IMPACT OF POPULATION GROWTH ON GROUNDWATER QUALITY – A CASE STUDY IN URBAN INDIA

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ABSTRACT

Water quality monitoring is a matter of utmost importance to maintain the quality of potable sources in rapidly growing areas. Recognizing the factors that have an impact on the quality of water source is vital. To assess the impact of population growth on groundwater quality for drinking, a study was undertaken in a capital city of eastern India. Based on density of residents, the study area was grouped into five clusters; covering all clusters a sum of fifty-eight samples from drinking water sources was collected and characterized by relevant water quality parameters. The nonparametric Kruskal – Wallis χ^2 was significant for all the parameters and a transition of NO_3 and K from densely to sparsely inhabited area had become evident from multi-comparison test and subsequently denoted the effect of population density on drinking water quality parameters in the study area.

KEYWORDS: Population growth, Groundwater quality, Urban India, Kruskal – Wallis χ^2, Multi-comparison test

1 INTRODUCTION

Water quality protection and maintenance is one of the major issues in environmental research. Monitoring water quality gives information to ensure suitability of a water source for its designated use. Assuring good quality of the water for drinking is prerequisite for well being of a civic society. In Asia, the urban population has grown by 53% per annum [1] that means to trigger up the demand for new settlement, energy, land and water, infrastructural build-up and thereby mounting the pressure on natural resources. If astute measures has not undertaken on time, receiving tainted water for drinking is the impending reality of our heavily urbanized future. The process of urbanization modifies natural hydrological situation, intensifies run-off, pollutant loading and wastewater discharge, decrease river base flow and subsequently magnifies the anthropogenic impact on the environment [2]. Water quality degradation due to urban growth and industrialization has described at several places around the World [3-6]. Extensive abstraction of water from underground aquifer beyond its recuperation capacity hastens the transportation of chemicals / pollutants through infiltration; overburden it with unfavorable substances and consequently limits its utility in various water use sectors. Arsenic contamination at shallow aquifer level has been observed in the urban areas of Punjab [7]. Nitrate contamination of groundwater due to seepage from septic system has been experienced in Austin, Tacoma, and Washington [8]. Consequences of anthropogenic activities on the quality of underground aquifer are reported from Thanjavaur city of south India [9], Varanasi in north India [10, 11] and Solapur, in central India [12]. Elevated presence of NO_3, Fe, F, Cl and SO_4 in groundwater is obtained at Puri, an acclaimed tourist place in eastern India [13]. Underground aquifer once gets adulterate then costs heavily to restore purity even after prolonged treatments and management practices. Groundwater is therefore at risk; prevent it from degradation needs strategic planning as it will be the major available drinking water source in our forthcoming future [14]. Water quality fluctuates with seasons, varies across the spaces due to geogenic make-up and anthropogenic intervention. Selection and analyses of water samples for recognizing the impact of factor/s, which predominantly influences the water quality are most crucial to organize the activities under water quality management. The effect of land use change on different water quality parameters are well demonstrated at regional and watershed scale at many places [15-19] where baseline data were available and data comparison makes effective for further planning and related activities. In general, under water abundant region, availability of primary dataset on water quality is hardly available or available in grey literature during the developmental phases; data interpretation thus becomes a challenge.

Bhubaneswar, the capital of Orissa is a fast growing city in eastern India. It has rapidly expanded, converted more and more unused land, forest-cover, and ranch to

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public settlement like residential colony, offices, malls and commercial complexes. The city accommodated 219211 residents in 1981, 411542 in 1991 and 648032 in 2001 with an average density of 2359, 3299 and 4800 resident/km^2 respectively. Groundwater is one of the important potable water sources, needs priori attention to maintain its quality during growing period of the city. No comprehensive information on drinking quality of groundwater at different localities is available. Disproportionate population growth with limited land mass put up stresses on water quality and the impact is not well defined or understood because it depends on physiography, socio-economic conditions and administrative set up at a particular local context.

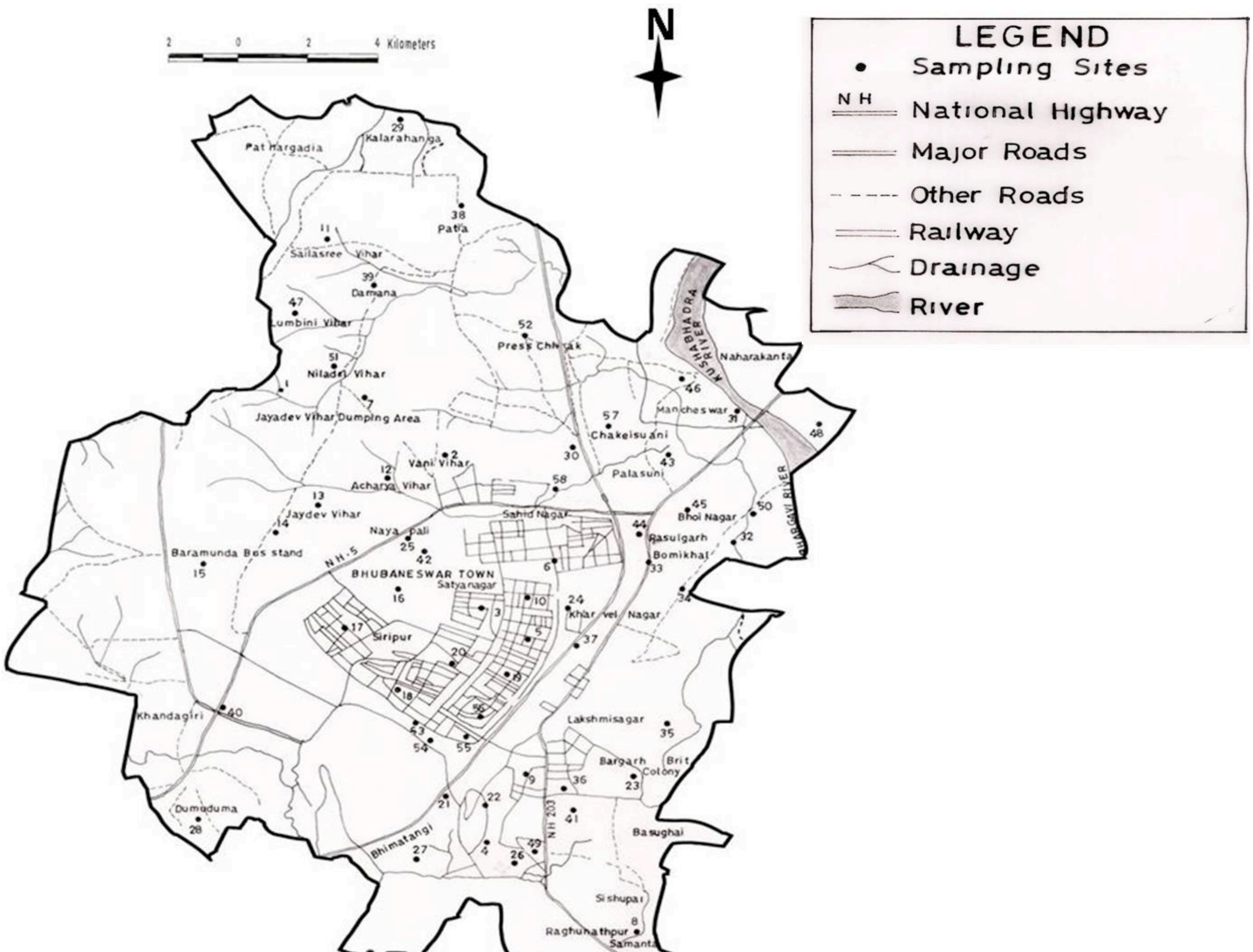
Population growth is one of the integral components of urban spread, manifests developmental status of a city under Indian context. The purpose of the study is to describe the use of nonparametric statistics and multi-comparison test for assessing the impact of population size on groundwater quality including its present status in a growing city of India.

2 MATERIALS AND METHODS

The study area is located at 20^{0}12′42″N latitude and 85^{0}47′18″E longitude, 45 m msl altitude and covered 135 km^2 geographical area. It receives 1450 mm (mean) annual rainfall, temperature ranges from 16 to 40^{o}C, enjoys humid tropical climate, and underlain by laterized Athgarh sandstone at east and alluvium at south – eastern part [20].

2.1 Sample collection and analysis

In respect of number of residents residing per unit area (million / km^2), the study area was distributed into five clusters designated as ‘very dense’ (D1, 0.025 – 0.02), ‘dense’ (D2, 0.02 – 0.015), ‘moderately (D3, 0.015 – 0.01), medium (D4, 0.01 – 0.005) and low dense’ (D5, 0.005 – 0) populated area [21]. Random sampling method was followed for collecting groundwater samples from various localities across the study area where residential establishments, commercial complexes and public offices have



MAP OF BHUBANESWAR CITY

FIGURE 1 - Sampling locations in the study area

TABLE 1 - Analytical methods and the equipment used for sample analyses

Tested parameters	Methods followed	Equipment used
pH	Electrometric	pH Meter (Metlar, 120 pH meter)
Conductivity	Electrometric	Conductivity Meter
Chloride	Argentometric titration	
Sulfate	Turbidimetry	Nephelometer (Systronics, 331 E).
Nitrate	Kjeldhal method	Gerherdt Nitrogen analyzer (Model: KB20)
Fluoride	Fluoride electrode	Ion selective electrode meter (Orion, 720A+)
Sodium, Potassium	Flame emission	Flame Photometer (Systronics, FPM 20)
Calcium, Magnesium	Titration by EDTA	
Iron	Colorimetric (using *o*-phenanthroline)	Visible Spectrophotometer (Systronics, Spectronic 20)

TABLE 2 - Population density and distribution of water samples collected in Bhubaneswar city

Category*	Area km^2	Population Density (per sq km) Range*	Administrative units*	Id. No. of collected water samples
Very dense area	5.27	20000 – 25000	Ward 8, 15, 28, Unit-28, Unit-7, Unit-14	21, 22, 23, 26, 27, 32, 33, 34, 35, 36, 37, 41, 43, 45, 49, 50, 53, 54, 55, 56, 57
Dense area	17.78	15000 – 20000	Ward 5, 9, 11, 23, Unit-2, Unit-3, Unit-9, Unit-11, Unit-30	5, 8, 19, 20, 24, 44
Moderately dense area	19.25	10000 – 15000	Ward 10, 12, 16, Unit-8, Baramunda Bus Terminal Surrounding Area, Unit-6 (Ganga Nagar, Bapuji Nagar) Unit-4 (Bhouma Nagar), Unit-30, Unit-31 (Buddha Nagar), Forest Park Area, Ram Mandir Area	3, 4, 6, 10, 14, 15, 16, 17, 18
Medium dense area	69.97	5000 -10000	Damana, Gadakan, Mancheswar, Vanivihar, Unit-13, Unit—15, Unit—16, Unit—17 (Nayapalli Area), Koradakanta, Unit—35, Tankapani Road, Unit—29, Kedargouri Area, Bindusagar Area, Lingaraj Nagar Area, Mahabhoi Sasan	2, 9, 12, 13, 25, 30, 31, 39, 42, 46
Low dense area	22.92	0-5000	Unit-22, Unit-20, Unit-19, Khandagiri, Udaygiri, Aiginia, Dumuduma, Begunia, Jadupur, Ransinghpur, Bharatpur, Sampur, Ghatikia, Ekamrakanan, Chandrasekharpur, Sikharchandi, Patia	1, 7, 11, 28, 29, 38, 40, 47, 48, 51, 52, 58

*Source: http://www.orissa.gov.in/forest&environment/ [21]

come up inconsistently over space. A total of 58 water samples covering all localities, was collected from bore well with a depth varied from 9 to 75 m below surface, at household / business centre / office / commercial complex, where the source was mainly utilized for drinking, washing and related household activities. The number of samples collected under D1 was 21, 6 in D2, 9 in D3, 10 in D4 and 12 under D5 populated area (Table 2). After drawing off water from the well for few minutes, the sample was collected in sterile and dried polypropylene bottle of 500 ml capacity and with 2/3 drops of ultra pure sulfuric acid (36N) at pH ≤ 2.0 for NO_3^-, and hydrochloric acid (12N) for Fe^{2+} ion analyses in separate containers. To obtain the maximum possible change of relevant water quality attributes, sampling was done during February – March 2008 i.e. at pre-monsoon period and were tested for relevant water quality parameters following the procedures (Table 1) outlined by APHA [22].

2.2 Data analyses

Data generated per sample were first arranged under respective population density clusters, analyzed for descriptive statistics and simple correlation (r) among the variables. Assuming the variation was not due to varied population sizes from where the samples collected in the study area as null hypothesis, the nonparametric Kruskal –Wallis test, which is independent on pattern of distribution was performed [23, 24]. It is a useful technique [25] for the sample (N) size >20 and also known as 'Analysis of variance by ranks'. The Kruskal –Wallis test statistic H was calculated as

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_i} - 3(N+1) \quad (1)$$

Where n_i is the no. of observations in the group i.e. N = $\sum_{i=1}^{k} n_i$ is the total no. of observations in all groups, and R_i is the sum of ranks of n_i in i^{th} group. The assigned rank was crosschecked by $\sum R_i$ = N (N+1)/2. For tied ranks, a correction factor (C) was introduced and the corrected H value (H_c) was computed [26] as follows:

$$C = 1 - \frac{\sum t}{N^3 - N} \quad (2)$$

$$H_c = \frac{H}{C} \quad (3)$$

$$\sum t = \sum_{i=1}^{m} (t_i^3 - t_i) \quad (4)$$

Where t_i is the number of ties in the i^{th} group, and m is the number of groups of tied ranks.

Data were then tested for homogeneity of ranks. Whenever a significant H-value was obtained from the Kruskal – Wallis test (1), a post hoc analysis for multiple comparisons was performed at α=0.05. Number of observations (n_i) was not same across the population density clusters (Table 2) therefore the test suggested by Dunn [27] for nonparametric multiple comparison with unequal sample sizes, was carried out. All statistical analyses were done in Statistical Analysis Software (SAS) package, version 9.0.

3 RESULTS AND DISCUSSION

Data pertaining to water quality attributes presented in Table 3, reflect that the samples were acidic to neutral in reaction with low salinity value. Calcium preceded by Na and Fe in cationic sequence while Chloride headed the anionic suite followed by Sulfate and Nitrate ions. Based on permissible limits of drinking water quality attributes [28, 29], 53% of the samples was found unfavorable by pH (6.5 – 8.5) and Fe (0.3 – 1.0 mg/l), and 18.96% by NO_3 content (45 – 100 mg/l). Nitrate concentration was high in 1/5 of the samples collected from bore well having a depth of ≤20 m from ground surface. Besides, K and EC also exceeded their respective threshold levels in 17.24 and 10.34% samples respectively.

3.1 Impact of population growth on water quality

A high to low value of water quality attributes is evident without maintaining any consistent trend with population size, from 'very dense' to 'low dense' clusters (Table 3). Nitrate (NO_3) concentration was highest under 'D1', Fe in 'D2' and K in 'D3' populated areas. Kruskal – Wallis χ^2 was significant for all the parameters at $P < 0.05$ level that means null hypothesis got rejected and the alternative hypothesis i.e. the variation in samples due to change in population sizes across the places from where it collected, became true. Among the estimated eleven water quality attributes, pH did not change much with population density classes; the concentrations of Na, Ca, Mg, F, Cl and SO_4 varied but not exceeded their corresponding thresholds prescribed under drinking water quality guidelines (Table 3) and hence not considered for multi comparison test statistics.

The multi – comparison analysis of the rest four parameters illustrated in Fig. 2, reveals that EC in 'D2' was at a par with 'D1', 'D3' and 'D4' but differed with 'D5'. Iron concentration under 'D3' was different from 'D1' and 'D5'; K at 'D1' was dissimilar with 'D2', 'D3', and 'D5' category. Nitrate concentration however distinctly varied between 'D1' and 'D4' / 'D5'. Thus, the change pattern of EC and Fe across the population density clusters was not evident but more or less visible in K and nitrate concentration. The EC was however not much deviated (10.34%) from its prescribed threshold but not Fe, which incoherently varied with population density classes. An elevated presence of Fe in groundwater is widespread in Orissa [30]. High iron concentration is due to the presence of Fe – oxyhydrochloride, it reduces to produce soluble Fe^{+2} species under reduced environment [20]. Presence of Fe in groundwater may therefore be due to geogenic influence rather than population size variation.

Disposal of human excreta and other forms of wastewaters in septic tank / cesspool is a common practice in urban areas. This wastewater is emptied to municipal sewerage system through drainage network. If the drainage channels are not properly covered or lined, frequent spillover especially during rainy season spread the wastes on surface, liquid seeps into vadose zone and contaminates the quality of underground aquifer. Skewed habitation, unplanned structures, lack of infrastructural services for collection, transportation, treatment, and disposal of domestic wastewater induce deterioration of water quality as observed in Lake Ömerli reservoir in Turkey [31]. Con-

TABLE 3 - Trend of water quality (Mean ± standard error) attributes across the population density clusters

Variables	Threshold levels for drinking water*	Population density clusters				
		High density area (D1)	Dense area (D2)	Moderately dense area (D3)	Medium dense area (D4)	Low dense area (D5)
pH	6.5 – 8.5	5.87 ± 0.10	5.56 ± 0.07	5.36 ± 0.14	5.73 ± 0.12	5.65 ± 0.13
EC (dS/m)	0 – 0.3	0.19 ± 0.02	0.34 ± 0.06	0.14 ± 0.03	0.11 ± 0.02	0.02 ± 0.01
Fe(mg/l)	0 – 1.0	4.59 ± 0.67	5.96 ± 0.67	13.21 ± 1.62	6.50 ± 1.29	4.27 ± 1.00
Cl (mg/l)	0 – 250	66.19 ± 2.44	69.74 ± 6.67	58.51 ± 4.99	56.74 ± 2.99	44.33 ± 2.32
Na(mg/l)	0 – 200	26.67 ± 1.74	27.67 ± 2.70	23.38 ± 2.46	19.10 ± 2.02	11.50 ± 1.21
K(mg/l)	0 – 10	9.40 ± 1.34	17.67 ± 3.92	3.81 ± 0.48	6.25 ± 1.14	2.54 ± 0.42
NO_3(mg/l)	0 – 45	110.68 ±12.7	17.74 ± 3.05	16.16 ± 3.08	4.27 ± 0.63	3.28 ± 0.82
F(mg/l)	0 – 1.5	0.08 ± 0.01	0.13 ± 0.01	0.10 ± 0.01	0.07 ± 0.01	0.06 ± 0.001
Ca(mg/l)	0 – 30	26.05 ± 2.18	26.72 ± 2.41	18.04 ± 1.50	17.64 ± 2.25	12.02 ± 1.43

Mg(mg/l)	0 – 10	6.23 ± 0.39	4.80 ± 0.44	7.65 ± 1.09	6.36 ± 0.93	4.40 ± 0.45
SO_4(mg/l)	0 – 500	10.81 ± 1.20	9.65 ± 1.26	6.30 ± 1.77	8.85 ± 1.30	3.37 ± 0.47

*Prescribed by WHO (2004) [29] and ISI (1991) [28] tamination of groundwater by NH_4 and NO_3 ions at Warri river plain due to growing activities of urbanization was reported from Nigeria [32]. The degree of contamination due to septic tank system may go up to 3 acres from one fourth of an acre [33]. Accumulation of Na, K, Fe and Mg was also noticed at sewage-dumped sites in Nigeria [34], but the magnitude of load varies depending upon volume and nature of discharge, waste treatment facility and local climate.

Simple correlation (r-value) among the water quality parameters (Table 4) reflects their interdependence e.g. NO_3, which positively correlated with pH in three of five population density clusters that may due to its role to act as terminal electron acceptor, and promoting microbial growth under anaerobic environment [35]. Excessive intake of NO_3 (>100 mg/l) could disrupt oxygen transportation and develops methaemoglobinaemia in infants, gastrointestinal cancer and related physiological disorders in adults [36]. Correlation between K and Cl, and Na indicate its role to control salt balance except in 'low density' populated area (Table 2). Potassium as such is not harmful but elevates blood K level, causes abnormal breakdown of protein molecule and renal dysfunction in human body at extreme concentration level [37, 38].

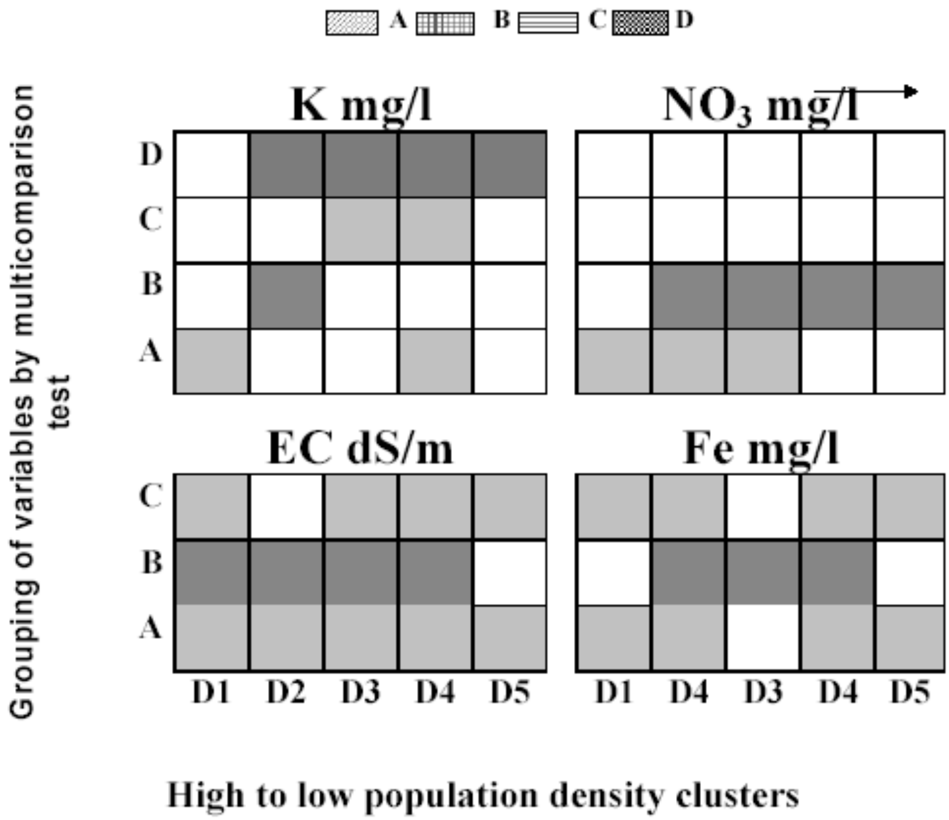


FIGURE 2 - Transition of particular water quality attributes with population density clusters

TABLE 4 - Simple correlation (r – values) among water quality attributes under different population density clusters

Attributes	pH	EC (ds/m)	Fe (mg/l)	Cl (mg/l)	Na (mg/l)	K(mg/l)
			Very dense (D1)			
K(mg/l)	-	0.76[b]	-	0.70[b]	0.79[b]	-
NO_3(mg/l)	0.46[a]	-	-0.43[a]	-	-	0.62[b]
			Dense (D2)			
K(mg/l)	-	0.83[b]	-	0.81[a]	-	-
			Moderately dense (D3)			
K(mg/l)	-	-	-	-	0.63[a]	-
NO_3(mg/l)	0.67[a]					
			Medium dense (D4)			
K(mg/l)	-	0.80[b]	-	0.85[b]	0.83[b]	-
NO_3(mg/l)	0.65[a]	-	-	-	-	-

[a] and [b] are significant at P < 0.05 and <0.01 levels

The study helps to generate first hand information on the impact of population size on water quality parameters. Impacted parameters thus emerge as essential attributes to monitor at periodic interval and undertaking necessary measures for maintaining their respective threshold concentration level/s to ensure good quality water for drinking purpose.

4 CONCLUSION

The effect of population growth and allied activities are not environment – friendly in all segments, unless addresses, providing quality services for the essentials remain impractical. Under the circumstances of non-availability of baseline data, applying nonparametric statistics, the effect of population growth on drinking quality of water was recognized and a transition of NO_3 and K concentration from intense to sparsely populated area was specified. The study thus provides an outline for recognizing the impact of population growth on particular water quality attributes and helps in structuring activities for monitoring and restoring drinking water quality of the concerned area.

The authors have declared no conflict of interest.

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