Research Paper

Groundwater Quality Assessment using Water Quality Index (WQI) in Liaquatabad Town, Karachi, Pakistan

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Abstract: The aim of present study is to evaluate the groundwater quality of Liaquatabad Town using water quality index (WQI) measured through physico-chemical parameters. For this purpose, groundwater samples (n = 31) were randomly collected through boring wells from various sites of study area. Data revealed that TDS content of groundwater is very high (mean: 1045.55 mg/L) which is double the WHO limit for drinking purpose. Elevated concentration of Ca, Na, Cl, and HCO_3 is reported in 85%, 33%, 40% and 70% wells respectively which are exceeding the corresponding WHO guideline for drinking purpose. Very high concentration of these major ions (Ca, Na, Cl, and HCO_3) is indicative of sewage mixing with groundwater in Liaquatabad. The calculated value of water quality index (WQI = 66.1) shows that groundwater in Liaquatabad town is not suitable for drinking purpose but can be used for industrial and irrigation purpose.

Keywords: Groundwater, quality, water quality index, Liaquatabad town.

Introduction

Water is an essential component of all forms of life; no organism can survive without water. Daily demand of drinking water of a man is normally 7% of his body weight (Iqbal and Gupta, 2009) but this water can become a threat to the continuation of life if it gets polluted with harmful or toxic substance (Abbasi and Vinithan, 1999). Water is mainly obtained from two sources, i.e. surface water which includes rivers, canals, fresh water lakes, streams etc. and ground water like well and borehole water (McMurry and Fay, 2004). In the present scenario, water demand is increasing all over the world due to rapid growth in population and more than half of the world depends on groundwater for survival (UNESCO, 1992). In Asia alone, about 1 billion people are directly relying on groundwater source (Foster, 1995). According to World Health Organization, about 80% of all the diseases in human beings are caused by water (Al-Hadithi, 2012). Usually the groundwater is considered less polluted as compared to the surface water, due to the less exposure to the external environment (Iqbal and Gupta, 2009). However, the modern civilization, industrialization, urbanization, increase in population and improper waste management are causing the degradation of groundwater quality (Agarwal, 2009).

Karachi is the biggest and densely populated (more than 20 million population) city of Pakistan which is facing the acute shortage of municipally supplied water since many decades. It is the main reason that residents of Karachi are rapidly switching over to the groundwater for drinking and other domestic uses. Despite of such drastic switch over no detailed work has been carried out so far to assess the status of groundwater quality in Karachi. Thus, present study is pilot work which is aimed at screening the groundwater for its quality to ensure its potential use in one of the core residential areas. Liaquatabad town is selected for this purpose due to the fact that it is densely populated town where middle to lower middle class of the society is settled since birth of Pakistan. Other objective of this study is to apply Water quality index (WQI) method to classify the groundwater of Liaquatabad town for various purposes.

Study Area

Liaquatabad Town is located in the central district of Karachi which lies between latitude 24.8880°-24.9223° N and longitude 67.0177°-67.0644° E (Fig. 1). Study area is mainly a residential occupancy which is spread over 11.28 sq. km area with dense population of 985,581 (KSMP, 2007). Liaquatabad Town has a middle class and lower middle class population. Liaquatabad and Nazimabad are the two major areas of the town and both were components of the defunct district central. Liaquatabad Town consists of 11 union councils including Rizvia Society, Firdous Colony, Super Market, Dak Khana, Qasimabad, Bandhani Colony, Sharifabad, Commercial Area, Mujahid Colony, Nazimabad, and Abbasi Shaheed.

One of the major problems is the leakage of sewage in different localities of Liaquatabad. The residents of Nazimabad are of the view that there is no water problem in their area and leakage of sewage is rare. However other parts of the study area are facing shortage of municipally supplied drinking water. Liaquatabad town is bordered by Lyari River in the South and Orangi nala in the west. Similarly, Gujjar nala is passing through the center of Liaquatabad town (Fig. 1).

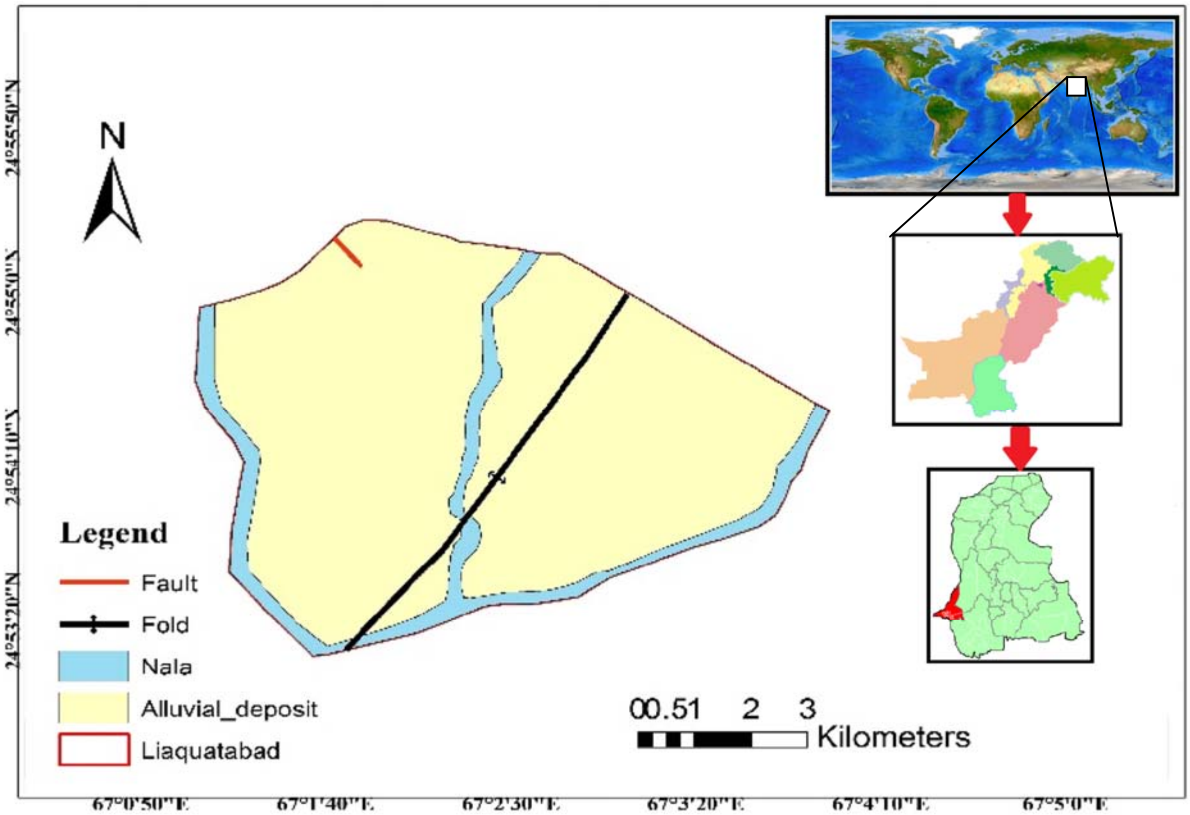

Fig. 1 Geological map of Liaquatabad town, Karachi

Geologically, this town is covered completely with Recent to Sub Recent alluvium. Sub-surface rocks belong to Nari and Gaj formations of Oligocene and Miocene age respectively. Nari Formation consists of sandstone with interbedded shales and subordinate limestones (Pithawalla and Martin- Kaye, 1946) which is overlain by the Gaj Formation having 50 m thick bed in the Karachi region comprising predominantly soft to hard sandstone and argillaceous limestone (Shah, 2009). Based on the thickness of Gaj Formation it is assummed that most of the wells (depth range: 16-46 m) of study area are tapping groundwater from the aquifers of Gaj Formation. Similarly rest of the wells are installed in the Nari Formation aquifers.

Materials and Methods

Sample Collection

Thirty-one groundwater samples were randomly collected from depth range of 16-78 meter. Groundwater was electrically pumped for 2-3 minutes to get representative sample from the aquifer. Location of each well was marked with the help of Global Positioning System (GPS) on the Google earth image (Fig. 2).

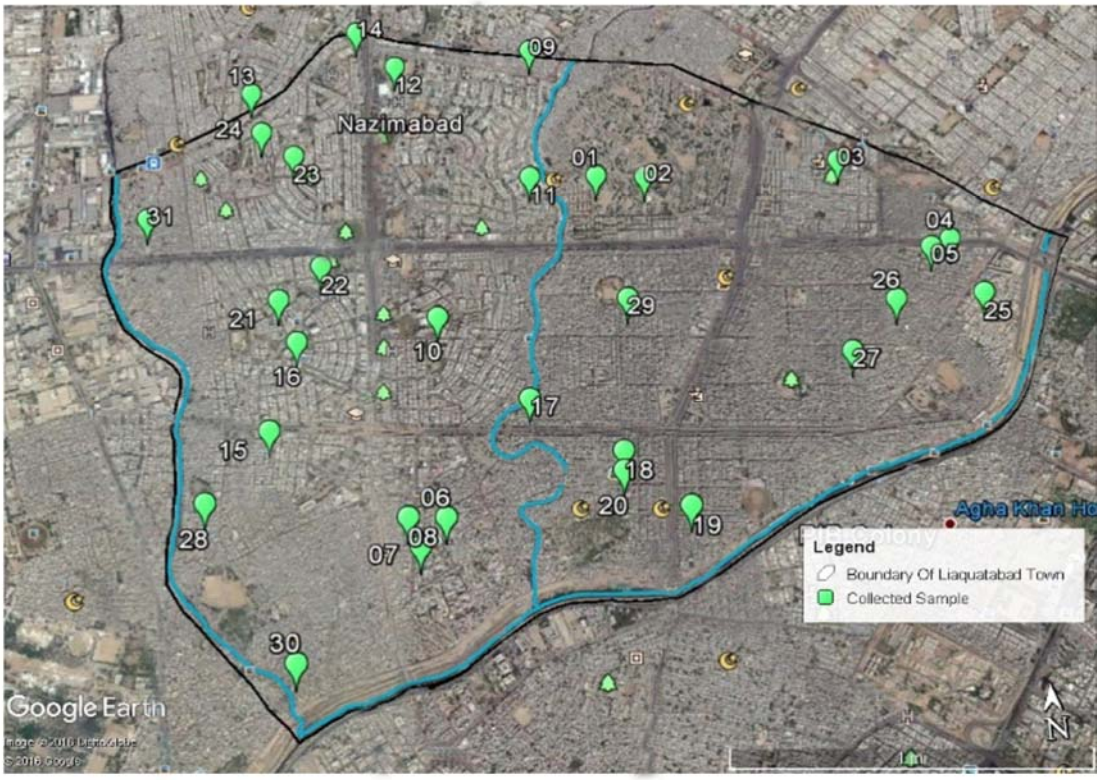

Fig. 2 Sample Location map using Google Earth Image

Groundwater samples were collected in plastic bottles of 1.5-liter capacity for physico-chemical analysis. Bottles were properly washed and rinsed thoroughly with distilled water and then with groundwater at each sampling site. For nitrate determination groundwater samples were collected in bottles of 100 ml capacity in which one ml boric acid solution was injected through sterile syringe to cease any further reaction.

Groundwater Analysis

The pH and total dissolved solids (TDS) of collected samples (n =31) were measured with the glass electrode pH meter (Adwa AD 111) and EC meter (Adwa AD 330) respectively. Concentration of sodium and potassium were determined by using flame photometer (Model No. JENWAY PFP7). Sulphate content was tested by gravimetric method, while bicarbonate by titration and chloride was estimated by argentometric titration method. The method used for the analysis of calcium was EDTA titration Standard Method (1992). Magnesium was estimated as the difference between hardness and calcium with the help of standard formula. Groundwater samples preserved in the boric acid were analyzed to determine the nitrate concentration by cadmium reduction method (HACH-8171) on spectrophotometer.

Water Quality Index (WQI)

WQI is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers (Yisa and Jimoh, 2010). It was first proposed by Horton (1965) which was later on generalized by Brown et al. in 1970. According to Bharti, 2011, WQI is a single number that rates the water quality by aggregating several water quality parameters and usually the higher score alludes to the better quality (Excellent, Good) and the lower score to degraded quality (Bad, Poor). Weighted arithmetic index method of WQI proposed by Brown et al (1970) was applied to evaluate the groundwater quality status Liaquatabad Town. Physicochemical parameters including pH, TDS and major cations (Ca, Mg, Na and K) and anions (HCO_3, Cl, SO_4 and NO_3) were used to calculate WQI of groundwater in Liaquatabad Town. WQI is calculated using following formula.

$$WQI = \frac{\sum Q_n W_n}{\sum W_n}$$

Where,

Q_n is the quality rating of nth water quality parameter,

W_n is the unit weight of nth water quality parameter.

The quality rating Q_n is calculated using the equation

$$Q_n = 100\left[\frac{(V_n - V_i)}{(V_s - V_i)}\right]$$

Where,

V_n is the actual amount of nth parameter present,

V_i is the ideal value of the parameter, $V_i = 0$, except for pH ($V_i = 7$)

V_s is the standard permissible value for the nth water quality parameter.

Unit weight (W_n) is calculated using the formula

$$W_n = \frac{k}{V_n}$$

Where, k is the constant of proportionality and it is calculated using the equation

$$k = \frac{1}{\sum V_s = 1,2,\ldots,n}$$

Results and Discussions

Physicochemical Parameters

Results of physicochemical characteristics of groundwater samples (n=31) have been summarized in Table 1. Total dissolved salt content (TDS) is found to be very high (mean=1045 mg/L) violating the WHO permissible limit (500 mg/L) in all the collected samples where it ranges between 508-3710 mg/L (Table 1). About one third of total collected samples even deviate from Pakistani guideline of TDS (1000 mg/L) for drinking purpose. The pH fluctuates between neutral to alkaline (range 7.1-8.0) which is within the WHO guideline (6.5-8.5) for drinking water.

Calcium content showed wide variation where it spans between 42-156 mg/L. Except a few, all the wells showed excessive Ca concentration against WHO reference value of 75 mg/L (Table 1). On the other hand, Mg content is found to be within its corresponding limit (range: 59-176.3 mg/L; mean: 93.5 mg/L) except one sample which contains elevated concentration of Mg (176.3 mg/L). This sample is also high in its TDS, Na, K and Cl contents (Table 1) which indicates sewage mixing with groundwater (Cole et al., 2004). It is widely believed that Mg occurs in relatively less quantity as compared to Ca in groundwater (Davis and De Wiest, 1966). However, one-third of collected samples show relatively high Mg concentration over Ca which depicts that the groundwater is interacting with dolomitic rocks and clays. Since the subsurface rocks are dominated by clays and limestone, the source of Mg in groundwater is assumed to be these lithic layers.

Sodium and Chloride distribution is very heterogeneous in the groundwater of Liaquatabad town where both varied in the range of 59-176 mg/L and 53-1049 mg/L respectively. About one third of total collected samples exceeded WHO permissible limit for Na and Cl concentration (Table 1). The mean concentration of both Na and Cl is found to jump over the WHO allowed values of 200 and 250 mg/L respectively. Interestingly all the samples high in Na are also high in Cl content except 3 wells (Table 1). It indicates that both these elements are released by the common source. The natural source of these two ions is halite dissolution, water-rock interactions, saline seeps, and minor atmospheric contributions (Panno et al., 2006).

In urban areas, human activities including road salt, effluent from industrial facilities, leachate from municipal landfills, effluent from private and municipal septic systems, and some agricultural chemicals are also responsible for the high Na and Cl content in the groundwater (Mason et al. 1999; Buttle and Labadia, 1999; Naftz and Spangler, 1994). Since Karachi is very densely populated city which developed infrastructure including highways and roads, the major contribution of these ions seems to be the human activities compared to natural source. Besides, low rate of rainfall and evaporation due to semi-urban climate are further concentrating this salt into the groundwater system of Karachi city.

A wide interval of bicarbonate concentration (range: 250-550 mg/L) occurred in the groundwater where about two third of total collected samples (n=31) are affected by its elevated content (Table 1). Generally, bicarbonate occurs as major anion in the groundwater system. However relatively high bicarbonate (mean: 338 mg/L) coupled with elevated Ca (mean: 99 mg/L) in the groundwater of Liaquatabad town suggests the interaction of water with limestone units occurring as part of Nari and Gaj formations. Calcite solubility is governed by pH i.e. the lower the pH (more hydrogen ions) the more calcite will dissolve (Pokrovsky et al., 2009). Similar is true about groundwater of study area where pH of almost all groundwater wells is found to be < 8 (Table 1).

Mean concentration of sulphate is found to be 97.68 mg/L which is within the admissible limit of WHO (250 mg/L) for drinking water. However, distribution pattern of Sulphate is highly uneven in the study area where it ranges between 16-252 mg/L. This heterogeneous distribution of sulphate suggests that multiple factors are influencing its concentration in study area. In industrialized countries sulphate concentration from atmospheric deposition varies between 0-6 parts per thousand (Krouse and Mayer, 2000; Rock and Mayer, 2002 ; Mayer, 2005). It is consistent with the fact that where enormous amount of sulfur is released in the atmosphere through industrial emission and fuel burning in Karachi city.

Similarly, groundwater revealed showed uneven distribution pattern of nitrate content (range: 2.4-19.1, mean: 8.54). About two third of total collected samples showed NO_3 concentration <10 mg/L while others exceeded the permissible guideline of WHO for drinking purpose. It indicates that either nitrate production in low in the aquifers or nitrate reducing bacteria are active in the groundwater of study area. Latter is supported by exceptionally high bicarbonate content suggesting that organic matter decomposition is likely due to nitrate reduction in the groundwater of study area (Davis and De Wiest, 1966).

Water Quality Index

Weighted arithmetic index method of WQI is used to assess the quality of groundwater in Liaquatabad town. It is a simple method that aims at giving a single value to water quality

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Table 1 Physico-chemicals parameters determined in groundwater of Liaquatabad Town

S. No.	Physical Parameters			Major Cations				Major Anions			
	Depth	pH	TDS	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3
	meter		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	55	8.02	3710	42	67.92	950	9	550	691.28	252.3	6.18
2	40	7.94	786	102	67.92	210	6	250	228.65	89.54	15.43
3	24	7.73	665	104	88.45	120	7	350	194.98	122.1	6.206
4	-	7.51	730	118	98.54	126	9	350	182.57	97.68	6.182
5	30	7.62	773	127	107.73	135	9	350	196.75	122.1	6.668
6	78	7.95	877	100	110.57	178	7	337.5	257.01	97.68	15.19
7	37	7.57	818	154	106.07	172	6	325	212.7	73.26	15.47
8	-	7.64	801	102	99.10	162	8	250	207.38	130.2	13.9
9	34	7.36	929	88	67.55	272	6	375	294.24	81.4	6.574
10	53	7.54	762	93	91.53	152	8	337.5	246.38	122.1	13.54
11	46	7.22	1270	92	85.13	325	6	550	478.58	130.2	5.017
12	37	7.66	1820	97	85.21	460	10	412.5	973.10	73.26	10.08
13	43	7.32	1120	90	100.24	240	9	325	428.95	170.9	13.51
14	-	7.36	1680	106	88.33	470	7	350	886.25	73.26	7.634
15	24	7.38	663	70	79.58	118	4	275	53.175	40.7	4.981
16	43	7.25	920	84	90.88	158	6	350	100.44	114	11.54
17	46	7.26	732	83	76.38	130	6	275	85.08	73.26	6.356
18	37	7.45	653	92	94.04	111	6	250	173.71	130.2	4.131
19	46	7.15	1130	108	125.87	162	13	312.5	414.77	40.7	5.526
20	70	7.29	784	86	99.27	120	7	300	223.34	16.28	4.532
21	24	7.69	724	100	83.84	120	5	312.5	200.29	16.28	5.652
22	46	7.39	840	68	59.05	179	5	350	223.34	138.4	5.112
23	43	7.21	1710	144	130.98	322	10	300	762.18	146.5	7.716
24	61	7.48	1600	100	110.57	326	11	300	671.78	146.5	19.17
25	26	7.61	798	156	67.07	160	6	332.5	230.43	73.26	5.072
26	16	7.59	508	98	71.81	93	15	332.5	115.21	56.98	2.48
27	18	7.41	715	88	96.71	112	14	322.5	212.7	40.7	7.936
28	70	7.56	848	70	101.45	150	6	335	272.97	65.12	7.208
29	18	7.55	716	68	97.93	175	7	377.5	210.93	81.4	15.22
30	-	7.29	1800	138	176.3	330	13	352.5	1049.3	114	7.32
31	58	7.99	530	98	73.02	110	8	290	154.21	97.68	3.084
WHO Limit	-	6.5-8.5	500	75	150	200	12	300	250	250	10
Mean	41.59	7.52	1045.6	98.9	93.52	220.9	8.03	338.06	342.99	97.68	8.54
Min	16	7.15	508	42	59.05	93	4	250	53.18	16.28	2.48
Max	78	8.02	3710	156	176.30	950	15	550	1049.3	252.3	19.17
St. Dev	16.61	0.24	621.94	25.24	23.11	168.2	2.78	68.12	270.2	48.48	4.43

by translating the list of parameters and their concentrations present in a sample into a single value.

This single value in turn provides an extensive interpretation of the quality of water and its suitability for various purposes like drinking, irrigation, industrial etc. (Abbasi and Abbasi, 2012). First step for calculating WQI of groundwater is to estimate the quality rating of each parameter using the formula: $Q_n=100*[(V_n - V_i) / (V_s - V_i)]$. If quality rating $Q_n = 0$ means complete absence of pollutants, while $0 < Q_n < 100$ implies that, the pollutants are within the prescribed standard and when $Q_n > 100$ implies that, the pollutants are above the standards (Gungoa, 2016). In collected samples Q_n of TDS (209.11), Ca (131.87), Na (110.45), HCO_3 (112.69) and Cl (137.20) are above 100 (Table 2) which indicates that these are the main components responsible for deteriorating the water quality.

Table 2 Water Quality Index of collected groundwater samples from Liaquatabad Town

Parameters	pH	TDS	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3
	-	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Observed Value (V_n)	7.52	1045.55	98.9	93.52	220.9	8.032	338.06	342.99	97.68	8.54
WHO limits (V_s)	8.5	500	75	150	200	12	300	250	250	10
Ideal value (V_i)	7	0	0	0	0	0	0	0	0	0
Q_n	34.67	209.11	131.87	62.35	110.45	66.93	112.69	137.20	39.07	85.40
$W_n = k / V_n$	0.35	0.01	0.04	0.02	0.01	0.25	0.01	0.01	0.01	0.29
Q_n*W_n	12.02	1.23	5.18	1.22	1.63	16.44	1.11	1.622	0.46	25.17
Water Quality Index = $\frac{\sum Q_n W_n}{\sum W_n}$ = 66.1										

Second step is to calculate the unit weight (W_n) of all the physicochemical parameters with the help of formula: $W_n = k / V_n$, which is shown in Table 2. These unit-weights transformed all the concerned parameters of different units and dimensions to a common scale (Bora and Goswami, 2016).

Table 3 WQI range, status and possible usage of the water sample (Brown et al. 1972)

WQI	Status	Possible usages
0 – 25	Excellent	Drinking, Irrigation and Industrial
25 – 50	Good	Domestic, Irrigation and Industrial
51 -75	Fair	Irrigation and Industrial
76 – 100	Poor	Irrigation
101 -150	Very Poor	Restricted use for Irrigation
Above 150	Unfit for Drinking	Proper treatment required before use.

Calculated value of water quality index (WQI=66.1) by Brown et al (1972) categorizes the groundwater of Liaquatabad town as fair quality water which lies in the range of 51-75 (Table 3). Weighted arithmetic index method of WQI reveal that the groundwater of study area is not suitable for drinking purpose. However, it can use for the industrial and irrigation purpose.

Conclusion

Groundwater quality of Liaquatabad town is not suitable for drinking purpose. The main outliers in the wells of Liaquatabad town deteriorating the water quality are TDS, Ca, Na, HCO_3 and Cl. High content of TDS, Na and Cl indicates the mixing of sewage water which may infiltrate from the river channels and nala surrounding the study area. Calculated value of WQI revealed that the groundwater is grouped into fair category of water quality which indicates that it is unfit for drinking purpose but suitable for the irrigation and industrial use.

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