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Evaluation of Shallow Groundwater Quality in Urban Areas of Karachi (Pakistan)-Inorganic Nutrients and Bacterial Contamination

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A total of 193 groundwater samples, collected from Karachi-urban areas, were analysed to determine the concentrations of nitrate, nitrite, ammonia and bacterial densities (coliform and faecal coliform bacteria). From nitrogen component view point groundwater quality of Karachi is acceptable for human consumption. However, coliform bacteria were higher in 83% samples than the WHO permissible limit. The inorganic nitrogen and bacteriological contamination levels suggest that the groundwater quality is mainly affected by wastewater.

Key words: Groundwater contamination, Inorganic nutrient, Faecal coliform

Introduction

Water contamination of pathogenic micro-organisms represents health risk (Falcao *et al* 1993). Microbial contamination is mainly due to the discharge of sewage with faecal wastes containing pathogenic microbes responsible for a variety of water borne diseases. Numerous cases of groundwater contamination by both ammonium and faecal coliform bacteria have been documented worldwide (Fried 1975; Jackson 1980; Chalapati *et al* 1986).

The quality of ground water of Karachi, a mega-city having a population of 14 million, has been deteriorated both chemically and biologically due to mixing of seepage of sewage wastewater from sewerage lines with ground water.

The locations and water quality of wells demonstrate the effect of point source contamination on the groundwater of Karachi. There are various non-point sources and although, their identification is not possible, they have a direct effect on increasing the contamination level of inorganic nutrients and bacteria in the groundwater of Karachi.

In the study area there are various receptacles for the sewage. Initially the earlier homes had bucket latrines and/or soak pits, which were later developed to septic tanks and cesspools. The waste and wastewater from these devices would eventually end in the sub-surface earth material. Unless choked or overflowed these facilities are not regularly attended. The extremely inadequate sewerage facilities experience frequent choking and overflowing. People living in slum areas (Kachhi Abadies) would at best have soakpits. Otherwise their sewage would be discharged in the open, generally through surface drains, often unlined, removing the sewage to some neighbouring open area, pit or storm drain. The natural intermittent or epheermal streams or man-made storm drains flowing in the urban areas no longer carry the storm runoff. They have perennial flow of untreated sewage, mixed with waste from various other urban sources. The overloaded sewerage is also subjected to leakage due to over flowing and choking. The holes punched by the sanitary staff also add to this leakage. In some places water lines are only a few centimetres below the sewerage line. Many water lines are virtually submerged in ground saturated with a mixture of water and sewrage. All this water from different non-point sources eventually gets infiltrated into groundwater through unconsolidated sediments of sand, silt, gravel and sandy clay.

The specific objectives of this work is to evaluate the bacteriological and inorganic nutrient quality of well water, to assess the potential contamination affecting the aquifer in this part of country, and to determine the potential health risks to the population associated with the use of the contaminated water in urban areas of Karachi for drinking and domestic purposes.

Materials and Methods

After carrying out the reconnaissance survey of the study area in 1993, it was decided to collect the samples according to population density in each district rather than size of the districts.

Groundwater samples (193) were collected from shallow domestics wells during the period 1993-1995 from five dis-

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tricts of Karachi (Fig 1). The inorganic pollutants were analysed in 1993, while the coliform and faecal coliform were monitored for three consecutive years in 1993, 1994 and 1995.

Two litre white polyethylene (plastic) bottles were used for collecting samples. The samples were divided into two portions, one was used for nitrate, nitrite and ammonia and the other for bacteriological analysis. For the bacteriological tests bottles were sterilised in an autoclave at 121°C for 30 min before taking to the field for sampling. Standard Methods (APHA, 1980) were employed for analytical work.

The most probable number (MPN) of coliforms and faecal (thermotolerant) coliforms were estimated by the multiple (five) tube method (APHA 1985). The results were compared with McCradys chart for the estimation of bacterial densities reported Mc Cradys (1918).

Results and discussion

Nitrate, nitrite and ammonia. Groundwater samples from the study area show that more than 80% of the samples for nitrate and nitrite, and 95% samples for ammonia are within the permissible limits of WHO standards. Results indicate that the number of wells with high nitrate content is very limited and only 3% of the samples are in the range 3 to 4.5 mg $NO_3\ l^{-1}$ (Fig 2) showing the influence of human disposal and seepage from sewerage system.

Statistical analysis of the inorganic nutrient shows high mean value, range and standard deviation of nitrite-nitrogen.

	Mean	Range	Standard Deviation
Nitrate-Nitrogen	0.43	0-4.5	0.89
Nitrite-Nitrogen	2.35	0-42	5.33
Total Ammonia	0.71	0-10.3	1.32

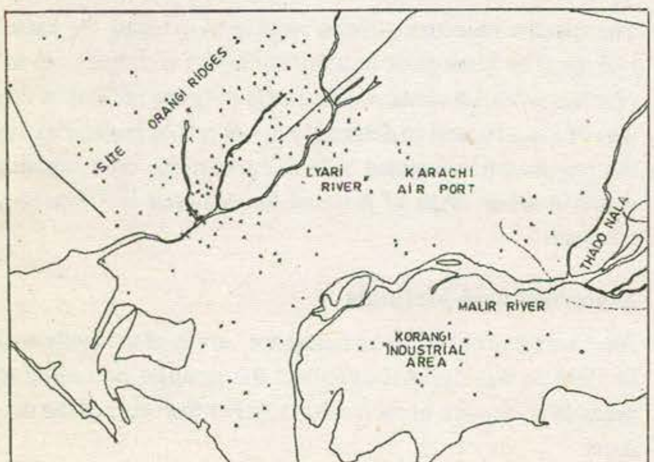

Fig 1. Sampling sites in Karachi urban area

In Karachi, seepage of sewage wastewater from sewerage lines is responsible for the deterioration of both chemical and biological quality of groundwater. The results indicate that seepage form the sewerage system is the most important anthropogenic source of pollution. The high rate of seepage through permeabe soils mainly due to the lack of repair works and sanitary seals, is a significant source of contamination of groundwater.

Coliform and faecal coliform bacteria. A lage number of the groundwater samples are polluted with faecal coliforms. The monitoring results show that 85% of the samples are contaminated by coliforms and faecal coliforms were beyond the recommended level of WHO standards (0 per 100 ml for both coliform and faecal coliform).

The rate of spread of faecal coliforms shows very clearly that the polluted area is increasing rapidly with every passing year (Fig 3). The concentration of faecal coliform bacteria is > 20 in 100 ml in the area close to the Malir and Lyari two rivers and their tributaries which pass through the densely populated localities.

The bacteriological WHO norm for acceptable drinking water (WHO, 1993) cannot be reached without the treatment of

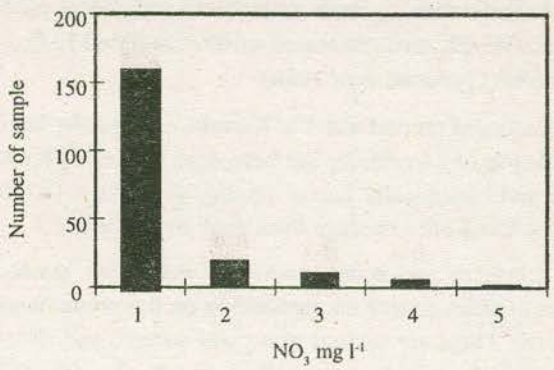

Fig 2. Frequency distribution histogram of nitrate.

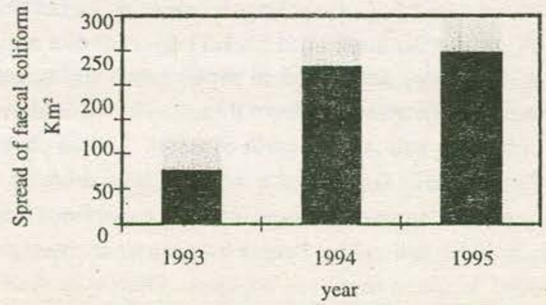

Fig 3. Spread of faecal coliform bacteria during the monitoring year.

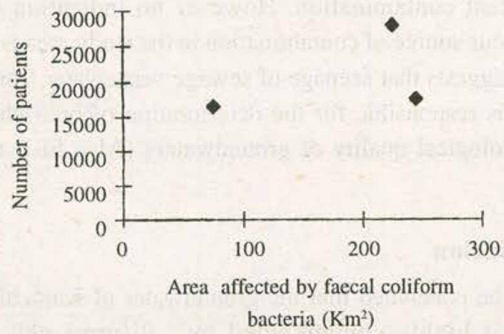

Fig 4. The relationship between faecal coliform bacteria and diarrhoeal patients.

the water. To simplify the interpretation of the high counts measure in well water, Feachem (1980). Three categories corresponding to the relative quality of the water:

Concentration	Quality of water
(Faecal colifrom count 100 ml^{-1})	
Less than 100	satisfactory
100-1000	strong contamination and risks to health
Greater than 1000	seriously pathogenic

Statistical results of coliform and faecal coliform bacteria of 93, 94 and 95 reveal that significant concentration of these bacteria occurred in 94 compared to 93 and 95. Classifying the groundwater of Karachi as proposed by Feachem (1980), the results show strong contamination and health risk to population density particularly in 1994.

	Mean	Range	Standard Deviation
CB (1993)	14.8	0-180	27.7
FCB (1993)	2.4	0-32	5.81
	Mean	Range	Standard Deviation
CB (1994)	40.0	0-238	43.4
FCB (1994)	9.55	0-156	15.7
	Mean	Range	Standard Deviation
CB (1995)	33.7	0-126	29.0
FCB (1995)	10.7	0-76	12.3

Eisen and Anderson (1979) in USA found that aquifers with an area of approximately 30 square meters in sand, silt, clay and gravel, just a few meters above sea level, are more contaminated and referred to as shallow aquifer system. The sand and gravel aquifers are most susceptible to contamination and there is a concern that pollutants in these aquifers contribute to widesparead degradation of the groundwater.

High levels of contamination with nitrate, ammonium and faecal coliform could occur as a result of unconsolidated sediments of sand, silt, clay and gravel being more vulnerable to infiltration of surface water into groundwater. This high vulnerability seems to be the result of the geology and climate of the region. There are two possible geological factors responsible for the high vulnerability of soils. Firstly, the sedimentary material, particularly sandstone and limestone rocks, display joints, cracks, fracture and fissure easily due to weathering of rocks, which allow infiltration of surface water into groundwater under sub-tropical sun and arid climatic condition facilitating the transport of contaminants. Secondly the unconsolidated deposits of sandstone are more permeable in Quaternary aquifers, further facilitating the infiltration of surface water into groundwater. The argument given by Eisen and Anderson (1979) seems to be the case for the groundwater of Karachi. He found that the contamination of groundwater from surface water is likely in silty and clay deposits within an area of approximately 30 square meters around point and non-point sources of contamination. Point sources result from the lack of proper sanitary practices and suitable drainage systems, and inadequate maintenance of the wells causing regular seepage of the contaminanats.

Throughout the history of Karachi, the poor quality of drinking water has been a major causal factor of epidemics. Faecal pollution of drinking water has frequently caused water borne disease on a large scale in the densely populated parts of Karachi.

Civil Hospital of Karachi has some statistics on water-borne disease especially for diarrhoea (since 1989) and for cholera (since 1993) which covers 30% of the population of the city (Table 1). If these figures are extended to the entire city, then the extrapolated figures of diarrhoeal patient (Table 2) up to the years 93, 94 and 95 reach to 16492, 27843 and 17536 respectively. Simultaneously the rate of deaths increases to 80, 107 and 140 in the consecutive years.

Fig 4 gives a picture of the situation. The number of cases of the diseases is well correlated with our results of faecal coliform bacteria. It shows that the spread of faecal coliform bacteria increases due to the infiltration of wastewaters into groundwaters. The number of faecal coliform bacteria or their spread mainly depends on the repair and maintenance work of the sewerage system by the civic agency. The infiltration of wastewaters into groundwater due to inadquate sanitation and deteoriated sewerage system is responsible for drinking water contamination causing diarrhoea and cholera in the studied area.

The results clearly show the severity of the problems, the pace of which will probably increase in the years to come. In addition to diarrhoea, other diseased such as typhoid, jaundice etc. occur through contaminated water and may also have the

Table 1
People affected by diarrhoea and rate of death in the year 93-95 (The data covers 30% population of the city)

Year	Number of patients	Number of deaths
1989	4658	8
1990	7643	47
1991	4813	0
1992	2986	0
1993	4123	24
1994	8383	32
1995	5261	42

Table 2
Extrapolated results of diarrhoeal patients and rate of deaths in Karachi

Year	Number of patients	Number of deaths
1993	16492	80
1994	27943	107
1995	17536	140

same impact on the population.

Classification of well water on the basis of degree of mineralisation. Nabiel *et al* (1994) classified the contamination of well water in three categories

Recent contamination	Sample being polluted with both ammonium and faecal coliform, characterized by total ammonia ranging from 0.01 to 1mg NH_4 l^{-1}, nitrate (NO_3<45 mg l^{-1}) and faecal coliform < 1 100 ml^{-1}.
Old contamination	Sample characterized by elevated level of nitrates i.e., total ammonia ranging from 1 to 5mg NH_4 l^{-1}. nitrate (NO_3 > 45 mg l^{-1}).
Continous source of contamination	Sample showing high levels (greater than old contamination) of ammonia, nitrate, nitrite and faecal coliforms.

This classification is based on the degree of mineralisation of organic matter (CH_2ON) into ammonia, nitrate and nitrite. Classifying the groundwaters of Karachi on this basis, the results show that more than 90% samples are affected by recent contamination and 8% by old contamination. This confirms that the groundwaters of Karachi are mainly affected by recent contamination. However no indication of any continous source of contamination in the study area is noted. This suggests that seepage of sewage wastewater from sewerage is responsible for the deterioration of both chemical and biological quality of groundwaters (Alaa El-Din *et al* 1992).

Conclusion

It can be concluded that the groundwater of Karachi urban areas is highly contaminated by coliforms and faecal coliforms, and moderately contaminated by ammonia, nitrate, nitrite.

The results suggest that its long-term use as a major drinking water source could have an impact on morbidity and mortality of the inhabitants. Although it appears that seepage from the drainage systems is the main factor contributing to the bacteriological contamination, and that inorganic nutrient is closely linked to infiltration of organic contaminants from the soil surface, a thorough hydrogeological study and a careful determination of the contaminant pathways must be undertaken before any definitive conclusion is drawn.

If the continued use of well water as a drinking water source is planned, a detailed hydrogeological study should first be undertaken. Corrective work should not be limited to the modernization of wells, since the reduction of the levels of bacteriological contaminants implies marked improvements in sanitation. Unfortunately, urban sanitation is often largely neglected as compared to the supply of water in most tropical cities (Cairncross 1989), even though it has been shown that improvements in excreta disposal often have a greater impact on the health of the population than improvement in water quality (Esrey *et al* 1985). Moreover highly permeable soil and shallow water table of Karachi-urban areas correspond to the situation where pit latrine sanitation and shallow underground water exploitation for drinking purposes are in direct conflict because of the facilitated migration of contaminants.

The results indicate that the modernization of a traditional well has no influence on the general bacteriological quality of water mainly because of reluctance (due to lack of knowledge, information, or education) of the population to change their behaviour when drawing water. This may be corrected either by implementing an education programme or by modifying well modernization (sealing of the opening with concrete and installation of a water hand or foot-pump). The former solution requires a long-term effort, while it has been observed that sealed wells are by far the best choice to provide and maintain a better quality water.

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