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Exploring water quality index and risk on quality of life in an industrial area: a case from Ghaziabad city, India

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Abstract: This paper makes an attempt to evaluate water quality index and its possible effect on quality of life in an Indian industrial city. Thirty six groundwater samples from CIS Hindon area of Ghaziabad city were analyzed with the help of standard methods of APHA. Water quality index was evaluated to assess suitability of drinking water. Rand Short Form 36 Items Questionnaire was used to examine the effect of water quality index on the quality of life of residents living around sampling stations. Results revealed that most of the water quality parameters were beyond the desired limit. Water quality index for 58% of the samples are very high and water quality is not suitable for drinking purpose. The statistical analysis showed that correlation between water quality index and quality of life was linear and negative. Therefore, proper groundwater management strategies are necessary to protect sustainability of water in the study area.

Keywords: Groundwater, Industrialization, Water Quality Index, Quality of Life, Ghaziabad

1. Introduction

Groundwater is an important source of drinking water in most of Indian cities. Rapid increase in industrialization and urbanization has led to deterioration in water quality [1, 2]. Prolonged discharges of industrial effluents, domestic sewage and solid waste disposal have caused groundwater to become polluted, and as a result many health problems have been cropped up in many cities of India [3]. Most of the industries discharge effluents without proper treatment in unlined channels. These effluents percolate underground and affect groundwater quality [4, 5]. Over exploitation of water due to increase in urban population has further affected groundwater quality.

Adequate availability of water supply both in the context of quantity and quality is essential for human existence. The demand for water has increased over the years and this has caused water scarcity in many parts of India. The situation has further aggravated the problem of water contamination. India is experiencing fresh water crisis mainly due to improper management of water resources and environmental degradation. Access to safe drinking water remains an urgent necessity in India as 30% of urban and 90% of rural households still depend on untreated surface or groundwater sources [6]. Though access to drinking water in India has increased since past decade but the adverse impact of unsafe water on health is still prevalent [7]. Groundwater quality is worse in the areas which are densely populated, thickly industrialized and characterized with shallow groundwater table. It has, therefore, become imperative to regularly monitor groundwater quality and to device its management strategies. In this backdrop, the present study was carried out to evaluate water quality index and its impact on quality of life. Evidence is taken from Ghaziabad city, India. Ghaziabad city is located in the north western part of India sharing the borders with the National Capital Territory Delhi. It is headquarter of Ghaziabad district. Owing to its location close to National Capital Delhi, over the years, the city has experienced rapid development and urbanization. The city since last two decades has been transformed into a full- fledged industrial town having distinct identity in the region, state and nation. It is also developing linkages to the international market. The industrial development of the city is characterized by the development of medium and large-scale industries on the outskirts of the city on both sides of river Hindon. A number of prestigious and large scale industries have been established in the city along Meerut road, Bulandshahar road, Link road, Sahibabad and Loni roads.

Geographically, Ghaziabad city is situated at 280 40' N latitude and 770 25' E longitudes. Geologically, Ghaziabad forms a part of the Indo-Gangetic plain. The area has overall flat topography with average elevation of 210 m above mean sea level and is drained by south flowing Hindon River. The normal annual rainfall in the area is 527 mm. The city has a population of 0.96 million [8].

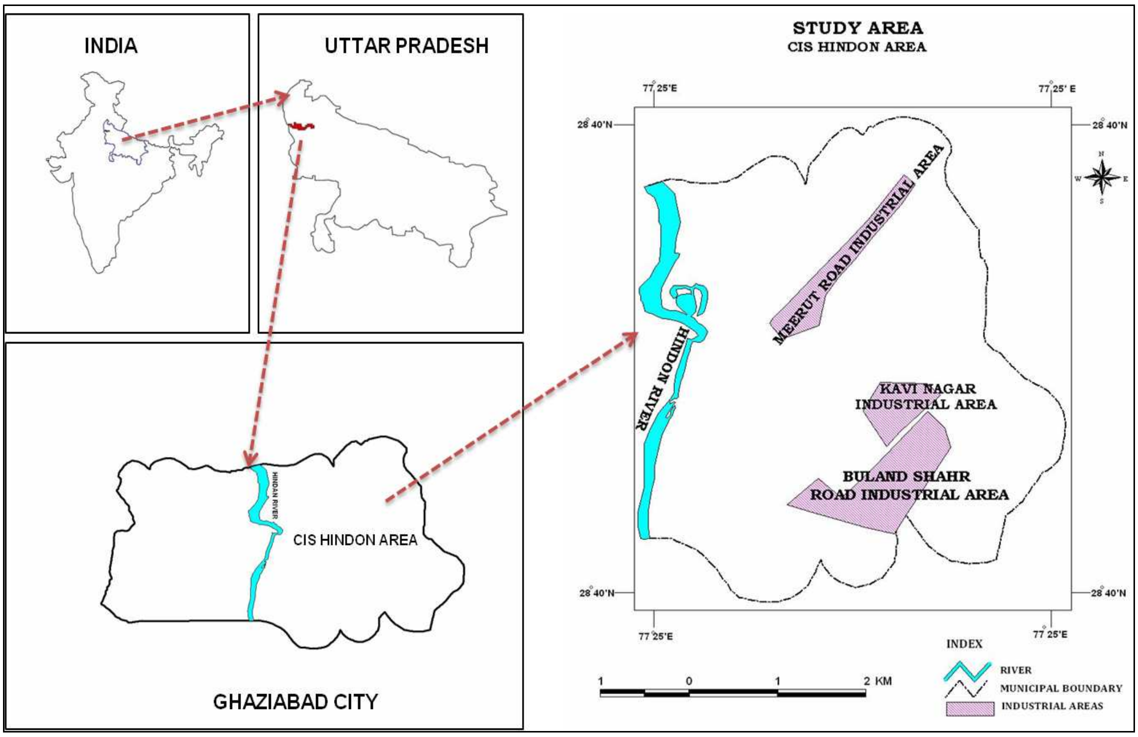

Figure 1. *Map showing location of the study area.*

Hydrogeologically, the city is underlain by moderately thick quaternary unconsolidated alluvium (consisting of sand and clay with thickness varying between 100 m and 300 m). This unconsolidated formation overlies Precambrian Meta-sediments and belongs to Aravalli super-group. The Hindon River flows through the middle part of the city along fault line and forms two distinct hydrogeological environments in the city, on either side, the eastern (Cis Hindon) and western (Trans Hindon) parts representing down thrown and up thrown blocks respectively. CIS Hindon area (Figure 1) has been chosen as the study area because it has comparatively more population and high concentration of industries than Trans Hindon area.

Hydrologically, CIS Hindon area has an aquifer down to 120 m below ground level. The average depth of water level is 3 to 15 m bgl. The general flow direction of ground water is southerly [9]. Meerut Road industrial Area, Kavi Nagar, New Kavi Nagar industrial areas and Bulandshahar Road industrial are major industrial regions in CIS Hindon area. There are 150 tube wells in Cis Hindon area capable of providing 124 MLD water while the demand for water is 150 MLD.

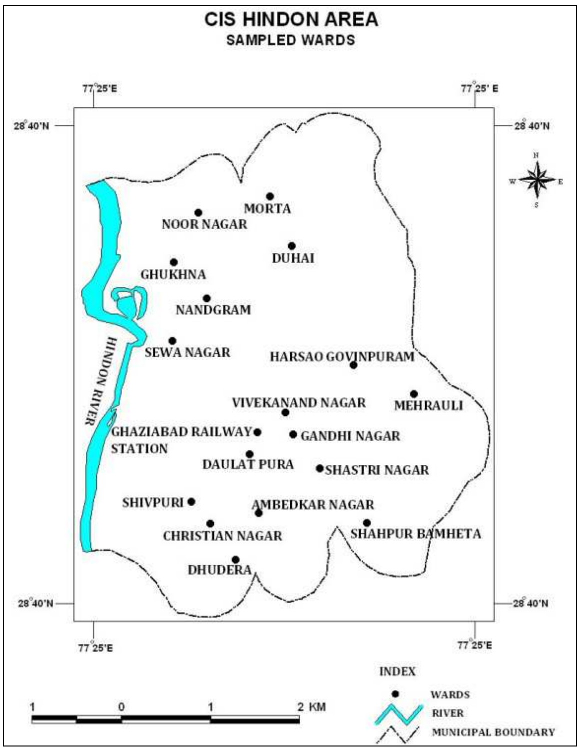

Figure 2*. Sampling sites in the study area.*

2. Materials and Methods

Thirty six water samples were collected from both the hand pumps and municipal water in the city during 2012.

Sampling locations were selected on the basis of industrial units. There are three prominent industrial regions in Cis Hindon river area. From each industrial region six wards were selected. In this way a total of 18 wards were selected (Figure 2). From each selected ward one hand pump and one municipal water samples were collected. Thus the analysis is based on 36 samples. Samples were collected in sterilized glass bottles for physico-chemical analysis of water; the pre cleaned plastic polyethylene bottles were used. Prior to sampling, all the sampling containers were washed and rinsed thoroughly with the groundwater to be taken for analysis. The samples were analyzed for eight physical and chemical parameters (P^H, total hardness, calcium hardness, magnesium hardness, nitrate, chloride, total dissolved solids and alkalinity) using standard methods [10].

To ascertain the suitability of groundwater for drinking purpose, Water Quality Index developed by Tiwari and Mishra (1985) was used [11]. Water quality index is one of the most effective tools to communicate information on overall quality status of water to the concerned user, community and policy makers [12, 11, 13, 14, 15, 16, 17, 18, 19, 20]. Thus, it is an important parameter for the assessment and management of groundwater [21]. WQI was calculated by weighted index method and the unit weight (Wi) of each parameter was obtained depending upon its weightage, by adopting the following equation:

$$WQI = (\sum q_i w_i) / (\sum w_i)$$

where $q_i = 100(V_i / S_i)$

$$W_i = K / S_i$$

$$\text{qpH} = 100\{(\text{VpH ? } 7.0) / (8.5 \text{ ? } 7.0)\}$$

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

W_i = unit weight for the ith parameter

K = constant of proportionality

Table 1. *Permissible limits prescribed by WHO (2004) and BIS (1993) and assigned unit weight for various parameters.*

Parameters	Recommended limit WHO	BIS	Unit weight (Wi)
P^H	7.0-8.5	7.0-8.5	0.005
Hardness	300	300	0.0033
Calcium	75	75	0.0133
Magnesium	50	50	0.02
Nitrate	45	45	0.022
Chloride	200	250	0.005
TDS	500	500	0.002
Alkalinity	200	-	0.005

It is well known that the more harmful a given pollutant is, the smaller is its permissible value for the standard recommended for drinking water [13]. So the “weights” for various water quality parameters are assumed to be inversely proportional to the recommended standards for the corresponding parameters. For the sake of simplicity, assuming that K = 1, for pH, assuming the same unit weight as that for chlorides; viz., 0.005. The unit weights (Wi), obtained from the above equation with K = 1, are presented in Table 1. According to this water quality index, the maximum permissible value is 100. Values greater than 100 indicate pollution and are unfit for human consumption.

Health related quality of life was assessed using RAND Medical Outcomes Study 36 Items Short-Form Survey. This is a self-report questionnaire containing 36 items that yield two summary scores- the physical and mental composite scores. The physical composite score comprises four domains (physical functioning, role limitations due to physical problems, bodily pain and general health). The mental composite score comprises vitally, social functioning, role emotion and mental health. The SF- 36 has been found to have satisfactory reliability and validity in individuals with stroke [22, 23, 24, 25]. Subsequently the measure has been translated into 120 languages and has been used around the world to gauge the health of local populations [26, 27, 28, 29, 30, 31]. Data regarding quality of life was collected through field survey using Rand questionnaire. Sample included of 36 respondents living around the sampling sites of water collection. Respondents were selected in the same manner as water samples were collected. The respondents were selected from the sampling sites for assessing the impact of water quality on health. The quality of life score was obtained by summing up the individual score of 36 questions. All the responses of the questions were made uniform. Higher scores indicate a higher perceived health-related quality of life. Pearson correlation was performed to find the relationship between water quality index and quality of life. Bivariate analysis was also performed to examine the influence of water quality index on quality of life.

3. Results and Discussion

The analytical results for all the parameters for the groundwater samples and water quality index in the study area are presented in Table 2. Statistical summary of groundwater sample data is given in Table 3 and number of water samples exceeding desirable limit is given in Table 4.

P^H is a term used universally to express the intensity of the acid or alkaline condition of a solution. It indicates the type and intensity of pollution. The limit of PH value for drinking water is specified as 7.0-8.5 [32]. The pH of groundwater in the study area is 7.1- 8.0 and with a mean value of 7.4 which is within the Bureau of Indian Standard’s desired limit [33].

Total dissolved solids indicate the general nature of salinity of water [34]. Total dissolved solids are composed mainly of carbonates, bicarbonates, chlorides, phosphates and nitrates of calcium, magnesium, sodium, potassium and manganese, organic matter, salt and other particles. TDS content is usually the main factor which determines the use of groundwater for any purpose [35]. TDS value ranged from 67 to 774 with an average value of 368. About 33% hand pump samples and 22% of municipal water samples exceed the desired limit of 500 mg/L. High concentration of TDS in hand pump water was found at SAMPLE 1 and S2 in Bulandshahar road industrial area; at S3 and S4 in Kavi Nagar and at S1 and S6 in Meerut road Industrial area. Municipal water at S3 and S4 in Bulandshahar Road and S1 and S2 in Meerut road industrial area were found to have more than 500 mg/l concentration of TDS. The highest value of 774 mg/l was recorded in the municipal water sample at S2 of Meerut road industrial area. High concentration of TDS in the groundwater samples is due to seepage from unlined sewage lines, domestic drains and leachates from waste dumps. Most of the collected water samples are slightly alkaline due to presence of carbonates and bicarbonates.

Alkalinity of water is its capacity to neutralize a strong acid and it is normally due to presence of bicarbonate, carbonate and hydroxide of calcium, sodium and potassium. The alkalinity value varied between 140 and 180 with an average of 432.7 mg/l. Samples from all sites have high concentration of alkalinity and exceed the permissible limit proposed by BIS. All groundwater samples except one municipal water sample from S1 in Bulandshahar road industrial area exceed the desirable limit of 200 mg/l, specified by World Health Organization. The high value at these locations is attributed to the effluents from the pharmaceutical and drug industries. The highest alkalinity was recorded in hand pump water sample at S5 in Bulandshahar road industrial area.

Total hardness varied between 50- 480 mg/l. Maximum allowable limit of TH for drinking water is specified as 300, and the most desirable limit is 100, as per World Health Organization's standard. Only one hand pump water sample from S4 and one municipal water sample from S5 in Bulandshahar road industrial area exceed the desirable limit. Maximum hardness value of 480 mg/l was recorded in municipal water sample from S5 in Bulandshahar road industrial area. This may be attributed to the anthropogenic activities like sewage and industrial waste disposal. Calcium and magnesium are related to hardness. The desirable value of Mg^{2+} is 50 mg/l. About 11% hand pump samples and equal percentage of municipal water samples exceed the desirable limit. Hand pump water sample from S4 and municipal water samples from S1 & S5 of Bulandshahar road industrial area exceed the desirable limit. Ca^{2+} values varied from 6 to 58 mg/l, with an average value of 24.5 mg/l. The desirable limit for Ca^{2+} for drinking water is specified as 75 mg/l. It is observed that almost all the groundwater samples from the study area are within the permissible limit as proposed by World Health Organization.

The sources of chloride in groundwater are weathering, leaching of sedimentary rocks, intrusion of salts, windblown salt in precipitation, domestic and industrial waste discharges, municipal effluents, etc [36]. The desirable limit of chloride for drinking water is specified as 200 mg/l. The concentration of chloride in the study area is between 13.0-2005.7 mg/l with an average value of 274.5. Relatively higher concentration of Cl is observed in the hand pump water samples from S1 & S4 in Bulandshahar road industrial area and from S2 & S4 in Meerut road industrial area. Municipal water samples from S4 & S5 in Bulandshahar road industrial area and from S3 & S4 in Meerut road industrial area exceed the permissible limit. It was also observed that the concentration was comparatively higher in municipal water samples. The excess of chloride in the water is usually taken as an index of pollution and considered as tracer from groundwater contamination [37, 38].

Higher concentration of chloride is attributed to the close proximity of these locations to a number of industries like garments, dyeing and printing, furnaces, glass, refractory and ceramics, etc. Chloride in excess imparts a salty taste to water and people who are not accustomed to high chloride can be subjected to laxative effects. Nitrate in groundwater varied from 0 to 200 mg/l. Nearly 22% of hand pump water samples and 11% of municipal water samples exceed the standard desirable limit of 45 mg/l, as per WHO norms. Hand pump water samples from S4 in Bulandshahar road industrial area; S2 & S3 in Meerut road industrial area and S2 in Kavi Nagar industrial area exceed the permissible limit while municipal water samples from S6 in Bulandshahar road industrial area and S1 in Kavi Nagar industrial area have nitrate concentrations greater than the desirable limit. All of these sampling points are very close to municipal waste dump sites and are prone to higher nitrate concentration.

Table 5 gives an overview of water quality. The water quality was ranked in four categories. Of the total water samples, 19 per cent samples from the seven locations showed WQI greater than 100 indicating that the water is not suitable for human consumption. The highest value of WQI (194) was found in hand pump water sample from S4 in Bulandshahar road industrial area. High concentration of nitrate (179 mg/L) in this water sample is attributed to high WQI. Two municipal water samples at S5 and S6 from the same industrial area showed WQI (110 & 167 respectively). High concentration of chloride, hardness, alkalinity and magnesium affected the quality of the municipal water at S5 while high concentration of nitrate and alkalinity affected the water quality index at S6.

WQI of municipal water sample at S1 and hand pump water sample at S2 was found to be more than 100 in Kavi Nagar industrial area. Nitrate and alkalinity affected the water quality index of municipal water sample at S1 while nitrate, chloride and alkalinity affected the water quality index of hand pump water at S2. In Meerut road industrial area hand pump water samples at S2 and S3 showed WQI more than 100. The high concentration of alkalinity and nitrate affected the quality of water at both these sample sites.

A close perusal of Table 5 further shows that 39% of the water samples were poor water quality samples. Four hand pump water samples at S1, S2, S5 and S6 and three municipal water samples at S1, S3 & S4 were having WQI ranging between 51 & 100 and thus possessed poor quality of water.

In Kavi Nagar, hand pump water sample from S3 and municipal water samples from S3 and S4 sites showed poor quality of water. Municipal water samples from S1, S2 and S4 and hand pump water sample from S6 in Meerut road industrial area revealed poor water quality.

To assess relationship between water quality index and quality of life, Karl Pearson's two tailed correlation was derived. The correlation was founded to be significant and negative between the two variables (Table 6). Explained variation in the relationship is moderate indicating that water quality index is not the only variable predicting the quality of life in humans. However, there is a clear indication that the quality of life is deteriorated when the water quality deteriorates.

Table 2. *Water quality parameters and water quality index in study area.*

	Water Samples	Physico-chemical parameters																Water Quality Index	
		P^H		TDS		Hardness		Calcium		Alkalinity		Chloride		Magnesium		Nitrate			
		HP	MW	HP	MW	HP	MW	HP	MW	HP	MW	HP	MW	HP	MW	HP	MW	HP	MW
Bulandshahar road	S1	7.6	7.56	599	67	285	135	58	6	335	140	510	22	33	61	2	17	72.27	68.4
	S2	7.1	7.26	522	311	125	105	20	10	660	535	164	102	18	18	42	10	73.42	44.4
	S3	7.34	7.46	265	757	125	195	26	34	375	335	53	1087	15	26	8	27	36.73	96.6
	S4	7.42	7.58	411	547	335	175	38	24	405	330	532	559	57	27	179	11	190.4	66.0
	S5	7.49	7.43	240	104	145	480	22	50	810	210	62	2005	21	85	36	3	76.35	110
	S6	7.52	8.01	241	194	220	190	30	20	400	305	115	106	36	33	19	200	62.77	167
Kavi Nagar	S1	7.24	7.86	330	219	210	125	22	34	485	360	106	44	9	30	3	145	38.34	133
	S2	7.62	7.77	489	279	165	50	20	20	530	320	239	155	27	8	165	11	154.4	37.8
	S3	7.19	7.54	537	352	170	175	34	24	610	530	173	217	20	27	3	10	54.03	59.2
	S4	7.30	7.59	510	323	105	250	26	20	350	375	319	577	9	50	18	12	48.15	72.2
	S5	7.55	7.25	271	198	105	120	12	20	450	340	26	13	19	16	8	15	39.88	39.0
	S6	7.51	7.78	187	279	125	120	14	20	345	410	22	53	21	16	1	0	33.4	43.8
Meerut road	S1	7.14	7.26	511	516	110	165	22	30	480	470	84	337	13	21	10	12	42.8	60.1
	S2	7.38	7.27	308	774	185	185	22	32	440	360	93	861	31	25	156	10	141.5	77.3
	S3	7.29	7.54	419	360	255	130	22	18	520	445	186	160	50	20	187	9	177.7	47.8
	S4	7.47	7.30	285	282	90	170	30	26	510	520	71	102	3	25	15	8	43.0	51.4
	S5	7.17	7.23	271	452	125	95	20	22	510	450	40	226	18	9	12	12	44.7	45.7
	S6	7.34	7.37	523	335	155	105	24	10	580	350	257	195	23	19	40	8	77.7	41.4

(All units except pH are in mg/l)

Table 3. *Statistical summary of groundwater quality data*

Variables	Min-Max	Mean ± SD
P^H	7.0-8.10	7.44 ± 0.22
TDS	67-774	368.5 ± 164.3
Total Hardness	50-480	166.8 ± 79.4
Calcium	6-58	24.5 ± 10.2
Alkalinity	140-810	432.7± 125.8
Chloride	13 -2005.7	274.5 ± 382.9
Magnesium	3 -85.2	26.4 ± 16.6
Nitrate	0-200	39.5 ± 61.3
WQI	33.4-190.4	74.1 ± 43.6

Table 4. *Number of groundwater samples exceeding permissible limit*

Parameters	Number of samples		Percentage	
	HP	MW	HP	MW
TDS	6	4	33.3	22.2
Hardness	1	1	5.5	5.5
Alkalinity	18	17	100	94.4
Chloride	5	8	27.7	44.4
Magnesium	2	2	11.1	11.1
Nitrate	4	2	22.2	11.1

Table 5. *Classification of groundwater based on water quality index.*

Industrial areas	Water Quality Index								Total water samples
	0-50 Good		51-100 Poor		101-150 Very poor		151-200 Unfit		
	HP	MW	HP	MW	HP	MW	HP	MW	
Bulandshahar Road	1(8.3)	1(8.3)	4(33.4)	3(25.0)	-	1(8.3)	1(8.3)	1(8.3)	12(100)
Kavi Nagar	4(33.4)	3(25.0)	1(8.3)	2(16.7)	-	1(8.3)	1(8.3)	-	12(100)
Meerut Road	3(25.0)	3(25.0)	1(8.3)	3(25.0)	1(8.3)	-	1(8.3)	-	12(100)
Total	8(22.2)	7(19.5)	6(16.7)	8(22.2)	1(2.8)	2(5.5)	3(8.3)	1(2.8)	36(100)

Table 6. *Correlation of groundwater quality index with quality of life*

Water Quality Index	Quality of life(Rand Questionnaire Score)		
	Number	**Min-Max**	**Mean ± SD**
0-50	15	45.5-57.91	53.752 ± 3.932
51-100	14	44.25-56.66	53.56 ± 3.437
101-150	03	42.58-51.41	47.88 ± 3.817
151-200	04	41.41-46.75	43.25 ± 2.177
Total samples	36	41.41-57.91	51.96 ± 5.17

Quality of life significantly related to Water Quality Index, with higher quality of life associated with higher quality of ground water with F=28.915; $r = -0.678$, $P < 0.01^{**}$

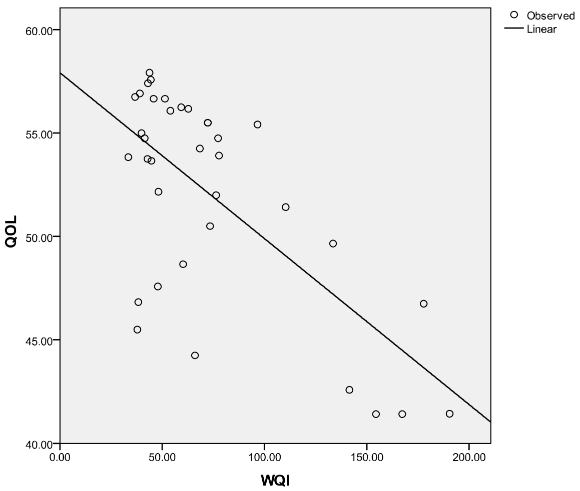

Figure 3. *Variation in quality of life*

Table 7. *Bivariate regression between water quality index and quality of life*

Beta coefficient	R^2
-0.678^*	0.460

Dependent variable: quality of life
*Correlation is significant at the 0.01 level (2-tailed).

About 46% variation (R^2 =0.460) in quality of life is explained by the WQI (Table 7). As the water quality index value increases, the quality of life is found to decrease (Figure 3). The changes in the quality of life score in relation to changes in water quality index more than 100 are minimal in all the sampled areas. This indicates that significant improvement in quality of life can be achieved if water quality index is brought down below 100.

4. Conclusions and Recommendations

The analysis of groundwater samples from three industrial areas of Ghaziabad city has shown high concentration of alkalinity, chloride, total dissolved solids, magnesium and nitrate. The water quality index was evaluated to assess the quality of ground water. WQI values for 58% of the samples are very high and water quality is completely unsuitable for drinking purpose. The study further reveals that 83% of water samples in Bulandshahar road industrial area, 50% water samples in Meerut road industrial area and 41% water samples in Kavi Nagar industrial area have poor water quality. The statistical analysis shows that the correlation between water quality index and quality of life was linear and negative. As the water quality index increases, the quality of life is found to decrease. The consumption of water around these industrial areas has caused water-related diseases to the residents. Water quality index values more than 100 show poor quality of life. For quality control and assessment through treatment programme, the consideration should be given to bring WQI below 100 so as to achieve better quality of life. Thus, attempts should be made to provide safe drinking water in order to save residents of the industrial areas of the city from contaminated water affecting quality of life. For this, it is essential to initiate measures to check the pollution from industrial effluents and to monitor the quality of groundwater regularly in the study area. These locations need some degree of treatment of water before consumption and also needs to be protected from the perils of the prevailing contamination. Comprehensive sewerage system for safe disposal of wastes should be developed to safeguard groundwater quality in the study area. Every drop of water should be saved. Groundwater extraction should be allowed to the extent that it can be replenished. Conservation of water through rainwater harvesting, groundwater recharge, recycling and reuse of industrial waste water provide wide scope for the appropriate planning and better management of water for existing water crisis in India. It is also heavily relies on district authorities, local government bodies, municipal cooperation, local institutions and local community to take appropriate steps to check water contamination. Our cities must draw up a model of sustainable growth. This requires finding ways of 'leap-frogging' so that we can have progress without pollution and inequity.

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