

Groundwater Quality Assessment Using Averaged Water Quality Index: A Case Study of Lahore City, Punjab, Pakistan

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Abstract. Water quality is considered as a major issue in mega cities of developing countries. The city of Lahore has over 10 million populations with the highest population density in the Punjab Province, Pakistan. Groundwater is the main source of drinking water in Lahore. The groundwater quality should be regularly monitored to cope up with drinking water quality issues. The water quality index (WQI), previously used in many studies was usually based on one-year data to analyze the water quality situation of the study area. However, the results obtained from the data, based on single observation from different points may have distortion. This might have occurred due to the inclusion of multiple types of errors induced in the data as a result of improper sampling design, lack of expertise in terms of both sampling method and sample testing, instrumental and human errors, etc. Therefore, the study evaluated the groundwater physicochemical parameters (turbidity, pH, total dissolved solids, hardness, chlorides, alkalinity and calcium) for three years. The averaged water quality index (AWQI) was computed using ArcGIS 10.3 model builder. The AWQI map indicated that the water quality in the study area was generally good except in few places like Anarkali, Baghbanpura, Allama Iqbal Town, Mughalpura and Mozang due to relatively higher turbidity levels. The results of this study can be used for decision making regarding provision of clean drinking water to the city of Lahore. Moreover, the methodology adopted in this study can be implemented in other mega cities as well to monitor groundwater quality.

1. Introduction

Provision of safe and clean drinking water to the masses should be the foremost priority of every government as it is the basic human right. In order to identify the potential areas for future environmental health problems, regular mapping of groundwater quality is a pre-requisite for every city, [1]. As water quality index (WQI) undertakes the analysis of multiple parameters, it is considered as an efficient tool for understanding the overall water quality scenario of the area [2]. The use of spatial interpolation techniques for the estimation of groundwater quality parameters is a common practice, [3]. Water quality analysis maps using GIS techniques can help in understanding, analysing, planning and decision making for the management of water distribution networks.

Lahore is the second largest city of Pakistan. Groundwater is the primary source of drinking water for its population. To maintain quality of water, the water samples from these tube wells are regularly tested for several water quality parameters. It has keenly been observed in the last decade that the water stress, due to increased use of water and rapid urbanization, has become a menace to the aquifer in Lahore, Kanwal et al., [4]. Its groundwater must be treated before using it for domestic and drinking purposes as there is persistent mixing of contaminated material in it, [5]. The WQI, previously used in many studies [1, 2], was usually based on one-year data to analyze the water quality situation of the study area. However, the results obtained from the data, based on single observation from different points may have distortion. This might have occurred due to the inclusion of multiple types of errors induced in the data as a result of improper sampling design, lack of expertise in terms of both sampling method and sample testing,

instrumental and human errors, etc. Therefore, instead of using WQI for one year, this study has been conducted to incorporate the temporal variations of groundwater quality. This has been achieved by the generation of averaged water quality index (AWQI) map based on three years' observations, thereby, minimizing the impact of above mentioned errors.

2. Materials and methods

2.1 Study area

Lahore is the capital of the Punjab Province with over 10 million populations. WASA Lahore is responsible for providing water, here, through its huge network of pipelines and tubewells that have capacity of 2-4 cusecs. The Water and Sanitation Agency (WASA) jurisdiction covers around 245km² area and is divided into 27 sub-divisions. The map (Fig. 1) shows the study area in Lahore District and the geographical locations of WASA tubewells.

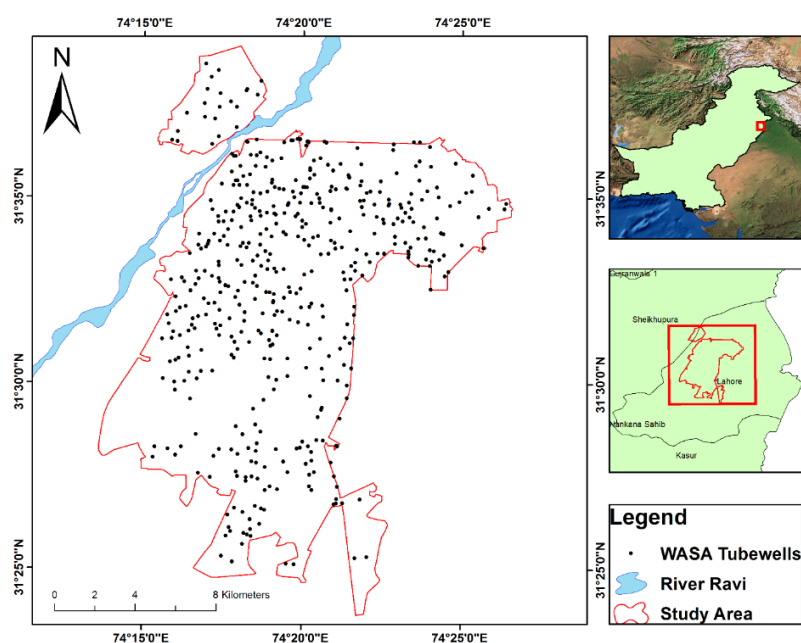


Figure 1. Study area and the geographical locations of WASA tubewells

2.2 Data acquisition and data preparation

The water quality parameters' (turbidity, pH, total dissolved solids, hardness, chlorides, alkalinity and calcium) data of three years (2010, 2011 and 2012) was acquired from the WASA, Lahore. The IBM SPSS Statistics version 20 was used to calculate the descriptive statistics (minimum, maximum, mean, standard deviation, kurtosis and skewness) of the water quality parameters and to identify the outliers. In addition, a geodatabase was created to maintain proper record of each year water quality parameters data for further spatial analysis in ArcGIS software.

2.3 Spatial interpolation

Inverse distance weighting (IDW) technique is considered as a better interpolation technique for representation of the spatial distribution of major ions in groundwater, [6]. It uses a weighted inverse function of distance from the point at which the value is to be obtained to already known points by making

a linear arrangement of values. It is based on the assumption that a sampled point closer to an unsampled point has more similar value to that unsampled point than the value of a sampled point farther, [7].

2.4 Water quality index

The WQI was computed for each year using ArcGIS 10.3 spatial analyst extension and model builder. It was based on physicochemical parameters (turbidity, pH, total dissolved solids, hardness, chlorides, alkalinity and calcium). Therefore, the relative weights for parameters were calculated and the WQI at every tubewell was estimated. The formula adopted for the calculation of WQI is given below:

$$WQI = Antilog [\sum_{n=i}^n W \log_{10} q_{ni}] \quad (1)$$

Where:

Weightage factor (W) was calculated by the following equation,

$$W_n = \frac{K}{S_n} \quad (2)$$

and K, Proportionality constant was derived from,

$$K = \frac{1}{(\sum_{n=i}^n \frac{1}{S_i})} \quad (3)$$

Where:

S_n and S_i are the WHO standard values of the water quality parameter.

Quality rating (q) is calculated using the formula,

$$q_{ni} = \frac{(V_{\text{actual}} - V_{\text{ideal}})}{(V_{\text{standard}} - V_{\text{ideal}})} * 100 \quad (4)$$

Where:

q_{ni} = Quality rating of i^{th} parameter for a total of n water quality parameters.

V_{actual} = Value of the water quality parameter obtained from laboratory analysis.

V_{ideal} = Value of that water quality parameter can be obtained from the standard tables.

V_{ideal} for pH = 7 and for other parameters it is equal to zero.

V_{standard} = WHO standard of the water quality parameter.

For validation, the WQI value obtained at a specific location as a result of manual calculations was compared with the result obtained at that particular point using ArcGIS model builder. Moreover, the WQI values for each year were interpolated using IDW technique to get the overall trend for the whole study area on yearly basis. The raster surface obtained showing WQI values as pixels was then classified as excellent, good, poor, very poor and unfit for drinking based on values 0-25, 26-50, 51-75, 76-100 and >100, respectively [8]. It is important to know that WQI values must be under index value of 100 for any water treatment program in order to promote better life standards, [9]. The AWQI was calculated by taking average of three maps using 'local' tool in ArcGIS.

3. Results and discussion

3.1 Statistical analysis

The descriptive statistics of water quality data for three years (Table 1) revealed that most of the mean values of the water quality parameters (pH, calcium, chlorides, hardness and total dissolved solids-(TDS)) did not change significantly in three years while the mean value of turbidity decreased in 2012. The mean values of alkalinity showed an increasing trend. The pH values for 2011 and 2012 had negative kurtosis.

Table 1. Descriptive statistics for 2010-12

Parameter*	Year	Minimum	Maximum	Mean	Std. deviation	Skewness	kurtosis
Turbidity	2010	0.00	5.84	1.5277	1.13905	1.470	2.272
	2011	0.00	6.73	2.1903	1.06798	0.651	2.266
	2012	0.00	8.80	.4719	0.75927	4.976	44.109
pH	2010	7.00	8.90	7.8471	0.26560	0.180	1.078
	2011	7.80	8.40	8.0302	0.20850	0.363	-1.216
	2012	7.60	8.30	7.9590	0.15452	0.471	-0.736
Alkalinity	2010	14.4	450.0	161.307	60.3229	1.194	2.549
	2011	65.0	462.0	212.155	74.4608	0.841	0.440
	2012	14.0	590.0	235.001	88.1709	0.839	0.813
Calcium	2010	9.6	112.0	34.235	16.8689	1.740	4.408
	2011	8.6	120.0	36.458	17.7421	1.610	3.750
	2012	3.3	296.0	35.479	24.1769	5.546	50.621
Chlorides	2010	6	175	37.00	32.316	1.867	3.377
	2011	8	278	39.13	40.197	2.984	10.755
	2012	8	242	34.25	29.620	2.891	11.584
Hardness	2010	45	480	169.04	79.286	1.569	3.668
	2011	29	480	175.48	82.789	1.065	1.191
	2012	5	784	170.10	87.183	1.967	7.947
TDS	2010	173.2	1480.5	428.374	211.9285	1.309	2.573
	2011	24.0	1139.0	392.190	194.5922	1.214	1.700
	2012	148.6	1155.4	407.862	196.9054	1.150	1.202

*The number of observation points for each parameter during 2010-12 were 210,221 and 346, respectively.

It meant that the pH distribution in these years had flatter peaks. The range of pH values in the following years was lower than the range of pH values in 2010 that had positive value of kurtosis exhibiting relatively peaked pH distribution. The relatively higher values of positive skewness for turbidity and calcium in 2012 and for chlorides in both 2011 and 2012 showed that most of the values in these years were within the minimum and the mean values for these parameters. The positive skewness was a cause of sharpness in the distribution peak so the kurtosis values of these parameters were also high.

3.2 Averaged water quality index map

In order to calculate the WQI for three years, the relative weight for each water quality parameter was calculated using equations (2) and (3). The relative weights for turbidity, pH, total dissolved solids, hardness, chlorides, alkalinity and calcium were 0.591751, 0.348089, 0.002959, 0.005917, 0.011835, 0.024656 and 0.014794, respectively. The quality ratings for each parameter were calculated using Eq. (4) and final results were obtained using Eq. (1). Three years interpolated WQI maps were overlaid and their average on cell by cell basis was calculated to get AWQI (Fig. 2) that presented a more reliable picture of the overall water quality. As turbidity had the highest weightage among all the parameters used in the computation of WQI, it was noticed that areas showing poor quality of water had relatively higher turbidity.

The AWQI map illustrated that water quality in the study area was generally good except in few places including Anarkali, Baghbanpura, Allama Iqbal Town, Mughalpura and Mozang. The WASA administration should install water filtration plants along with tubewells at Anarkali, Baghbanpura, Allama Iqbal Town, Mughalpura and Mozang where AWQI had specified 'poor' water quality.

It is important to realize that these filtration plants do not only decrease the turbidity values but will also minimize the bacteriological growth in water to improve the drinking water quality and lower the rate of waterborne diseases in the study area. In areas where AWQI indicated ‘good’, the residents should take potable water directly from the tubewells instead of taking drinking water from house tap to avoid any contamination that affects the water distribution network due to leakage from sordid pipelines and corrosion of metal pipes.

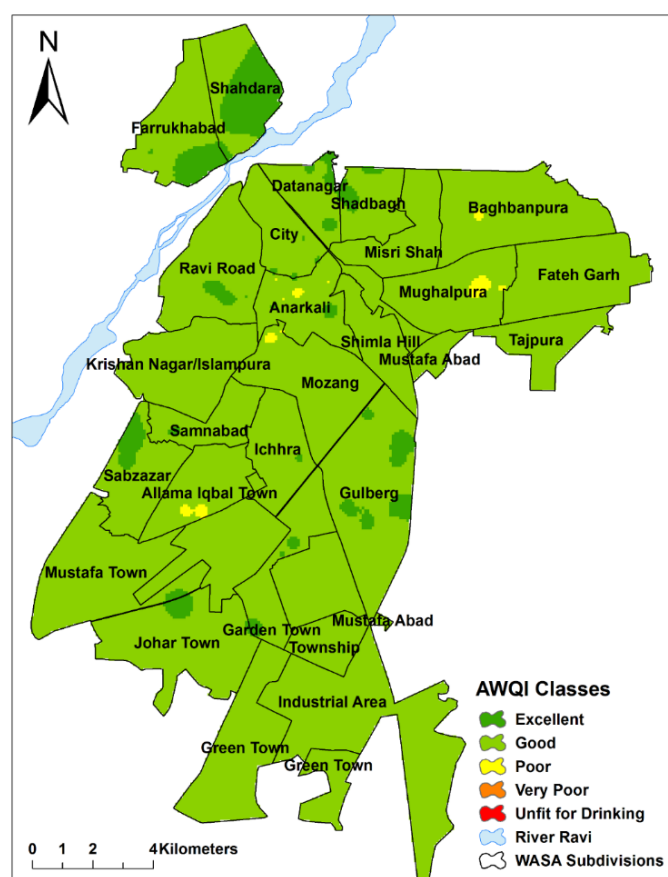


Figure 2. Averaged water quality index map

4. Conclusions

The WQI, previously used in different studies, is an important tool for analysing the quality of water. In this study, an attempt has been made to improve the results of this tool by incorporating a temporal aspect. The AWQI map revealed that physicochemical parameters of water were in general within the limits and there was not any issue in the study area. Most part of the WASA Lahore jurisdiction had AWQI ‘good’ for drinking apart from some patches, where it was ‘poor’. The reason for this ‘poor’ indication was relatively higher levels of turbidity. It is anticipated that the evaluation of groundwater quality of Lahore using AWQI and GIS techniques do not only help in the modernization of decision making and planning technique but will also contribute to the overall performance of the WASA, Lahore.

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