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Appraisal of Drinking Water Quality in Lahore Residence, Pakistan

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Abstract. A comprehensive study for the spatial distribution of drinking water quality had been conducted for residential area of Lahore, Pakistan. The study had made use of the geographic information system (GIS) for geographical representation and spatial analysis of groundwater quality. Physicochemical parameters including electric conductivity, pH, TDS, Cl, Mg, Ca, alkalinity and bicarbonates from 73 of the water samples had been included in the analysis. Water quality data had been geo-referenced followed by its interpolation using inverse distance weighted (IDW) for each of the parameters. Very high alkalinity and bicarbonates values were observed in most parts of the area. For the comprehensive view, water quality index map had been prepared using weighted overlay analysis (WOA). The water quality index map was classified into five zones of excellent, good, poor, very poor and unfit for drinking as per WHO standards of drinking water. 21% region had excellent quality of the underground water and 50% was found good for drinking. Poor quality of water was found in southeastern part, covering 27% of the study area. Only 2% of the area was found under the very poor and unfit water quality conditions for drinking.

Keywords: drinking water quality, groundwater, water quality index, GIS, weighted overlay

Introduction

Groundwater is one of the most important resources available to humanity for their social and economic growth (Nwanwoala *et al*., 2012; Christophoridis *et al*., 2011). It is the most suitable form of fresh water as it contains almost balanced salt concentration, which is good for human use. Despite the fact that earth has a lot of water, only 2.5% of the earth's total water is fresh and only one-third of this small amount of fresh water is available for human use (PCRWR, 2007; Hassan *et al*., 2005). Recent developments in living standard, agriculture and industrialisation have greatly increased the demand of the groundwater (Mahmood *et al*., 2013). In arid and semi-arid regions the total water withdrawn for human usage has almost tripled from 1382 km^3/year in 1950 to 3973 km^3/year in 2000 and the worldwide projection has predicted that human water consumption would reach to 5235 km^3/year by 2025 (Clarke and King, 2004).

Any addition of undesirable substances to groundwater by human or natural activities is called contamination. Once a local aquifer is contaminated, it is almost impossible to clean it up as the cost of its purification is usually very high. Owing to its unique characteristics such as hydrogen bonding and polarity, water has ability to dissolve many components which leads to its contamination. The quality of groundwater is equally important as its quantity (Mahmood *et al*., 2013; Majandang and Sarapirome, 2013; Rehman, 2008), therefore, environmental protection policies give highest priority to its monitoring (Mahmood *et al*., 2013). Monitoring of water resources for its quality is necessary to avoid any outbreak of water born diseases (Ullah *et al*., 2013). Groundwater always moves by the force of gravity from recharge areas to the areas of its discharging. Its movement in most areas is slow as few feet per year, but in more permeable areas such as channels in limestone, movement could be as much as several feet per day.

Listed parameters by researchers that can alter groundwater contamination are pH, electric conductivity (EC), turbidity, salinity, total dissolved solids (TDS), alkalinity, bicarbonates, chloride, calcium, oil, grease and heavy metals (Brindha *et al*., 2014; Singh *et al*., 2014; Verma *et al*., 2013; Usali and Ismail, 2010). Groundwater is monitored in many parts of the world, mainly by measuring groundwater levels, groundwater recharge, and its contamination level. The results of these measurements are often interpolated and combined with other information to produce various groundwater thematic maps at local and regional scales. Over the time, many countries and states have developed groundwater mapping programmes for their entire territory or

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for areas in which their most important groundwater resources are located. World-wide Hydro-geological Mapping and Assessment Programme (WHYMAP) thus bring together the huge efforts in hydro-geological mapping at regional, national and continental levels.

It is widely reported that degradation of groundwater is arising due to overexploitation of groundwater in Pakistan, India and other developing countries (Moench and Dixit, 2004). Currently fresh water stress in Pakistan has reached over 40% and the situation is going to get worse by the year 2025, just like other countries of the world. Lashari *et al*. (2007) estimated that about 60-70% population of Pakistan depends directly or indirectly on groundwater for its livelihood.

The mega city Lahore, Pakistan is facing serious challenges for the provision of safe and sufficient drinking water and the situation is predicted to be getting more severe in coming days.

The present study therefore, was conducted for spatial analysis of groundwater quality in this area.

Materials and Methods

Study area. The mega city of Lahore with an area of 17,000 hectares is provincial capital of Punjab and second largest city of Pakistan. It lies between Bari Doab and Rechna Doab, and is located along bank of river Ravi. It is located between 31°15´-31°45´N and 74°01´and 74°39´E with an average height of 217 m above the mean sea level (Fig. 1). It is delimited on the north with the Sheikhupura district, in the east with Wagah boarder and in the south with Kasur district. The river Ravi flows on the northern and western out skirts of the city (Mahmood *et al*., 2013).

The climate of the study area is hot and semi-arid with long and intensely hot summers, dry and warm winters, monsoon and mud storms. The average rainfall is about 575 mm/year but it can vary in the range of 300-1200 mm providing 40% recharge to the groundwater.

The area is underlain by 300 m thick bed of alluvial deposits, as investigated by WASID during the period of 1961-62 (WAPDA, 1980). The major recharge source for local aquifer is river Ravi, that flows now occasionally and BRBD Canal on the aquifer behaves as a single contiguous, unconfined aquifer. Underlying strata wise the area consisted predominantly of sand, silt and thin lenses of clay.

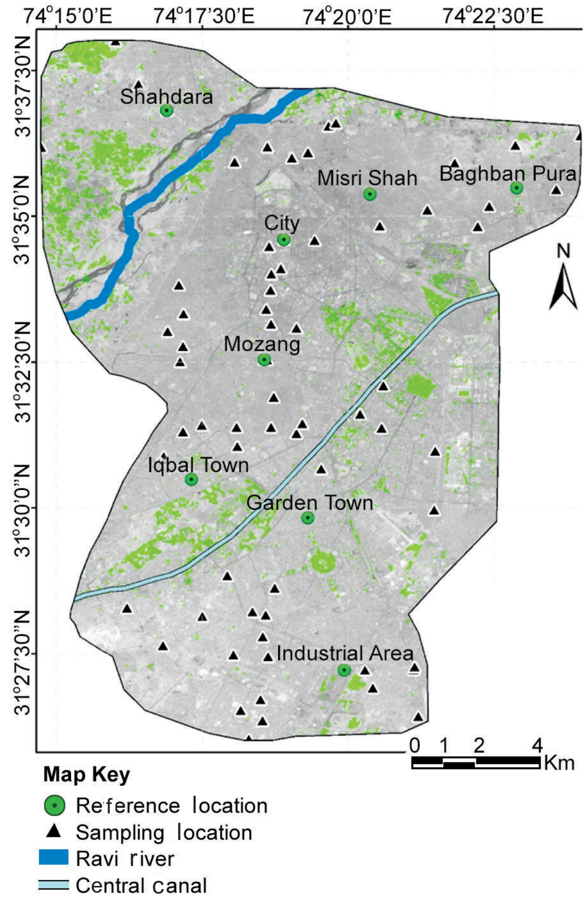

Fig. 1. Study area.

Provision of water supply to most of the study area is responsibility of Water and Sanitation Agency (WASA), Lahore. Water quality data for the year 2012 was acquired from WASA, Lahore, which periodically collects water samples from their installed tube wells in residential area of Lahore. They analysed collected water samples in their laboratory for 19 of the drinking water quality parameters. The analyses of the water samples carried out through standard methods for examination of water (APHA-AWWA-WPCF) as per WHO guildlines for drinking water (WHO, 2011). The analysed parameters include temperature, odor, colour, taste, pH, turbidity, TDS, conductivity, total hardness, Ca, Mg, alkalinity, Cl, NO_2, NO_3, CO_3, HCO_3 and *E. coli* (Table 1).

A total of 73 well seperated groundwater samples from residential area of the city had been chosen to carry out this work. Parameters considered for this study include pH, total dissolved solids (TDS), chloride (Cl), electrical conductivity (EC), bicarbonates (HCO_3), alkalinity (alk),

Table 1. Water quality data used in the study

No.	Location	Subdivision	pH	Alkalnity	TDS	EC	Ca	Mg	Cl	HCO_3
1	2-D-1 Green Town	Green Town	8.1	204	350.2	556	11.2	7.68	16	204
2	3-C-1 Township	Green Town	7.8	324	396.9	630	25.6	15.4	27	324
3	3-D-1 Green Town.	Green Town	8.1	202	385.5	612	11.2	10	17	202
4	5-D-1 Green Town	Green Town	7.8	366	687.9	1,092	38.4	27.8	32	366
5	5-D-2 Kir Kalan Village	Green Town	7.8	344	652.6	1,036	28.8	24.5	30	344
6	A3 Johar Town	Johar Town	7.8	424	720	1,143	32.8	29.7	24	424
7	A-Block Gulshan Ravi	Krishan Nagar	8.1	210	372.9	592	36	24.9	28	210
8	Abu Bakar Block.	Garden Town	8	370	517.8	822	38.4	27.3	35	370
9	Adda Crown Bus	Anarkali	8	242	618.6	982	33.6	30.7	46	242
10	Aibak Park Mozang	Mozang	7.8	296	849.8	1,349	72.8	48	10	296
11	Akbari Gate (New)	City	7.8	414	652.6	1,036	14.4	24.5	103	414
12	Alia Town	Baghban Pura	7.8	200	280.3	445	49.6	24.5	31	200
13	Aslam Iqbal Park	Mozang	8.1	246	392.4	623	32.8	18.7	45	246
14	Awa Pahari Queens Rd Mozang	Mozang	8.1	148	495.1	786	60	21.1	103	148
15	Awami Colony	Industrial Area	8	244	447.9	711	19.2	13.9	25	244
16	Aziz Colony Chatha Park	Farrukhabad	7.9	360	553.7	879	64.8	36.5	84	360
17	Bank Stop Main Fazal e Haq Co	Industrial Area	7.9	370	669	1,062	24	21.6	55	370
18	B-Block, Gulberg II	Gulberg	7.8	180	395	627	19.2	13.4	23	180
19	Cattle Park	Anarkali	7.8	252	293.7	625	60	36.5	49	252
20	C-Block, Faisal Town	Garden Town	8.1	302	380.5	612	25	18	15	302
21	Chah Motia Data Nagar	Data Nagar	7.8	216	249.4	396	49.6	19.7	39	216
22	China scheme	Misri Shah	7.9	188	248.8	395	24.8	16.3	15	188
23	Clifton Colony	Iqbal Town	8.1	190	299.8	476	19.2	10	20	190
24	D-Block, Faisal Town.	Garden Town	8	220	301	478	16.8	10.6	20	220
25	Dhobi Mandi	Anarkali	7.8	304	406.3	646	57.6	32.2	65	304
~~26~~	~~Dhoop Sari~~	~~Krishan Nagar~~	~~8~~	~~164~~	~~175.1~~	~~278~~	~~28.8~~	~~17.8~~	~~11~~	~~164~~
27	E-Block Johar Town	Johar Town	7.9	334	746.1	1,213	32.8	24.5	20	334
28	F-1 Block Johar Town	Johar Town	8.3	324	463	735	43.2	27.4	24	324
29	Faisal Park	Farrukhabad	7.8	200	202.2	321	35.2	19.7	28	200
30	Fareed Colony	Industrial Area	7.9	400	714.4	1,134	40.8	29.3	48	400
31	Fareed Kot	Anarkali	7.8	350	933.6	1,482	80	48	68	350
32	Farrukhabad	Farrukhabad	8.1	184	332.6	528	39.2	17.2	23	184
33	FC Block Gulberg II	Gulberg	8	160	282.2	448	16.8	15.8	19	160
34	Foot Ball Ground Gulshan Ravi	Krishan Nagar	8	170	176.4	280	32.8	15.4	17	170
35	G IV Block Johar Town	Johar Town	8.3	158	299.2	475	12.8	10	14	158
36	General Hospital	Industrial Area	8.2	282	479.4	761	21.6	11.5	24	282
37	Hanif Park Tonda Phatak	Data Nagar	8	122	190.8	303	20	10.8	15	122
38	Huma Block	Iqbal Town	7.8	180	261.4	415	24.6	13.4	34	180
39	Hussain Park	Data Nagar	8.2	164	223	354	40.8	18.9	15	164
40	Jahanzaib Block	Iqbal Town	7.8	160	245.7	390	25.6	11.5	13	160
41	Jinnah Park Sultan Pura	Misri Shah	8.2	186	395.6	628	48.8	20.6	67	186
42	Kamran Park	Farrukhabad	8.1	160	240	381	66	12	23	160
43	Kanchi Stop	Industrial Area	7.8	446	834.1	1,324	40	24.5	40	446
44	Kanji House Gujjar Pura	Misri Shah	7.8	162	332	527	26.4	15.8	14	162
45	Karmabad, Rehman Pura	Ichra	8	242	249.4	396	21.6	7.2	18	242
46	Khokhar Road # 3	Data Nagar	8.1	126	163.1	259	32.8	11.5	10	126
47	Lahori Gate	City	7.8	222	400.6	636	58.4	24.5	45	222
48	Madhulal Hussain	Baghban Pura	8.3	184	364.1	578	24.8	11.5	22	184
49	Makkah Colony (New)	Gulberg	7.8	284	492.6	782	27.2	19.7	30	284
50	Match Factory	Farrukhabad	8.1	246	369.8	587	51.2	19.6	13	246
51	Mehmood Booti Disposal	Baghban Pura	8.1	180	199	316	25.6	15.8	10	180
52	Mori Gate	City	7.9	186	243.8	387	192	19.7	18	186
53	Napier Road	Anarkali	7.8	346	824	1,308	60	21.1	130	346
54	Nargis Block	Iqbal Town	7.9	270	553.1	878	46.4	26.9	48	270
55	N-Block, Model Town Ext.	Garden Town	7.8	400	589	935	43.2	26.4	32	400
56	Neelum Block	Iqbal Town	7.8	234	518.4	823	35.2	20.6	59	234
57	Nisar Press Gulberg	Gulberg	7.8	462	817.1	1,297	45.6	34.1	55	462
58	Rasool Park	Ichra	8.3	126	422.7	671	47.2	22.1	105	126
59	Rehman Pura	Ichra	8	226	545.5	866	16.8	9.6	23	226
60	Rustam Park	Krishan Nagar	7.8	230	454.8	722	32	20.6	51	230
61	Saad di Mill	Baghban Pura	8.1	240	287.2	456	34.4	15.4	15	240
62	Saadi Park	Mozang	8.2	294	355.9	565	35.2	16.3	56	294
63	Sawami Nagar (Old)	Misri Shah	8.1	206	510.9	811	41.6	32.6	98	206
64	Shah di Khoi	Johar Town	7.8	382	481.9	765	48	12.9	22	382
65	Shah Kamal (New)	Ichra	8	184	521	827	17.6	11.4	18	184
66	Siddique Pura	Data Nagar	8	134	204.7	325	24.8	12.5	10	134
67	Surria Jabeen Park	Baghban Pura	7.8	202	477.5	758	44	23.5	34	202
68	Takia Lehri Shah	Ichra	7.8	234	600.3	953	40.8	20.6	58	234
69	Takia Mehmood Shah	Krishan Nagar	8.1	242	166.9	265	27.2	17.3	15	242
70	Timber Market	City	7.9	220	228.6	363	15.2	10.1	28	220
71	Usman Block	Garden Town	7.9	254	430.9	684	34.4	17.8	62	254
72	Wasan Pura	Misri Shah	8	168	252.6	401	28.8	18.7	20	168
73	Zafar Ali Rd Gulberg V	Gulberg	8	194	367.9	584	16	10.1	23	194

Magnesium (Mg) and Calcium (Ca). All this collected data is shown in Table 1 and their corresponding statistics are given in Table 2.

An overview of the used methodology is given in Fig. 2. The spatial reference to each of the sampled location had been measured using global position system (GPS). The used model of GPS for ground survey was GPSmap-76CSx receiver, having horizontal accuracy of ±3 m. All the quality data were then georeferenced using the location data in the form of a point shapefile

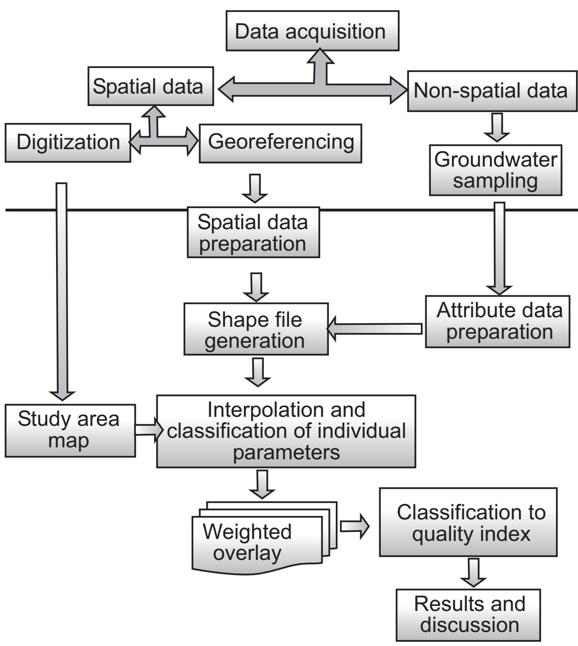

Fig. 2. Flow chart of methodology.

in ArcGIS 9.3. The point data was then interpolated to generate continuous rasters for each of the selected water quality parameters. The used technique of interpolation, Inverse Distance Weighted (IDW) belongs to deterministic family of interpolators as suggested by a number of previous studies (Bairu *et al*., 2012; Latha *et al*., 2012; Abulhakeem *et al*., 2011; Balakrishnan *et al*., 2011; Singh *et al*., 2011; Latha *et al*., 2010).

IDW is based on the fact that the nearby values are more related to each other than values that are far apart. In other words, for this spatial interpolation technique the influence of a known data point is inversely related to the distance from the unknown location, being estimated (Shepard, 1968). The mathematical expression of the inverse distance weighted is given as:

$$z_o = \frac{\sum_{i=1}^{s} z_i \frac{1}{d_i^k}}{\sum_{i=1}^{s} z_i \frac{1}{d_i^k}}$$

where:

z_o = estimated value at point-o; z_i = the value at known point-i; d_i = is the distance between point-i and point-o; s = the number of known points used in estimation and k = the specified power.

Boundry of the Lahore residents is marked/digitized using Quick Bird imegery having spatial resolution of 2.6 m, improved to 0.6 m by high resolution merging. Layers obtained from the interpolation contains continuous values for each of the parameters which make

Table 2. Data statistics and applicable classification scheme

Parameter	Min	Max	Mean	Range	Assigned value	Weight
Eletric conductivity (EC) (μS/cm)	260	1469	864.5	< 500	1	12
				500 – 1000	2	
				> 1000	3	
pH	7.80	8.29	8.05	7.5 – 8.0	2	16
				> 8.0	3	
TDS (mg/L)	169	929	549	< 500	1	28
				500 – 1000	2	
HCO_3 (mg/L)	122	481	301.5	< 240	1	9
				240 – 400	2	
				> 400	3	
Cl (mg/L)	10	129	69.89	< 250	1	8
Ca (mg/L)	11	191	101	< 75	1	8
Mg (mg/L)	7.2	47.7	27.45	< 30	1	8
				30 – 75	2	
Alkalanity (mg/L)	122 l	481	301.5	< 200	1	12
				240 – 400	2	
				> 400	3	

data more complex. To overcome this problem of diversity in parameteric values all the rasters have been classsified as per WHO standard classification. This three-classes scheme of WHO for each of the parameters has been used by a number of researchers for groundwater quality assessment (Bairu *et al*., 2013; Latha *et al*., 2012; Abulhakeem *et al*., 2011; Balakrishnan *et al*., 2011; Singh *et al*., 2011; Latha *et al*., 2010).

Finally the water quality index (WQI) is calculated through weighted overlay analysis (WOA). WOA is a GIS based framework to conceptulize a spatial phenomenon depending over more than one geographic parameters as is the case of groundwater quality. Weights have been assigned to each of the constituting quality parameter showing their relative importance in overall quality indexing. These weights have been assigned to the parameters following earlier studies by Bauru *et al*. (2013) and Latha *et al*. (2012). The assigned weights are shown in Table 2.

Maximum weight of 28 had been assigned to TDS showing its dominating significance in water quality assessment. Cl, Ca and Mg are assigned the minimum weight of 8, as they have relatively low importance in the overall quality assessment of groundwater (Bairu *et al*., 2013; Latha *et al*., 2012). Other parameters like, electric conductivity, bicarbonates and pH are given weights between 8 and 28 depending on their relative significance for the phenomenon. Ratings and weights are multiplied to calculate final output. Finally the water quality index is computed through WOA and had been classified as excellent, good, poor, very poor and unfit for drinking purpose depending on their degree of fitness for human consumption.

Results and Discussion

The study has prepared thematic maps for each of the studied quality parameters and then their common representation has been made using WQI map for the year 2012. Variation of the EC was within the permissible limit of 1,500 μS/cm at 25 °C as suggested by WHO. However, lower values were mostly concentrated in northern parts of the study area comprising of Farrukhabad (Shahdra), Data Nager, Baghban Pura, Krishan Nager and few patches of westerly located Iqbal Town, and Johar Town as well. Higher values were found in Gulberg, Industrial area, Mozang, Anarkali and a portion of Johar Town sub-divisions. Spatial distributions of electric conductivity (EC) of the underground aquifer is shown in Fig. 3A.

All of the study has been found well within the range of maximum acceptable limit of pH for drinking water i.e., 9.2 as per WHO standards. In this way groundwater of the area is mainly neutral to slightly alkaline in nature. As per WHO classification scheme only two classes were formed in the measure range of the pH value. Second ranked category covers the maximum area while Class 3 has some portions of Furrakhabad, Krishan Nager, Mozang, Johar Town, Green Town and Industrial area sub-divisions. Spatial distributions of pH concentrations are shown in Fig. 3B. Spatial concentration of Cl is given in Fig. 3C, where all the sample data lies in a single class. The permissible limit for HCO_3 is 240 mg/L and only 21% of the study area is found under this permissible limit. Spatial distribution of HCO_3 is shown in Fig. 3D. Maximum of the study area is found with 500 mg/L of TDS, whereas higher values are found in parts of Anarkali and Mozang sub-divisions as shown in Fig. 3E. Dissolve magnesium in water is the most common mineral that makes water hard, 98% of the groundwater samples were found within the desirable limits (30 mg/L), whereas higher values had been found in Mozang, Misri shah, Gulberg, Anarkali and Furrakabad

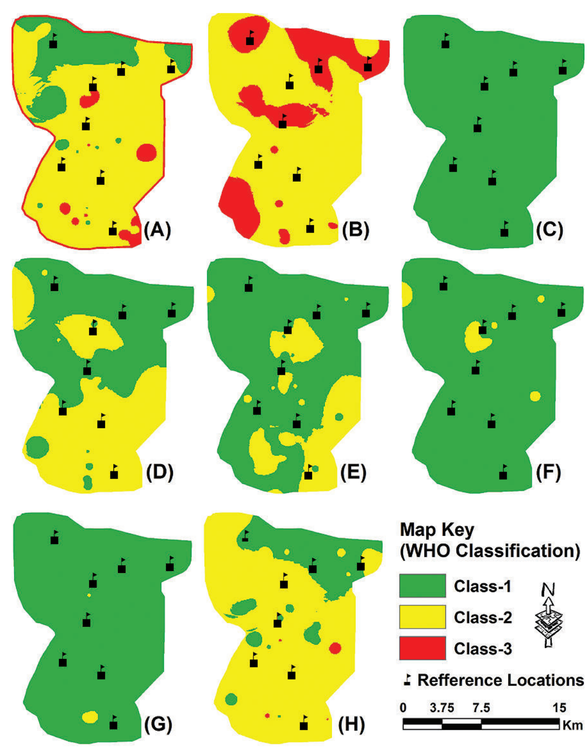

Fig. 3. Spatial distribution of individual parameters (A)-EC; (B)-pH; (C)-Cl: (D)-HCO_3; (E)-TDS; (F)-Mg; (G)-Ca: (H)-alkalanity.

sub-divisions as shown in Fig. 3F. There are two spots of higher Ca concentration, one found between Anarkali and Mozang and the other at southern side of the study area, as shown in Fig. 3G.

About 21% of the study area was under permissible limits of alkalinity and the areas under relatively extreme conditions were distributed over patches of Johar Town and Gulberg sub-divisions as shown in Fig. 3H. High concentration of alkalinity in these areas may be the result of huge construction work including under passes and a flyover, involved heavy drilling in ground. All the measured and predicted values of Cl are almost similar and fall in one of the three classes defined by WHO. Similarly Ca is within the permissible limits and formed two of WHO classes. It is notable that the common regions for extreme measures of majority of the parameters are Mozang and Anarkali subdivisions.

Water quality index. The water quality index values have been divided into classes of excellent, good, poor, very poor and unfit for drinking. Layer generated in this way is further subjected for calculation of areas corresponding to each of the class which shows that 21% of the study area is under excellent conditions, 50% is good, 27% is poor, less than 2% is very poor and a very small portion of the region is found unfit for drinking. This area wise comparison of different classes is depicted in Fig. 4.

The hot spot that is classified as unfit for drinking is found at the same region which was stated to have the deepest groundwater levels in the Lahore (Mahmood *et al*., 2013). The same region is found prominent in most of the individual parameters maps (TDS, HCO_3, EC and alkalinity) for their high values as shown in Fig. 2. Very poor quality of groundwater is centered at the depression centre of ground water in the city and its chunks have also been found at out skirts of the study area including parts of Gulberg, Johar Town and Anarkali subdivisions. Poor quality groundwater is found mostly in south eastern parts of the study area however, its patches are also found in Anarkali, Misri Shah and Furrakabad subdivisions. 71% of the study

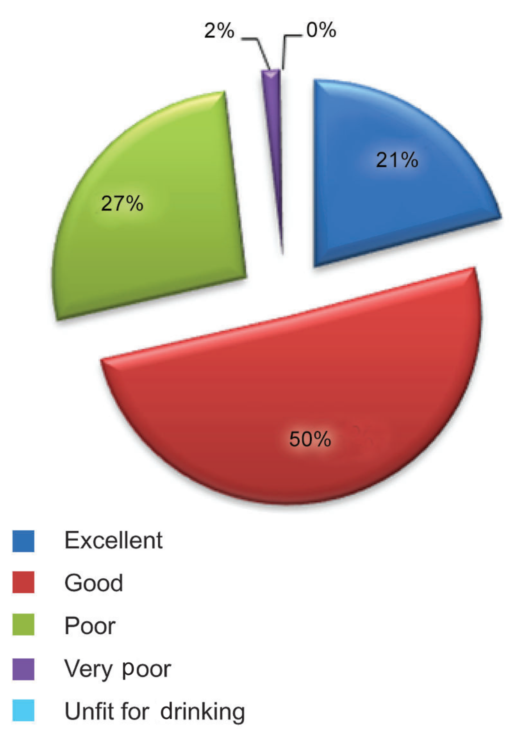

Fig. 4. Drinking water suitability area comparison chart as per WHO standard classification.

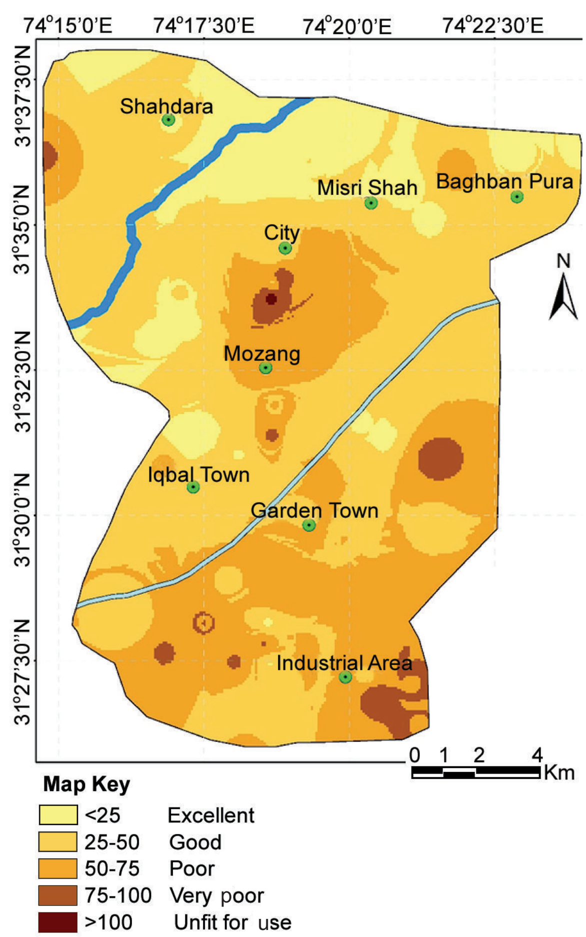

Fig. 5. Water quality index map.

area is found under good and excellent groundwater conditions that is located in the north, the only exception exist around the central depression zone.

The existence of concentering zones of gradually degrading water quality in the central portion of the study area as shown in Fig. 5 shows that the quality of extracted water is somehow linked to over exploitation of the fresh water resource. There is no recharge from this portion of the area and water reached there, by the lateral movement of the recharge from edges of the city. In this way degradation of the water quality seems to be occurring during its path through the underground materials.

Conclusion

This study concludes that groundwater quality parameters including pH, electric conductivity, Ca, Cl and TDS are well within the permissible limits defined by WHO for the drinking water. However alkalinity, HCO_3 and Mg are crossing their respective safe limits in some parts of Lahore residence.

Groundwater in subdivisions of Gulberg, Anarkali and Mozang sub-divisions, is found to be marginally fit for drinking purpose. So these areas need special attention of authorities regarding provision of the safe drinking water to the community. Surrounding areas of the above mentioned locations have also been spotted to be touching upper limits of the safety margins, so in near future these regions of groundwater may also become unsuitable for human use. Estimation of the health damage done by intake of the polluted water can be made by the field observation, showing increased use of filtration plants in the Lahore residence.

Visible correlation between distribution of poor quality of groundwater and impervious surfaces along with high abstraction rates of water reflects that urbanisation is the root cause of all this environmental damage. High abstraction rates along with increasing pervious surfaces has already been reported to cause a cone like depression in under-ground aquifer cantered between Muzang and Anarkali subdivisions. This cone like depression causes the water to flow latterly from remote areas of recharge to discharge zones. This lateral flow may be the reason of dissolving substances from underlying lithology. The possible solution to the issue for the local government is to minimize this lateral flow, ultimately, reduce the depression. It is possible through locally distributed groundwater recharge facilities in the study area and controlling pumping rates. People awareness plans are necessary to stop unnecessary wastage of this precious fresh water resource for the sustainable development of the mega city of Lahore.

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