ith parameter

K= the constant of proportionality

It is well known that the more harmful a given pollutant is the smaller its permissible value for the standard recommended for drinking water. So the weights for various water quality parameters are assumed to be inversely proportional to the recommended standards for the corresponding parameters.

According to this Water Quality Index, the maximum permissible value is 100. Values greater than 100 indicate pollution and are unfit for human consumption.

Table 2
Classification criteria standards based on NSF- WQI.

Range	Quality
90-100	Excellent
70-90	Good
50-70	Medium
25-50	Bad
0-25	Very bad

2.5. GIS analysis

The study is carried out with the help of topographic sheets and Arc GIS 9.3. The paper map of the study area has a 1:50,000 scale and was digitized to the UTM coordinate system by applying the on-screen digitizing method. GPS is used to map the location of each sampling well; and finally, the results of QWI were added to the concerned well. Spatial Analyst, was used to find out the spatio- temporal behavior of the groundwater quality by using a spatial interpolation technique through Inverse Distance Weighted (IDW)(ESRI, 2008). This contouring method has been used in the present study to delineate the locational distribution of water pollutants or constituents. This method uses a definition or a selected set of sample points for estimating the output grid cell value. It determines the cell values using a linear weighted combination of a set of sample points; and, it controls the significance of known points upon the interpolated values based upon their distance from the output point, generating thereby a surface grid as well as thematic isolines (Asadi et al. 2007).

Table 3

Water quality index in study area.

		Spring season		Fall season	
UTM X	**UTM Y**	**WQI**	**water quality rating**	**WQI**	**water quality rating**
694431	3268632	59.34	medium	63.84	Medium
699392	3271840	45.43	bad	48.84	bad
680397	3319017	68.38	medium	59.93	Medium
677995	3316275	66.05	medium	50.90	Medium
675133	3314344	66.93	medium	80.98	good
711609	3269199	53.70	medium	56.50	Medium
713014	3268378	63.39	medium	65.96	Medium
713766	3268110	43.33	bad	55.97	Medium
672977	3316688	69.98	medium	72.86	good
718187	3267832	52.69	medium	53.21	Medium
721133	3266822	47.05	bad	46.13	bad
668142	3315072	67.97	medium	66.00	Medium
671851	3312491	76.46	good	71.55	good
667905	3309150	80.48	good	82.30	good
707575	3260212	53.90	medium	49.41	bad
669925	3306635	78.27	good	65.45	Medium
716035	3257967	60.07	medium	64.80	Medium
672556	3320024	69.87	medium	62.97	Medium
669848	3321285	61.50	medium	62.20	Medium
718467	3255846	62.82	medium	72.61	good
720685	3253230	66.55	medium	63.39	Medium
677127	3319809	67.30	medium	64.07	Medium
680738	3321378	64.98	medium	62.73	Medium
723958	3268964	43.84	bad	50.16	Medium
729335	3263008	62.87	medium	65.48	Medium
731114	3265403	48.87	bad	45.26	bad
677134	3322619	56.98	medium	53.51	Medium
673431	3326637	62.36	medium	66.02	Medium
725399	3264829	54.58	medium	57.51	Medium
725776	3264668	55.30	medium	54.73	Medium
727772	3267489	55.93	medium	60.36	Medium
674779	3291985	48.43	bad	69.72	Medium
692402	3277461	73.77	good	71.87	good
669723	3325718	55.56	medium	61.26	Medium
690944	3278849	65.20	medium	64.52	Medium
654627	3330381	55.92	medium	74.69	good
682889	3285235	52.11	medium	49.23	bad

Table 3
Water quality index in study area.

		Spring season		Fall season	
UTM X	**UTM Y**	**WQI**	**water quality rating**	**WQI**	**water quality rating**
	3337679	72.30	good	75.11	good
679128	3309480	71.70	good	67.57	Medium
652624	3333377	67.75	medium	64.84	Medium
678935	3311883	56.43	medium	74.44	good
681046	3312004	66.80	medium	66.84	Medium
649720	3333680	54.48	medium	51.20	Medium
684265	3306628	70.02	good	49.56	bad
688952	3305387	49.57	bad	60.54	Medium
712740	3290294	54.72	medium	50.36	Medium
692126	3303802	67.20	medium	71.55	good
690461	3321425	71.98	good	71.20	good
647721	3335505	72.07	good	71.50	good
688701	3322744	65.26	medium	72.93	good
691335	3320590	71.39	good	68.43	Medium
650109	3339372	61.20	medium	63.23	Medium
686633	3319183	49.48	bad	63.93	Medium
682466	3317598	66.61	medium	67.27	Medium
655230	3301782	61.84	medium	64.57	Medium
684797	3317835	73.77	good	70.11	good
659428	3340815	64.57	medium	67.27	Medium
688143	3316896	58.70	medium	69.05	Medium
678937	3314477	63.71	medium	69.23	Medium
675171	3311546	63.82	medium	64.52	Medium
671393	3310604	58.25	medium	61.61	Medium
654490	3341856	59.85	medium	51.97	Medium
672507	3306636	56.25	medium	61.00	Medium
670425	3306062	53.93	medium	57.16	Medium
663787	3342293	50.25	medium	56.08	Medium
662779	3330600	52.00	medium	69.98	Medium
657359	3331366	66.52	medium	64.20	Medium
667360	3338981	57.82	medium	53.79	Medium
661120	3326679	52.20	medium	48.64	Medium
680768	3304460	78.54	good	80.57	good
677644	3307641	53.18	medium	57.43	Medium
663200	3339012	72.07	good	65.70	Medium
678738	3300412	69.15	medium	75.98	good
640033	3347150	67.75	medium	67.25	Medium
635696	3352064	57.74	medium	64.15	Medium
642692	3345312	68.30	medium	60.89	Medium
639972	3342336	52.69	medium	65.62	Medium
656765	3307793	54.49	medium	60.51	Medium
637797	3348870	66.39	medium	66.14	Medium
661654	3309072	52.85	medium	52.31	Medium

Table 3
Water quality index in study area.

		Spring season		Fall season	
UTM X	**UTM Y**	**WQI**	**water quality rating**	**WQI**	**water quality rating**
659490	3306143	62.86	medium	63.20	Medium
696380	3299426	58.64	medium	68.69	Medium
663638	3307370	57.70	medium	66.80	Medium
677200	3305552	62.05	medium	51.38	Medium
676179	3305190	75.77	good	80.20	good
676100	3302102	59.95	medium	54.57	Medium
668491	3304416	57.59	medium	44.67	bad
666204	3329886	58.18	medium	56.34	Medium
661607	3317168	58.25	medium	62.75	Medium
662233	3319004	72.39	good	73.84	good
662701	3319668	66.77	medium	64.50	Medium
669733	3296104	49.56	bad	49.39	bad
667196	3296915	56.11	medium	66.57	Medium
669651	3296307	74.09	good	61.46	Medium
675245	3297089	64.09	medium	78.00	good
671276	3303404	56.05	medium	60.96	Medium
665568	3297078	57.36	medium	61.81	Medium
666955	3293608	55.07	medium	56.84	Medium
661073	3291138	64.77	medium	70.00	Medium
664287	3292140	56.59	medium	69.93	Medium
666174	3295068	61.56	medium	50.44	Medium
664175	3289779	72.23	good	73.43	good
662202	3290239	67.64	medium	61.13	Medium
662376	3290193	66.36	medium	73.70	good
664083	3293854	60.63	medium	77.52	good
665475	3295969	46.71	bad	65.30	Medium
656830	3292024	68.27	medium	71.16	good
654851	3299980	71.64	good	70.80	good
655953	3297940	63.09	medium	63.32	Medium
661832	3296736	65.15	medium	62.38	Medium
663612	3295730	63.84	medium	65.11	Medium
661815	3291954	72.64	good	78.07	good
661869	3291091	77.79	good	75.52	good
661587	3292323	48.88	bad	55.33	Medium
663115	3292085	54.77	medium	74.63	good
664444	3295006	61.57	medium	66.57	Medium
664822	3293746	61.39	medium	57.05	Medium
662767	3292989	53.84	medium	64.18	Medium
666706	3290028	65.20	medium	64.52	Medium
662885	3294521	48.21	bad	46.41	bad

3. Results and discussion

Each of the 8 parameters: pH, dissolved oxygen, BOD (biochemical oxygen demand), Fecal coliform, temperature, total phosphate, nitrates and total solids have been considered as the important water parameters for classifications of ground water quality in the fall and spring seasons. The NSF WQI has been computed for 120 samples in the groundwater of three Marvdasht, Kharameh and Zarghan plains (table3).

3.1 Spring Season:

pH of water samples varied between 6.7 to 8.2. Total suspended Solids varied between 63 mg/l to 1650 mg/l. Dissolved Oxygen varied between 4 mg/l to 11 mg/l. Likewise BOD of water samples varied between 0.41 to 9.5 mg/l. NO3 of water samples varied between 2.2 to 218 mg/l and PO4 of water samples varied between 0.01 to 0.4 mg/l. The WQI for 120 samples ranges from 43.3 to 80.5, ten percent of them are between 25 to 50, so they are in bad categories and 73 percent of them are between 50 to 70 so they are in medium categories based on National Sanitation Foundation (NSF).

3.2. Fall season

pH of water samples varied between 6.8 to 8.5. Total suspended Solids varied between 70 mg/l to 1500 mg/l. Dissolved Oxygen varied between 3 mg/l to 9 mg/l. Likewise BOD of water samples varied between 0.25 to 2.25 mg/l. NO3 of water samples varied between 0.4 to 165 mg/l and PO4 of water samples varied between 0.01 to 0.18 mg/l. The WQI for 120 samples ranges from 44.7 to 82.3. In the fall season 7.5 percent of the samples are in bad categories and 70 percent of them are in medium categories based on National Sanitation Foundation (NSF).

The values of WQI showed the higher percent of bad category was found in the spring season as compared with a fall. It indicates the effective ionic leaching, over exploitation and anthropogenic activities such as discharge of effluents from industrial, agricultural and domestic uses. It indicates the impact of percolation, seepage and moving of water during winter and spring precipitation. In fall season, the ground water is stagnant and the source of contamination was only the natural source of rock-water interaction while anthropogenic activities are also contributing the pollution load on ground water quality during spring.

3.3. Spatial analyst of water quality index

The spatial distribution map of WQI in the fall and spring seasons, to find out the spatio- temporal behavior of the groundwater quality, are presented in figure 2.

Most of the ground water samples in both seasons were found in the range of medium category. In two seasons bad quality of drinking water are in the Dashtbal–Lanetavosi, Kharameh and Zarghan plains. The high value of WQI at these stations have been found to be mainly due to the higher values of nitrates, phosphates, fecal coliform, total suspended solids and biochemical oxygen in the groundwater because of accumulation of pollutants and industrial centers are in these Zarghan and Dashtbal–Lanetavosi plains. And about Kharameh plain in the north of the plain the concentration of sulfat and chloride in the groundwater is higher than WHO standard. Nearing the Bakhtegan Lake, existence of Gurpi and sachon formations and Hormoz salt dome are natural reasons for increasing chloride in Kharameh plain and in the places whit high groundwater level, evaporation is an effective factor on the chlorid concentration. The N03 ranges from 12 to 100 with an average value of 50.1 mg/lit. The maximum concentration of nitrates in all seasons, are higher than WHO standard (Samani et al. 2013). High Fecal coliform and high value of DO and total suspended solids can be because of sewage treatment effluent. Biochemical oxygen demand measures the amount of oxygen consumed by organic matter and microorganisms. Sources of organic material can be both natural and human. Human sources of organic material in the study area are wastewater treatment plants, food-processing factories, lawn fertilizers and grass clippings. These sources add organic matter to the groundwater and increase the biological oxygen demand as aerobic bacteria that decompose this organic matter consume the available dissolved oxygen. If the amount of organic matter is out of balance, some organisms may not get the oxygen that they need to survive. Only those that are pollution-tolerant will survive, diminishing the diverse and complex ecology of an ecosystem that once had an abundance of oxygen.

F

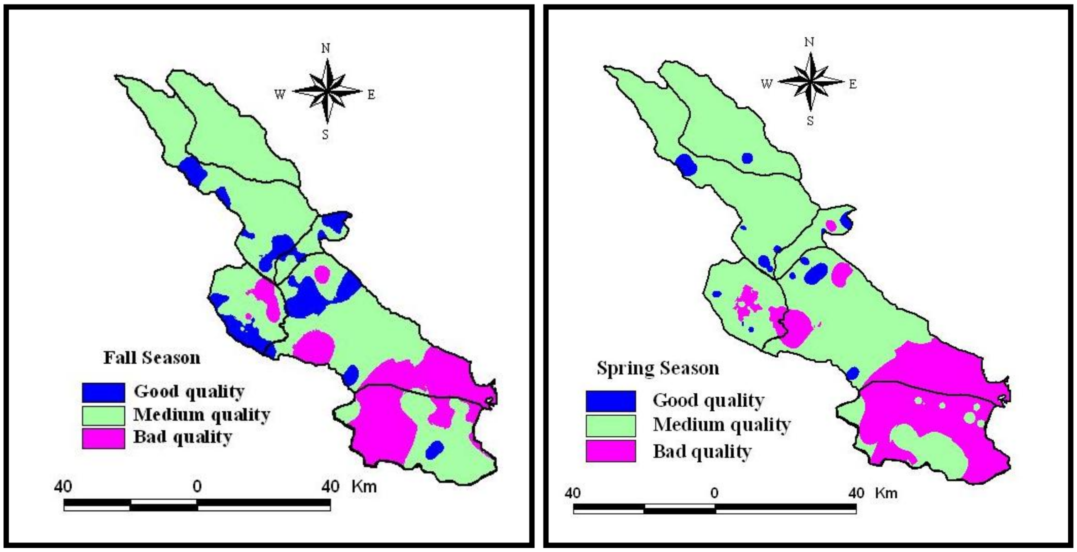

Fig. 2. The spatial distribution map of WQI in fall and spring seasons

4. Conclusions

The WQI for 120 samples in spring season ranges from 43.3 to 80.5 and in fall season ranges from 44.7 to 82.3. The WQI values in spring season in 10 percent of the samples are between 25 to 50, so they are in bad categories 73 percent of them are between 50 to 70, So they are in medium categories based on National Sanitation Foundation (NSF). In fall season 7.5 percent of the samples are in bad categories and 70 percent of them are in medium categories.

The best quality of the groundwater for drinking use, has observed in Bidgol-Mayin and Dashtak- Dorodzan plains. Accumulation of pollutants and industrial centers are in the Dashtbal–Lanetavosi, Kharameh and Zarghan plains and because of this in two season bad qualities for drinking water are in these plains. In the spring the higher percent of bad category as compared with fall season indicates the effective ionic leaching, over exploitation and anthropogenic activities by winter and spring precipitation and then they will penetrate and accumulate in groundwater.

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