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Survey and zoning of nitrate-contaminated groundwater in Iran

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Abstract

Groundwater quality management is important in arid and semi-arid regions, as in Iran. Nitrate (NO_3^-) is a common anion that contaminates groundwater. The present study determined the nitrate concentrations of aquifers in Iran. Data derived from studies in which the nitrate concentration had minimal spatial error at different periods were used for analysis. This included a total number of 2353 nitrate samples taken from wells located in all area of Iran. These were extracted from 82 articles and covered all of provinces. Furthermore, in every region, the average and maximum nitrate concentration were identified and kriging interpolation technique was used to obtain the spatial distribution of groundwater quality parameters by Arc view GIS 10.2 software. The results showed that the nitrate levels in samples from some regions were above the maximum standard level. Nitrate contamination in some regions had increased over the last 10 years. Genetic algorithms were applied to determine the relationship between average nitrate concentration and population density, consumption of drinking water and agricultural water use. The results show that water use in agricultural areas and the subsequent consumption of fertilizer are the main source of groundwater contamination with nitrate in Iran.

1. Introduction

Environmental problems in arid and semi-arid regions such as Iran are becoming the focus of increasing international attention[1].Groundwater resource assessment, management and sustainability are of utmost importance in arid and semiarid regions where water is commonly of critical economic and social significance. Groundwater is the major source of water supplies for drinking and for the domestic, industrial, and agricultural sectors in Iran[2]. Many municipal water supplies are derived solely from groundwater. Polluted groundwater is less visible, but more difficult to clean up, than pollution in rivers and lakes[3]. Nitrate(NO_3^-) is present naturally in water body[4] and common anion that contaminates groundwater[5]. The state of groundwater pollution has become critical as the population and agricultural development have increased in Iran. Pollution assessment is an important factor in policymaking in any country[6]. Pollution assessment is a basis for initiating protective measures for important groundwater resources. Identifying nitrogen and processes affecting nitrate pollution is essential to improving water quality[7]. Groundwater is a major source of drinking water in Iran, supplies more than 50% of public and accounts for almost all water supplies in rural households. Its contamination is one of the most serious problems in Iran[8]. Sources of nitrate pollution in groundwater can be either natural or human. Natural sources of pollution include nitrogen fixation in the soil (as a result of transformation of land) and influence the level of nitrates in the groundwater. Human sources include urban waste disposal, human waste through absorption wells, seepage from landfills, municipal wastewater, output of septic tanks and drain output caused by agricultural activity [9]. Natural transformation processes such as denitrification or nitrification also affect the nitrate concentration in groundwater. These are the most important sources of the increase in nitrates in the groundwater. Areas with a high level of groundwater and shallow aquifers are the first recipients of nitrate contamination [10]. Nitrate penetrates the soil and enters the groundwater. Because of its high water solubility and dispersion properties, it affects a wide span of area. Nitrates are mainly used as fertilizer in agriculture because of their high solubility and biodegradability [11]. For this reason, they are a major source of groundwater contamination. Nitrogen in different forms is a crucial input in agricultural production, but it puts environmental pressure on the groundwater, soil and air [12]. It is well-recognized that groundwater is a valuable natural resource and should be protected from deterioration and chemical pollution; however, agricultural practices, demographic growth and economic development mean that the amount of nitrogen released to the subsurface from fertilizers, sewage and animal waste has increased over the last decade[13].The allowable limit of nitrates in water has been set at 50mg/lby the Iranian National Institute of Standards [14], 50 mg/l by the World Health Organization [15]and 45 mg/l by the US Environmental Protection Agency [16].

Survey and zoning of groundwater contaminated by nitrates was beyond the scope of some studies. Bolgeret al.[17]zoned of underground water contaminated by nitrates in Australia using GIS to obtain the concentration of nitrates in different areas. They used reviews, books related to the issue, and local measures. Raheli-Namin et al. [18]as well zoned of groundwater-quality probability mapping and evaluated Cl, SO_4, EC and NO, and selected the best geostatistical method for mapping groundwater quality in the Ghara-su Basin of Golestan Province, Iran. Wang et al. [19] used the nitrate concentrationsin616 irrigation wells to predict the nitrate concentrations in northern China using GIS. Another example of using GIS for the benefit of environmental problem-solving is a study by Nas and Berktay [20] in which groundwater contamination by nitrates in the city of Konya, Turkeywas simulated using data from139 wells in 1998 and 156 wells in 2001. The National Atmospheric Deposition Program in the USA has developed maps showing the spatial pattern of nitrates derived from selected sampling sites for 2002. They developed a contour map using the nitrate measurements at the specific sampling locations to create contours and isolines through interpolation of data points[21]. Furthermore Ben Aakame et al. [22] assessed the physicochemical quality (such as nitrate concentration) of well's water in the region of Northwest of Morocco, which is used in the supply of drinking water for a large population.In another research in this region, long-term assessment of surface and ground waters quality in Tensift region during the period of 2003 to 2012 was investigated[[23].

Official reports state that water contamination in Iran is caused by agricultural drainage water (87%), sewage (11%), and industrial wastewater (2%).A significant percentage of contaminants in agricultural drainage water are from nutrients(fertilizers) and pesticides[24]. Although several studies on groundwater nitrate contamination have been carried out in Iran, none have investigated the overall nitrate concentrations in the groundwater resources. This research determined the range of contamination of groundwater resources with nitrates using GIS. It also presents a formula describing the relationship between nitrate concentration and the Iranian population density and water use by different sectors.

2. Methods and Materials

2.1. Study area

Iran is located in southwestern Asia at 24° to 40° N latitude and 44° to 64° E longitude (Figure 1). The climate is primarily very arid, arid or semi-arid, but some subtropical areas can be found along the Caspian coast [25].

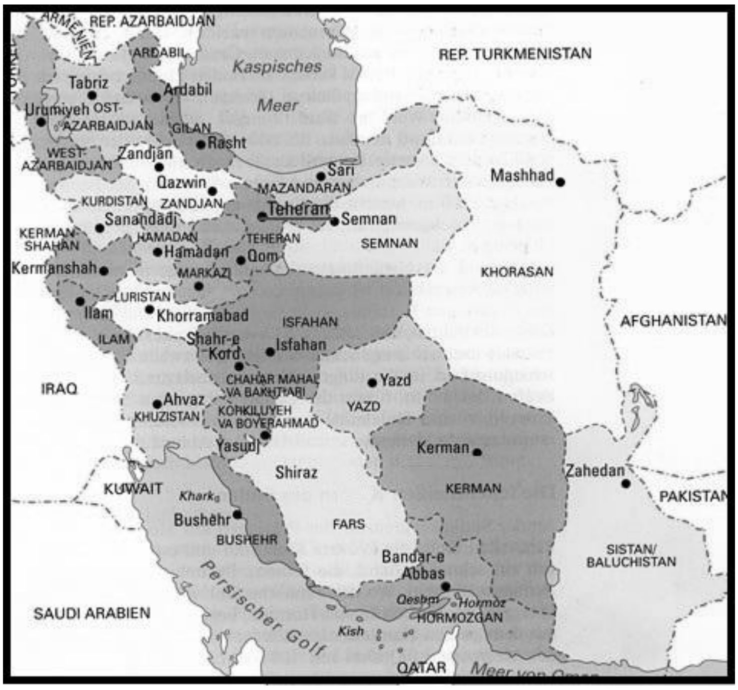

Figure 1: Study area

Iran is the eighteenth largest country in the world with a total area of 1,648,195 km^2. The capital and largest city is Tehran, which is located in north-central Iran. Other large cities are Mashhad, Karaj, Isfahan, and Tabriz. The total population is over 75 million, with over 12 million people living in Tehran alone[26].

2.2. Data collection

This research was carried out in two steps. The first was collection and entering the initial data (nitrate concentration) into the geographical information bank. The second was the preparation and analysis of maps. Data on the nitrate concentration in the groundwater were collected from papers published in international and national journals and those presented at conferences in the last ten years.

Google Scholar, Sciencedirect and Springer databases were searched using the keywords: nitrate concentration, nitrate pollution in groundwater, removal of nitrates, groundwater contaminated by nitrates, provincial capitals and major cities, especially in the important plains of Iran. Using initially, the total of 134 scientific articles survived; and then 82 regions were selected. The papers which had less credible or high error rates were removed from the database. National and official data such as population were collected from the Statistical Center of Iran [27].

2.3. Technical analysis

After collecting the data, the average and maximum concentration and their standard deviations (SD) were obtained and used to determine the average and maximum concentrations of nitrates in every region. The K-S test is the way to show whether the data is normal or not and this test was used in SPSS Statistics (ver. 19), for all regions. A total of 2353 wells in 82 regions of Iran were investigated. The regions were identified using Arc GIS software (ver. 10.2) and Google Earth. Genetic algorithms were applied using Genetic Algorithm (Gene X Pro Tools ver. 4.0) to discover the relationship between average nitrate concentration and population density, consumption of drinking water and agricultural water use.

3. Results and Discussion

3.1. Analysis of data

According to The K-S test shows in table 1, the average and maximum data both followed normal distributions. The regions and their UTM coordinates are listed in Table 2. The UTM coordinates are shown on the map of Iran in Figure 2. In analysis of average nitrate concentration in difference regions, only in 7 regions (about 8%) have nitrate concentrations above the standard limit, however, when the maximum nitrate concentration was considered, this increases to 40 regions (49%) (Figure 3).

Table 1: K –S Test

		mean	max
N		82	82
Normal Parameters[a,b]	Mean	24.9641	58.5920
	Std. Deviation	17.22212	50.00218
Most Extreme Differences	Absolute	.137	.156
	Positive	.137	.156
	Negative	-.098	-.156
Kolmogorov-Smirnov Z		1.237	1.415
Asymp. Sig. (2-tailed)		0.94	.063

a. Test distribution is Normal.

b. Calculated from data.

Table 2: Region's location

No	City or plain / Province (Code)	X	Y	Ref.	No	City or plain / Province (Code)	X	Y	Ref.
1	Ardebil / Ardebil (1)	260912.082	4236551.451	[29]	42	Kerman / Kerman (18)	507970.24	3350399.39	[28]
2	Tabriz / East Azarbayejan (2)	613950.14	4213872.02	[30]	43	Sirjan / Kerman (18)	371354.07	3259417.5	[28]
3	Marand / East Azarbayejan (2)	566627.06	4253457.23	[32]	44	Songhor / Kermanshah(19)	737651.41	3851587.4	[31]
4	Ahar / East Azarbayejan (2)	680455.36	4262181.11	[34]	45	Gorgan/ Golestan (20)	271722.86	4080798.07	[33]
5	Bonab / East Azarbayejan(2)	593450.97	4133165.73	[36]	46	Gharasoo/ Golestan (20)	236784.66	4079784.5	[35]
6	Maraghe/ East Azabayejan (2)	556478.25	4135176.21	[38]	47	Gilan plain / Gilan (21)	375429.1	4127091.07	[37]
7	Khoy / West Azarbayejan (3)	494708.5	4267245.92	[30]	48	Talesh / Gilan (21)	378541.2	4156347.2	[39]
8	Mahabad / West Azarbayejan (3)	564389.93	4068795.35	[41]	49	Shiraz / Fars (22)	653481.7	3273896.39	[40]
9	Karaj / Alborz (4)	494588.44	3966228.27	[43]	50	Darab / Fars (22)	261195.27	3183465.22	[42]
10	Hashtgerd / Alborz (4)	471557.01	3979815.06	[1]	51	Kamfirooz / Fars (22)	614650.52	3355300.2	[44]
11	Arak / Markazi (5)	379017.24	3773301.25	[46]	52	Pasargad / Fars (22)	709730.03	3343319.56	[45]
12	Koohroud / Markazi (5)	418894.72	3893608.86	[46]	53	Zarghan / Fars (22)	623541.65	3254781.25	[47]
13	Amanabad / Markazi (5)	412065.62	3742684.96	[46]	54	Marvdasht / Fars (22)	651245.85	3325478.21	[47]
14	Eilam / Eilam (6)	631191.43	3722552.41	[48]	55	Droudzan / Fars (22)	703164.7	3112549.7	[47]
15	Esfahan / Isfahan (7)	562919.76	3613244.75	[50]	56	Lorestan / Lorestan (23)	260915.25	3724910.93	[49]
16	Varzane / Isfahan (7)	655146.6	3588329.97	[52]	57	Romeshgan / Lorestan (23)	274156.32	3687351.51	[51]
17	Shahreza / Isfahan(7)	581470.63	3541670.94	[54]	58	Sari / Mazandaran(24)	684079	4047821.04	[53]
18	Kashan / Isfahan(7)	537998.54	3761593.66	[54]	59	Sari plain / Mazandaran(24)	490707.1	4051471.91	[55]
19	west of Esfahan / Isfahan(7)	523541.21	36125781.25	[57]	60	Mazandaran plain / Mazandaran(24)	495216.25	3945621.37	[56]
20	Ardestan / Isfahan(7)	536571.25	36814125.63	[59]	61	Nour / Mazandaran(24)	492574.12	4025891.35	[58]
21	Borazjan / Boushehr(8)	521120.4	3237569.37	[61]	62	Miandoroud / Mazandaran(24)	5087153.2	4059862.3	[60]
22	Tehran / Tehran(9)	538047.7	3949779.8	[63][64]	63	Hamedan / Hamedan(25)	272648.12	3853582.88	[62]
23	West Tehran/ Tehran(9)	511375.63	3952995.71	[43]	64	Toyserkan / Hamedan(25)	266333.35	3826036.85	[65]
24	Shahriar / Tehran(9)	501855.27	3939058.98	[67]	65	Sangestan / Hamedan(25)	279955.5	3851708.93	[66]
25	Shahrekord / Charmahal(10)	488270.71	3576883.95	[69],[70]	66	Nahavand / Hamedan(25)	257485.14	3786269.22	[68]
26	Lordegan / Charmahal(10)	483807.85	3486157.05	[72]	67	Alvand / Hamedan(25)	259871.32	3725782.58	[71]
27	Mashhad / Khorasan Razavi(11)	735332.82	4015988.88	[74], [75]	68	Razan / Hamedan(25)	263541.87	3845621.8	[73]
28	Khaf / Khorasan razavi(11)	715489.25	3987415.24	[77]	69	Yasooj / Kohkiloye(26)	556311.81	3393008.77	[76]
29	Neyshabour/ KhoraanRazavi(11)	694526.87	3712583.57	[79]	70	Gachsaran / Kohkiloye(26)	480122.8	3359486.21	[78]
30	Avan / Khouzestan(12)	247048.48	3553848.8	[47]	71	Bahabad / Yazd(27)	407657.37	3526705.55	[5]
31	Eize / Khouzestan(12)	393044.52	3521555.315	[81]	72	Yazd / Yazd(27)	267412.5	3447820.41	[80]
32	Dezfoul / Khouzestan(12)	257538.09	3586028.12	[83]	73	West Yazd / Yazd(27)	250122.76	3532089.17	[82]
33	Zanjan / Zanjan(13)	277226.42	4062758.25	[85]	74	Zahedan / SistanBaluchestan(28)	292925.47	3264769.46	[84]
34	Semnan / Semnan(14)	715662.61	3939895.14	[87]	75	Iranshahr / SistanBaluchestan(28)	270478.71	3011080.64	[86]
35	Majn / Semnan(14)	348983.9	3956992.62	[89]	76	Minab / Hormozhan(29)	507956.84	3002825.17	[88]
36	Shahrood / Semnan(14)	328562.2	3974215.95	[91]	77	Bandar lenge / Hormozhan(29)	286205.8	2942563.03	[90]
37	Ghazvin / Gazvin(15)	409959.76	4014889.32	[93]	78	Bandar Abbas / Hormozgan(29)	426575.04	3007437.1	[92]
38	Qom / Qom(16)	488570.57	3833172.97	[95]	79	Bojnord / north Khorasan(30)	529077.91	4147491.8	[94]
39	Qorve / Kordestan(17)	755308.41	3895266.6	[96]	80	Bojnord plain/ north Khorasan(30)	516894.09	4129908.06	[94]
40	Anar / Kerman(18)	335150.09	3416578.71	[98]	81	Birjand / south Khorasan(31)	708372.52	3638565.7	[97]
41	Jiroft / Kerman(18)	571973.9	3172441.37	[100]	82	Birjand plain/ south Khorasan(31)	712547.3	3538465.1	[99]

3.2. Graphical output

GIS is a powerful and promising tool for problem-solving in environmental issues. Most of environmental problems have obvious spatial dimensions and spatially-distributed models can interact with GIS. Interpolation technique was used to obtain the spatial distribution of groundwater quality parameters for zoning nitrate concentrations across Iran because kriging is known as the best unbiased linear estimator.

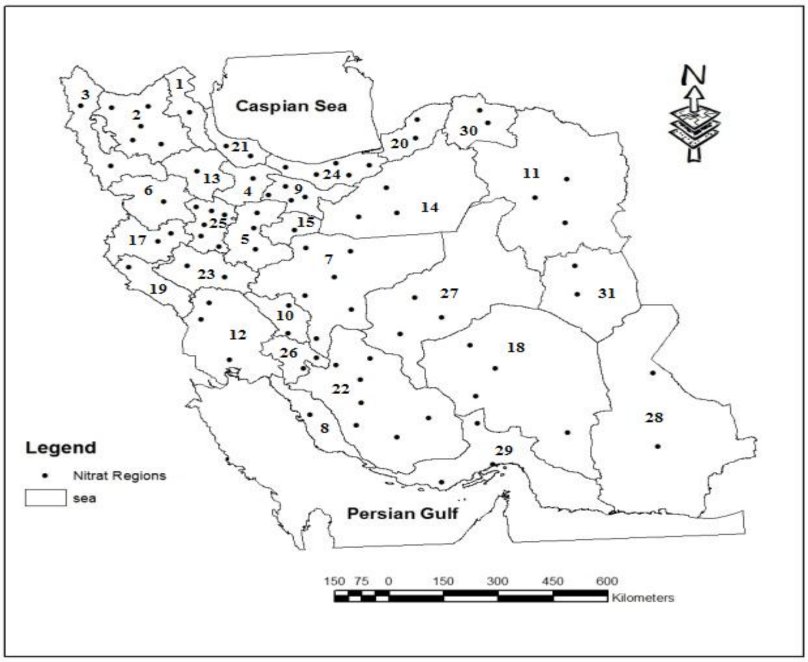

Figure 2: Location of 82 spatial regions.

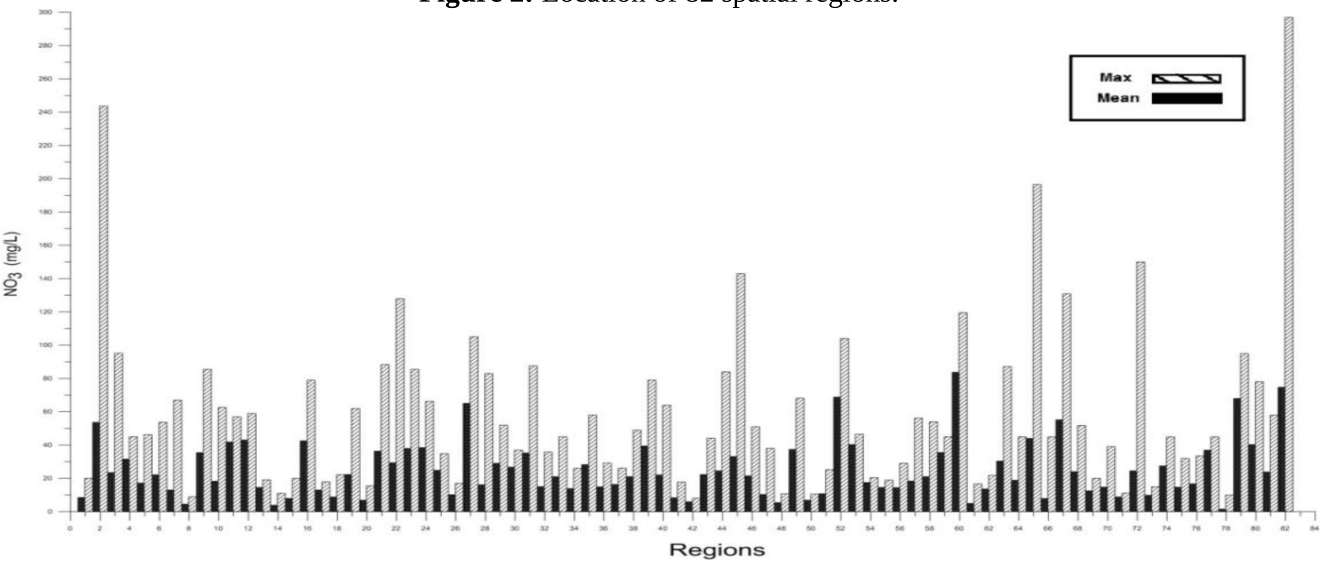

Figure 3: Mean and maximum concentrations of nitrate by region.

The output map for mean nitrate concentration (Figure 4 left) shows that high nitrate concentrations in groundwater were observed in the northeast (Khorasan province), northwest (Hamedan (25) and east Azerbaijan provinces (2)), southwest (Fars province (22)) and north (Mazandaran province (24)). The output map of maximum nitrate concentration shows that the highest nitrate concentrations were seen in the northeast (Golestan province (20)), northwest, north and center (Yazd province (27)).

The population density map (Figure 5) shows that the deserts located in the central plateau of Iran have the lowest population density. The highest population density is located in the north, northeast, northwest and west of Iran. Consequently, the highest nitrate concentrations were found in groundwater resource in the populated regions.

Official data on water consumption in agriculture and urban sectors was collected, analyzed and the patterns of water consumption were obtained using GIS kriging (Figure 6). A comparison of the agricultural water consumption and average nitrate concentration maps indicate that the regions contaminated by nitrates (average concentration of nitrate exceeds Iranian and international standards (45 mg/l of NO_3^-)) [14]. and the areas of high consumption of agricultural water coincide. Because a significant percentage of pesticide residue and chemical fertilizers remain in the agricultural drainage water, they ultimately enter the surface and groundwater sources.

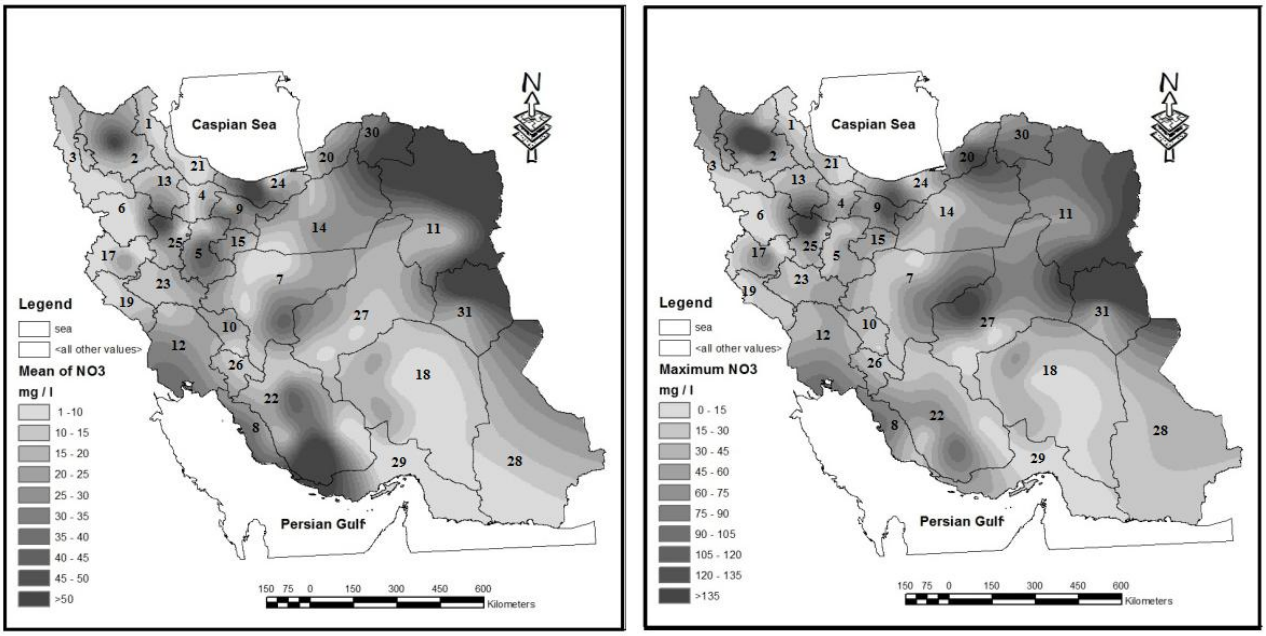

Figure 4: Spatial pattern of nitrates in Iran: (left) average; (right) maximum concentration.

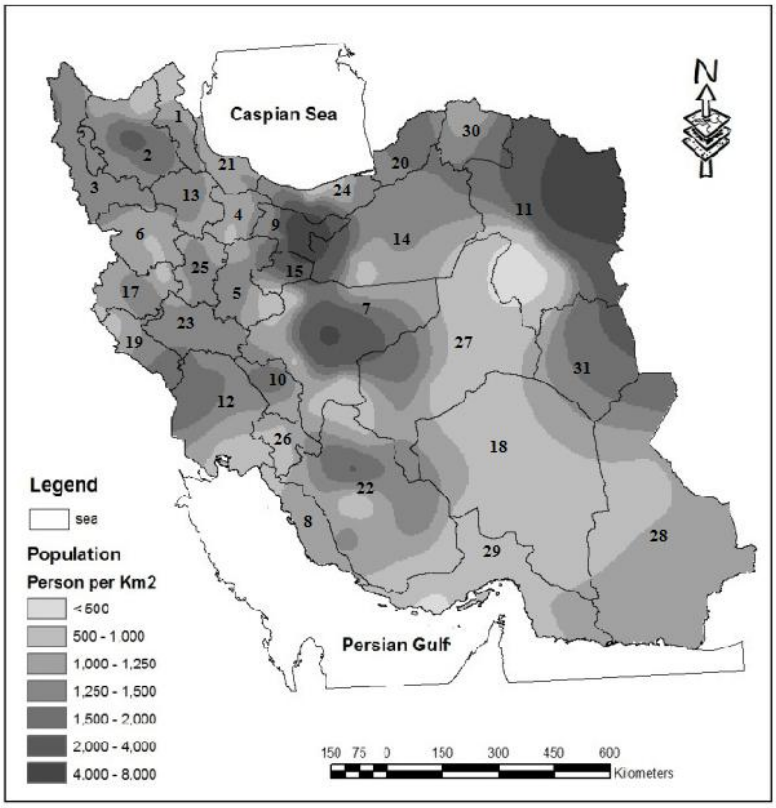

Figure 5: Population density of Iran.

The relationship between average nitrate concentration and population density, consumption of drinking water and agricultural water uses was obtained using Genetic Algorithm (Gene X Pro Tools ver. 4.0) as:

$$NO_3 = \left[\frac{\sin(-5.499 \times P \times D)}{\sin A^3}\right] + \left[\frac{2.024}{\sin D^3 - \sin A \times 2.505}\right] + \left[\log((A^2 - 2.603 \times D) \times (A - P))^2\right] \quad (1)$$

Where A is agricultural water use, D is drinking water, P is population and NO_3 is the mean concentration of nitrates. The R^2 was 0.76 and SD was 0.21. Agricultural water use (A) had the maximum weight in the equation as was confirmed by trial and error in Excel software. This result depends on water use in the agricultural sector and consumption of fertilizer in Iran. The obtained results of formula and experimental data followed the linear correlation as shown in Figure 7.

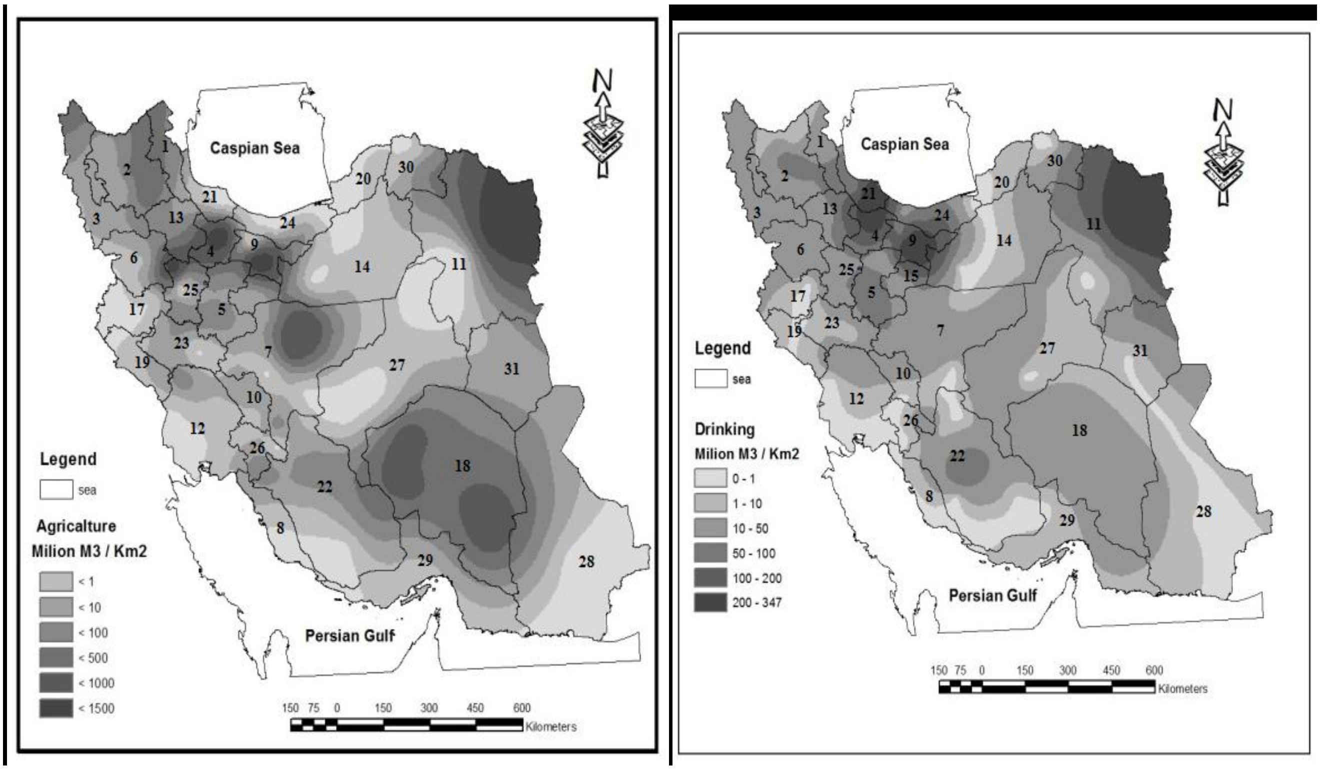

Figure 6: Zoning of water consumption: (left) agricultural water; (right) drinking water.

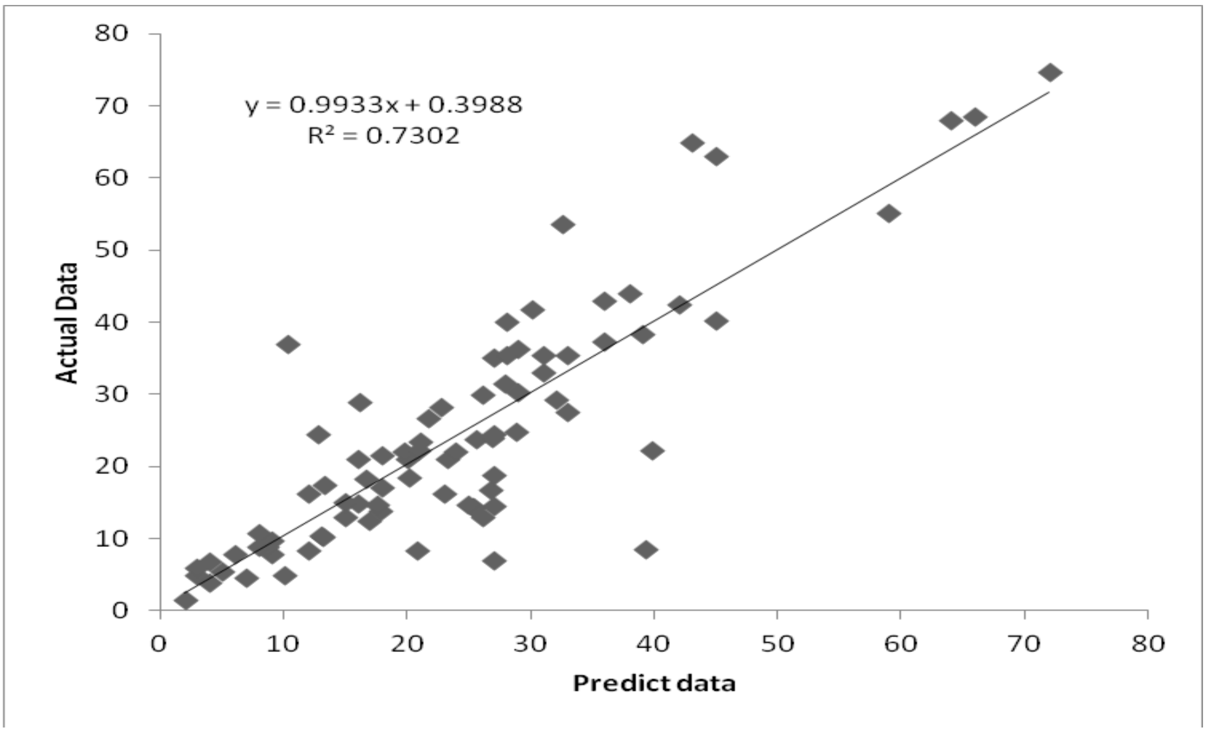

Figure 7: Correlation between results of formula and Experimental data

Conclusion

The goal of water-quality zoning is to determine the level of water quality in different zones, identify zones having similar water quality conditions and locating environmentally-critical regions. The GIS maps based on average and maximum concentrations of nitrate in different regions of Iran indicate that the nitrate concentration in samples from some regions were above international and national standards. In some regions, nitrate concentrations had increased in last 10 years. Zoning the nitrate concentrations across Iran by kriging showed a suitable correlation between population density and agricultural water use and drinking water consumption. The GA technique confirms that agricultural activity is the primary source of contamination of groundwater by nitrate in Iran. Agricultural research and education, new eco-biological farms and the reuse of treated wastewater could reduce nitrate groundwater contamination.

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