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An integrated approach for quality assessment of drinking water using GIS: A case study of Lower Dir

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Abstract

The present study was carried out to assess the quality of drinking water quality in district Lower Dir located in Khyber Pakhtunkhwa, northern Pakistan. A total of 33 water samples were collected from different locations of the study area. The parameters studied were pH, electrical conductivity, alkalinity, total hardness, calcium hardness, magnesium hardness, total solids, total dissolved solids, total suspended solids, sodium, chlorides, nitrites, sulphate and potassium. Thematic maps were prepared for all the studied parameters using ArcGIS 9.3 platform. The results were compared against the standard permissible limits suggested by World Health Organization (WHO) for drinking water. The results showed that the water parameters of the areas distant from the Panjkora river lie within the WHO suggested permissible limits, whereas the water quality of the riverine areas is alarming for some parameters. It is suggested to monitor water on regular basis to avoid its further deterioration and minimize its devastating impacts on the local society. The domestic wastes and agricultural run offs should be treated properly before disposing off. The wastes should be dumped to proper disposal sites instead of river banks.

Keywords: GIS; Water Quality; River Panjkora; Inverse Distance Weightage (IDW); Permissible limits.

1. Introduction

Water greatly influences all aspects of our ecosystem and is the primary requirement for human life sustenance on planet earth (Randhir, 2012). Clean drinking water is the basic need of human beings. Deprivation of water can kill an object much earlier than deprivation of food (Chattarjee, 1983). It has been estimated that without food, human beings can survive for approximately 20 days but start struggling for life in absence of water just after a day (Srivastava, 1995). It is estimated that the water quantity on earth is approximately 1.4 trillion cubic meters (Farid et al., 2012). Of the total quantity of water less than 1% is available for human use (Qadeer, 2004). More than 80% people utilize clean drinking water in Khyber Pakhtunkhwa (Yousaf et al., 2013).

Water is always been a valuable natural resource for different human activities but its pollution is a major concern (Prasad and Narayana, 2004). Being the most drinking fluid, water is a major source of transmitting diseases. Obtaining safe drinking water is the primary concern in most of the developing countries because many of the water sources are non-potable directly without treatment (Joyce et al., 1996). About 50% of all reported cases of illness and 40% of deaths in Pakistan are due to drinking of poor water quality (Chhatwal, 1990). According to a survey conducted by World Health Organization in 1975, 80% of all diseases in developing countries are water born (Tebbutt, 2002).

Drinking water quality has been debated throughout the world, firstly because of increasing utilization for human needs and secondly because of the ill effects of the increased industrial activities (Thurman et al., 1998; Leoni et al., 2005). Generally direct discharge of domestic wastes, industrial effluent, leakage from septic tanks and poor management of farm wastes are the major sources of water pollution (Huttly, 1999; Jain et al., 2005).

The fresh water sources in Pakistan are glaciers, rivers and lakes. Pakistan is suffering from water shortage due to reduced rains, melting of glacier, poor water storage and management initiatives. Pakistan is often top rated among the countries that might face the severe water shortage in near future. Water pollution in the flowing water is also a big concern. The resultant health risks include disease in almost all the body systems such as diarrheal diseases, respiratory disease, cancers, neurological disorders and cardiovascular disease etc. (Keusch et al., 2006; Chandra et al., 2006; Brown et al., 2006; Speizer et al., 2006; Simoes et al., 2006; Gaziano et al., 2006). Ground water is often recommended for drinking as the underground layers such as clay, sand and rocks act as natural filters and can minimize the hazardous pollutants (Kjellstrom et al., 2006). Presently groundwater is the most abundantly (>70 %) consumed valuable natural resource for various human activities (Prasad and Narayana, 2004).

GIS is a set of tools for collecting, analyzing and managing spatial information. It derives new information from existing datasets. The geoprocessing functions collect spatial information, apply analytical functions and generate results in form of interactive maps and tables (ESRI, 2008). The spatial analyst extension in ArcGIS provides several interpolation tools. Interpolation is a procedure used to analyze the values of the collected samples and estimate values for unsampled locations and is frequently used to assess the water quality at unknown locations (Saeed et al., 2012; Kayalvizhi and Sarkar, 2012; Somvanshi et al., 2012; Raikar and Sneha, 2012). It is based on the principle of spatial autocorrelation or spatial dependence, which measures degree of relationship or dependence between near and distant objects. Different interpolation approaches produce varying results. Inverse Distance Weightage (IDW) method of interpolation is based on spatial distance among the sample points. It is used when the set of points are dense enough to capture the extent of local surface variation needed for analysis. IDW determines cell values using a linear-weighted combination set of sampled points. The weight assigned is a function of the distance of an input point from the output cell location. The greater the distance, the less influence the cell has on the output value (Childs, 2004).

The aim of this study is to assess the drinking water quality of Lower Dir using ArcGIS.

Study area

The study area is comprised of Lower Dir (Fig. 1). The main drinking water sources of Lower Dir are tube wells, dug wells, streams and hand pumps. The elevation of Lower Dir ranges from 1200m to 2800m above sea level and experience an annual rain fall of 1468.8 mm and 253.7 mm during December and March respectively (Khan et al., 2010). River Panjkora originates from Kohistan, Upper Dir (Ullah et al., 2014). It flow southward dividing Upper Dir and Lower Dir into two halves. River Panjkora joins river Swat at Bosaq Pull.

2. Materials and methods

Water samples were collected using polythene bottles at 33 locations (Fig. 1). These bottles were first washed with tape water and were then rinsed using double deionized water. Samples were collected in equal numbers (11 samples) from tube wells, dug wells and hand pumps in the study area. Water sampling was carried out from March through May 2013. The conductivity and pH were determined on the site, whereas the samples were transported to laboratory of Department of Environmental Sciences, University of Peshawar and Water Testing laboratory of Carp hatchery and training center Sher Abad, Peshawar for further analysis.

Portable pH meter was used for measuring the pH of the water samples (Natner, UK). The conventional methods referred by American Public Health Association (APHA/AWWA, 1998) were followed for determining total alkalinity, total suspended solids (TSS), total dissolved solids (TDS), total hardness, magnesium hardness, calcium hardness, chlorides, and sulphate contents. Portable conductivity meter (Jenway, England) was used for finding conductivity. Sulphonilic method using UV Spectrophotometer (Hitachi-U-2000) was used for measuring Nitrite contents. For measuring sodium and potassium contents Flame Photometer (Jenway-FPF-7) was used. The colour, odour and taste of the water samples were detected organolaptically.

ArcGIS 9.3 software was used for mapping spatial distribution of groundwater quality based on parameters selected in this study. Water quality data as well as location data from Global positioning system (GPS) was combined into Microsoft Excel and was then imported into ArcGIS. All measured water quality parameters were imperiled to basic statistical analyses namely, minimum, maximum and mean. Superficial interpolation by IDW was applied to estimate the concentration of various physical and chemical parameters over the whole district. The surface of different parameters generated from IDW was classified from low to high.

Mean and standard deviation of the samples were calculated with Microsoft Excel 2010. Accuracy assessment was carried out by skipping different sampled locations for all the parameters and standard error was find out to evaluate the variation between measured and interpolated values. Standard deviation was calculated for the values of measured and interpolated values using Microsoft Excel 2010. Standard error was calculated using the given equation, Eq. 1 (SE_x is showing standard error, S is showing standard deviation while n is showing the number of observations of sample).

$$SE_{\bar{x}} = \frac{s}{\sqrt{n}} \quad \text{(Eq. 1)}$$

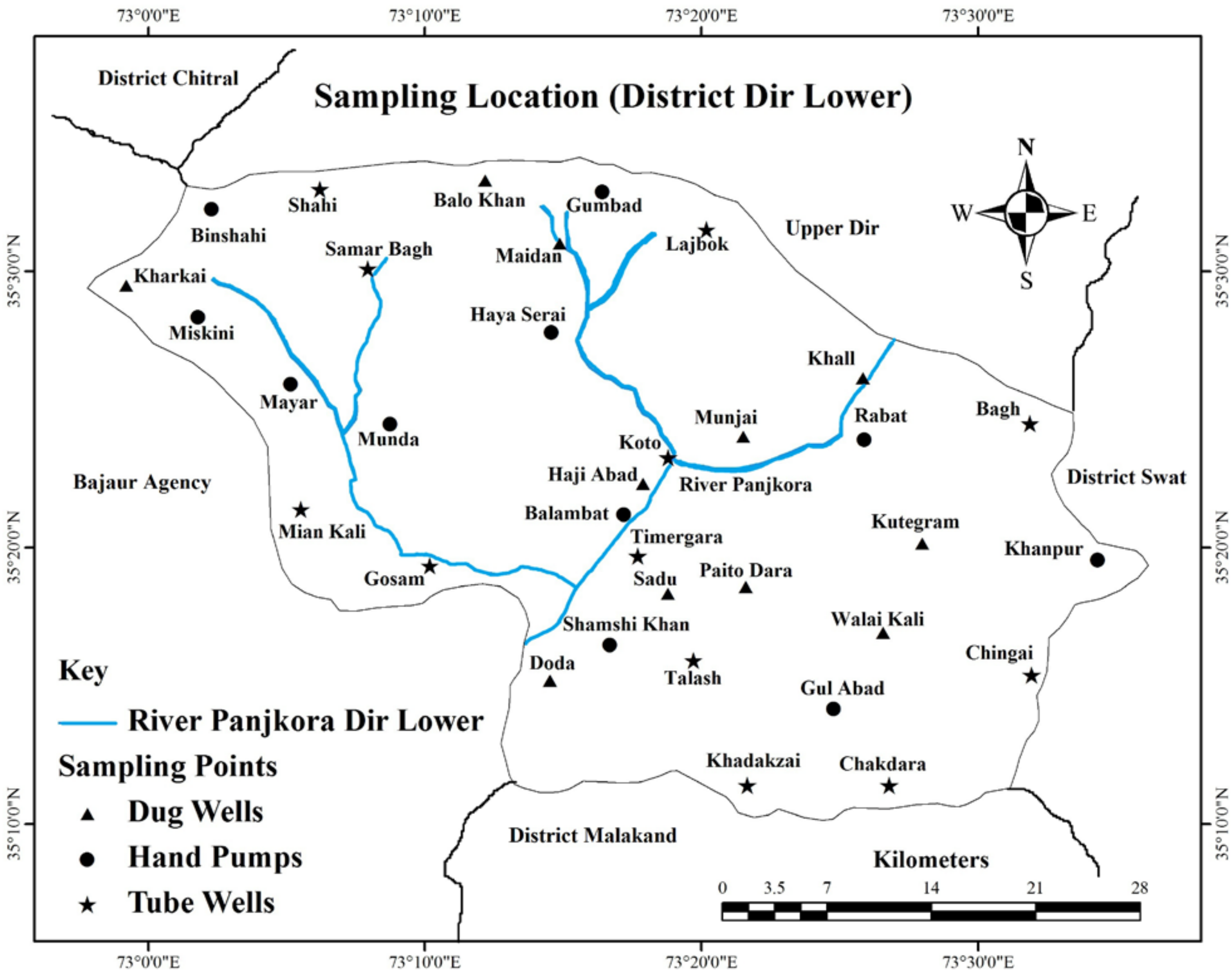

Fig. 1. Map of Lower Dir showing sampling sites and river Panjkora.

3. Results and discussion

The results of the observed physico-chemical parameters are showing variations within a specific range, some collections sites were having lower value for the studied parameters while some higher. The range (min-max), mean and standard deviation of physico-chemical parameters for tube well, dug well and hand pump samples along with the WHO suggested permissible limits are given in Table 1. The results showed that 87% of collected water samples were colorless, odourless and tasteless while 20% water samples were turbid.

The figures given (Fig 2. to Fig. 4.) are showing the spatial distribution of the studied parameters over the whole district. Table 3 is showing Pearson correlation coefficient matrix for the studied physico-chemical parameters.

The results showed that electrical conductivity was higher than the permissible limits suggested by WHO (1997, 2004, 2008 and 2011). The pH of the study area had no alarming situation and falls within the permissible limits suggested by world health organization (WHO, 2004; WHO, 2011). The mean TDS value fall within the WHO suggested limits (WHO, 2008). The TSS values for most of the samples were higher than the recommended limits may be due to discharge of untreated wastewater, infiltration and agricultural runoff. The TSS results showed that tube wells were having better quality followed by hand pumps. The TSS mean value for Dug wells was quite higher than the WHO suggested permissible limit. It may be due to the low aquifer of these wells. Maximum samples were falling within permissible limits for total hardness, calcium and magnesium hardness, yet some water samples were having higher magnesium values than WHO suggested limits. Alkalinity, chloride, sodium and potassium values for all sampling sites were lying within permissible limits while Nitrite value was higher than the WHO suggested limits for sixteen samples.

Accuracy assessment was carried out by skipping one point data from interpolation. Different parameters were then retrieved for that point from IDW based map. Subsequently the IDW estimated values is correlated with in situ measurements, and RMSD/RMSE was derived to assess the accuracy of the IDW. The results are given in Table 2. The results for SE showed that all the parameters are having less variation when compared for measured and interpolated values except total hardness (TH = 7.232) and electrical conductivity (EC=38.528), thus showing accuracy of the maps for the parameters studied. These two parameters (TH and EC) are varying because of their higher values than WHO suggested ones in most of the riverine areas, as coastal pollution of sea or river gives rise to certain parameters due to local contamination of fish or shellfish (Kjellstrom et al., 2006).

4. Conclusions

Our study showed that the parameters including pH, total suspended solids, total solids, electrical conductivity, nitrate, and Magnesium hardness were deviating from the standard limits. All the other parameters were within the WHO suggested permissible limits. The values of the samples, collected from the areas situated near river Panjkora, were higher for four parameters namely electrical conductivity, pH, total solids and total suspended solids than the suggested limits across all sampling points. This might be due to several factors, including 2010 flood, agricultural runoff, domestic wastes, and dumping of the waste materials into the river Panjkora.

Water resources of the areas distant from river Panjkora were quite safer and there was no alarming change. On account of more depth, water of tube wells was safer as compare to hand pumps and dug wells. While comparing the sampled sites, no drastic changes were recorded in the physico-Chemical parameters among the sampled sites except in electrical conductivity (Table 3). It is due to the similar prevailing climatic conditions during the study period (Singh et al., 2005) and less pollution due to less industrialization of the study area.

Table 1. Description of physico-chemical parameters of water samples of Lower Dir.

Parameters	Tube wells				Dug wells				Hand pumps				WHO *
	Min	Max	Mean	S.D	Min	Max	Mean	S.D	Min	Max	Mean	S.D	
Electrical conductivity µs/cm	680	2250	1203	655	717	3250	1402	990	710	3170	1176	732	1000*
pH	6.9	7.8	7.3	0.3	7.1	8.5	7.4	0.4	6.7	7.9	7.3	0.4	6.5-9.2
Total solids mg/L	890	975	902.7	37.04	910	1250	1024.1	116.19	880	1040	951.8	52.83	1000
Total dissolved solids mg/L	720	900	830.9	56.78	800	2010	1198.64	425.78	880	960	899.66	23.1	1000
Total suspended solids mg/L	1	15	5.636	4.632	5	35	14.82	11.74	3	20	7.182	5.793	5
Total hardness mg/L	260	425	338.6	63.09	420	615	517.5	77.37	475	590	524.09	44.99	500
Calcium hardness mg/L	150	240	164.5	46.93	210	340	271.4	41.24	250	340	285.91	32.31	250
Magnesium hardness mg/L	75	205	160	47.802	105	280	212.27	54.9	115	220	155.36	37.01	150
Total alkalinity mg/L	190	420	283.2	68.1	205	345	243.2	16.02	200	415	292.73	79.23	500
Chloride mg/L	60	210	151.91	47.13	160	220	182.27	16.02	88	170	114.45	29.15	250
Sulphate mg/L	60	305	194.1	95.5	170	290	234.54	43.44	200	312	246.82	40.82	250
Nitrate mg/L	0.5	1.8	0.827	0.398	0.5	1.8	0.936	0.51	0.5	2.0	0.736	0.524	0.5
Sodium mg/L	120	250	182.73	39.22	100	220	166.54	39.2	180	232	205.73	16.2	200
Potassium mg/L	1.9	21.3	7.718	6.293	3.6	13.7	7.073	3.631	4.6	20.3	10.82	6.493	75

Min = Minimum, Max = Maximum, S.D = Standard deviation, * = * Limits suggested by World Health Organization

Table 2. Accuracy and assessment of IDW based maps created for spatial distribution.

S.No	Location	Parameter	M. V	I. V	S. D	S. E
1	Koto	Electrical conductivity	735	1048	221.32	38.528
2	Timergara	pH	7.8	7.525	0.194	0.0338
3	Chakdara	Total solids	895	932.5	26.516	4.616
4	Samar Bagh	Total dissolved solids	870	910	28.284	4.923
5	Talash	Total suspended solids	4	4.25	0.1768	0.031
6	Khall	Total hardness	600	541.25	41.542	7.232
7	Munjai	Calcium hardness	310	290	14.142	2.462
8	Sadu	Magnesium hardness	190	175	10.606	1.846
9	Maidan	Total alkalinity	220	243.75	16.794	2.923
10	Haji Abad	Chloride	180	137.5	30.052	5.231
11	Munda	Sulphate	200	190	7.071	1.231
12	Balambat	Nitrate	2	1.425	0.406	0.071
13	Rabat	Sodium	232	208	16.971	2.954
14	Haya Serai	Potassium	6.3	4.475	1.290	0.225

M.V = Measured value, I.V= Interpolated Value, S.D= Standard Deviation, S.E= Standard Error

5. Recommendations

To conserve and maintain the water quality, all those anthropogenic activities that cause water pollution should be controlled. Regular assessment of water quality and mass awareness programs regarding the major issue of water scarcity, water pollution and preserving water quality should be organized to educated local masses to cope with the current scenario. Furthermore installation of water filters and replacement of old pipes will greatly help to control waterborne diseases. Treatment of the water wastes from houses and agricultural run offs should also be carried out before entering into the river and other water bodies.

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Table 3. Correlation coefficient matrix of the studied physico-chemical parameters of the water at Lower Dir.

	EC	**pH**	**TS**	**TDS**	**TSS**	**T.H**	**Ca.H**	**Mg.H**	**T.A**	**Cl_2**	**SO_4**	**NO_2**	**Na**	**K**
EC	1													
pH	**0.797**	1												
TS	**0.692**	**0.657**	1											
TDS	**0.577**	0.483	**0.81**	1										
TSS	**0.797**	**0.578**	**0.787**	**0.829**	1									
TH	**0.644**	0.283	**0.6**	**0.541**	**0.512**	1								
Ca.H	0.247	0.284	**0.596**	0.441	0.477	**0.825**	1							
Mg.H	0.31	0.35	**0.597**	**0.608**	**0.697**	0.489	0.346	1						
T.A	0.318	-0.09	-0.052	-0.11	0.022	-0.06	-0.07	0.002	1					
Cl_2	0.016	0.06	0.159	0.344	0.255	0.044	-0.23	**0.586**	0.083	1				
SO_4	-0.096	0.396	0.458	0.347	**0.5**	0.444	**0.59**	0.41	0.038	0.025	1			
NO_2	0.341	**0.627**	**0.605**	**0.546**	**0.74**	0.318	0.249	**0.574**	0.03	0.178	0.476	1		
Na	**0.723**	0.225	0.196	0.197	0.217	0.267	0.196	0.201	0.208	0.033	0.497	0.385	1	
K	0.221	-0.48	-0.16	-0.15	-0.29	0.139	-0.09	0.077	0.444	0.261	-0.225	-0.36	0.097	1

Bold r-Values >0.500 are significant at $p < 0.05$.

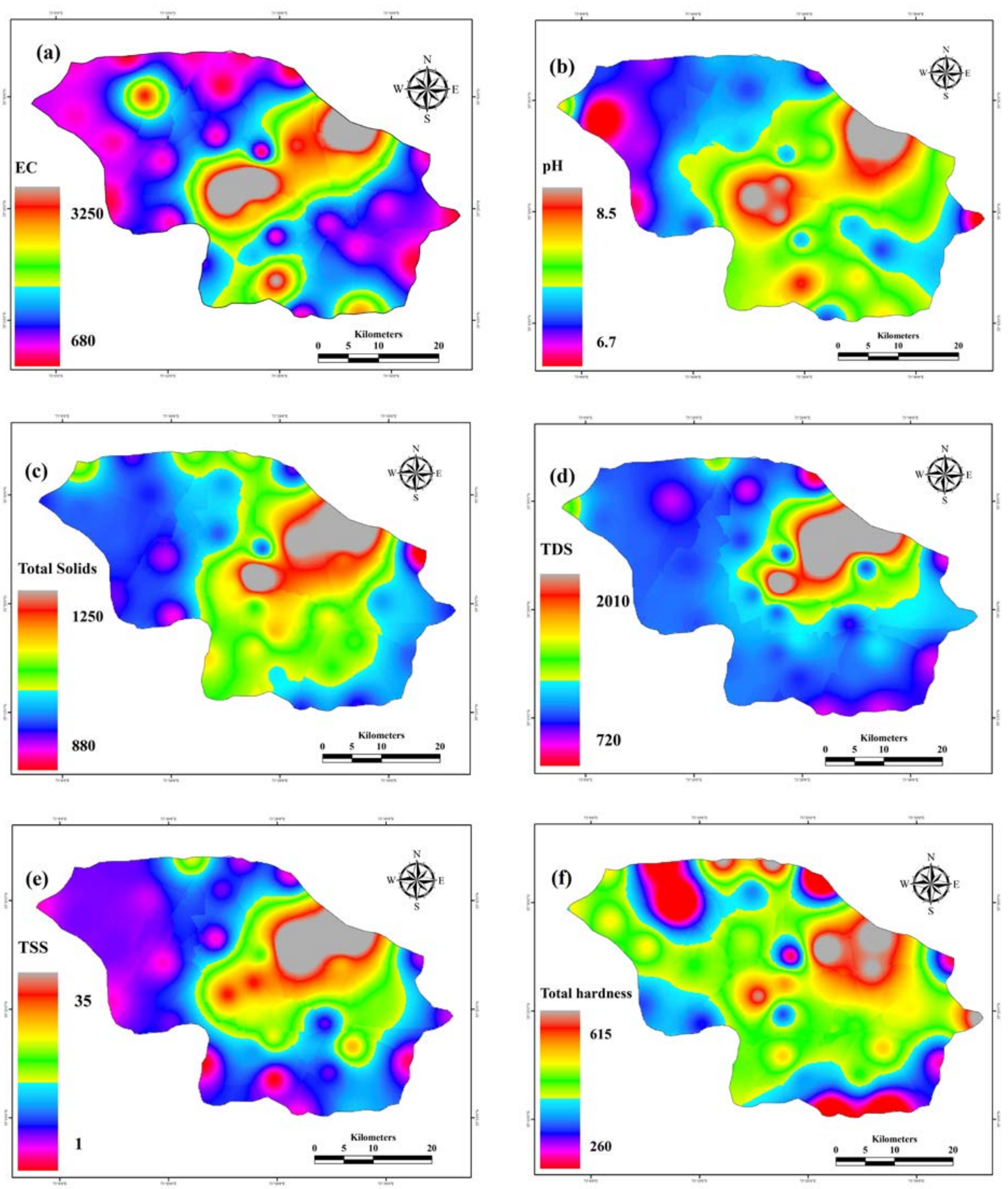

Fig. 2. IDW based distribution. (a) electrical conductivity (b) pH (c) Total solids (d) Total dissolved solid (e) Total suspended solids (f) Total hardness.

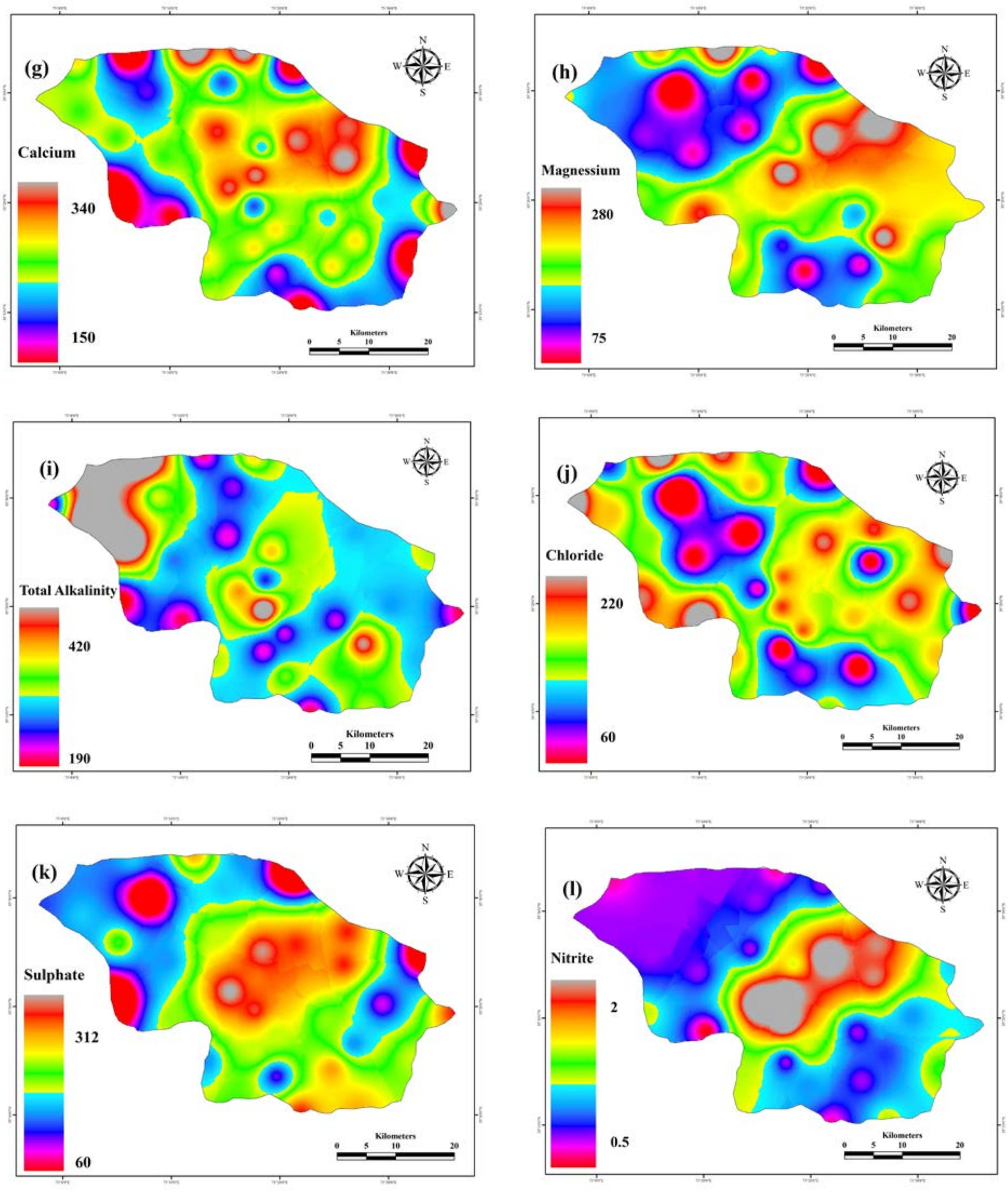

Fig. 3. IDW based distribution. (g) Calcium (h) Magnesium (i) Total alkalinity (j) Chloride (k) Sulphate (l) Nitrate

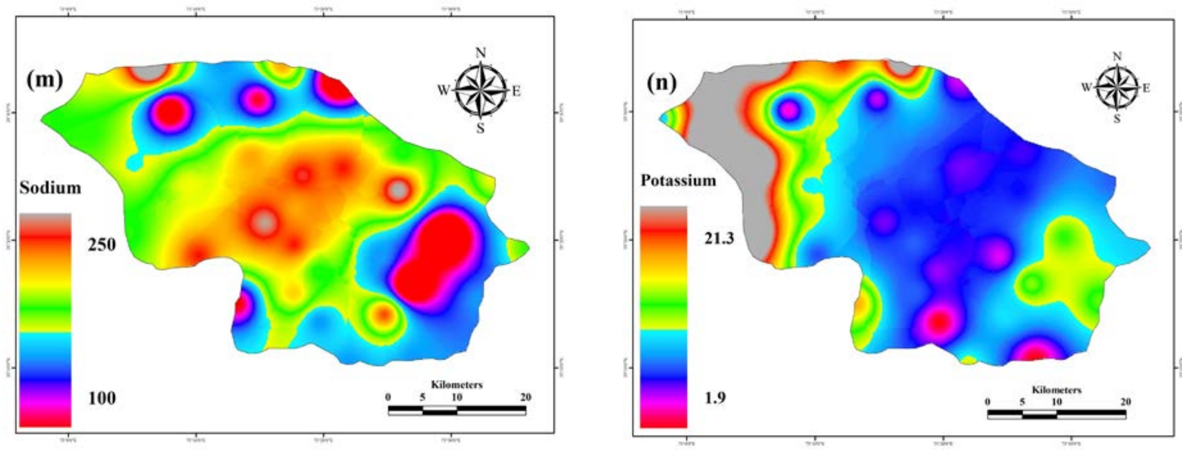

Fig. 4. IDW based distribution. (m) Sodium (n) Potassium

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