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Pollution of limestone aquifer due to urban waste disposal around Raipur, Madhya Pradesh, India

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Abstract During the rainy season deterioration in the quality of water, supplied through dug wells and tube wells, near an abandoned limestone quarry was reported. The abandoned quarry is now being used as an urban waste disposal site. The problem was further complicated by hospitalization of several inhabitants who were using this water for domestic purposes. Looking into the consequences, chemical analysis of water from the quarry, dug wells and tube wells was carried out. The water was found to be contaminated. The transportation of pollutants from the quarry to the groundwater system was facilitated by karst features. Furthermore, four major sources—domestic waste disposal, water conservation structures, landfills, and water wells—contributing to pollution were identified. This case study is an attempt to provide an understanding of how the karst features facilitate groundwater contamination. It will help us answer a few questions such as why karst hydrogeology deserves special attention in urban expansion and what protective measures should be planned in view of rapid urbanization.

Key words Pollution — Waste disposal — Aquifers — India

Introduction

Groundwater pollution resulting from waste disposal has recently become a matter of worldwide concern. It is well known that the disposal of all forms of waste has some risk of pollution of groundwater when the disposal site is in a karstic region. Karst is terrain with distinctive hydrology and landforms arising from a combination of high rock solubility and well-developed secondary porosity (Ford and Williams 1989).

Raipur city is situated at 21°14′14″N latitude and 81°38′05″E longitude, with a population of over 500,000 (Fig. 1). Chandi limestone of the Raipur Group (Chhattisgarh Supergroup) forms the major hydrogeologic unit in this area (Fig. 2). The primary porosity of this Upper Proterozoic limestone is negligible, and the secondary porosity is developed due to karst, which plays an important role in groundwater occurrence and movement.

Problem

The water-quality problem, considered for the present study, resulted from the observation of a variation in color of groundwater with suspended sediments. The water was supplied by tube wells in a residential locality near an abandoned limestone quarry. This abandoned quarry is now being used as an urban waste disposal site. The problem was encountered in the rainy season when the quarry filled with precipitation and surface runoff water. This phenomenon was overlooked and the people continued using water. After some time, many of the residents in the nearby slums had to be hospitalized due to waterborne disease like cholera, dysentery, and gastroenteritis. Jaundice, malaria, and typhoid were also on the rise. The message was clear, an epidemic had broken out.

Analytical results

Analysis of water samples from dug wells and tube wells adjacent to the quarry and of the water collected in the abandoned quarry was carried out following the methods described in APHA, AWWA, and WPCF (1975). The ana-

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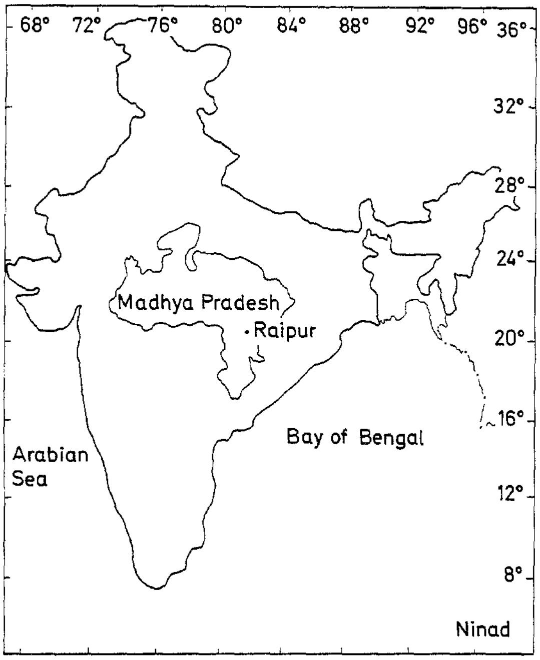

Fig. 1. Location map

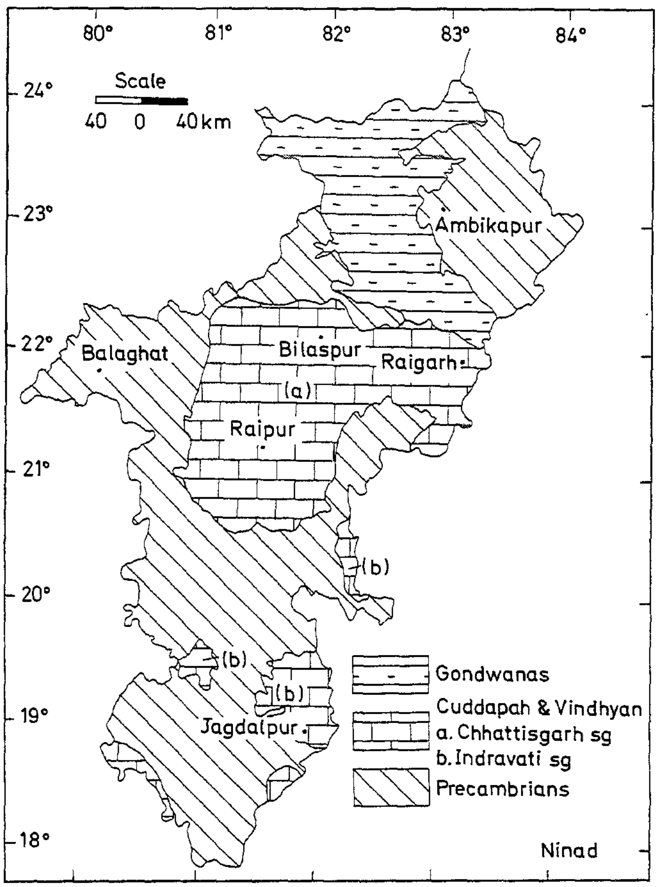

Fig. 2. Map showing regional geology

Table 1. Range of concentrations of chemical constituents in water samples from various sources[a]

Sample collected from	Ca	Mg	Na	K	HCO_3	Cl	SO_4	Total alkalinity	Total acidity	Free CO_2	Total CO_2
Quarry water	232–236	44–48	93.50–96.40	46.48–63.91	301.34–348.92	737.4–921.7	100.4–134.0	200–225	60–75	52.8–66.0	228.8–264.0
Tube well	392–420	40–58	116.50–142.40	4.98–11.62	364.78–380.64	829.5–921.7	108.0–140.0	225–275	90–120	92.4–105.6	303.6–347.6
Dug well	392–408	40–64	139.50–210.67	4.15–162.69	364.78–475.80	829.5–1152.1	108.0–133.8	225–300	90–120	79.2–105.6	290.4–343.2

[a] Based on 20 samples; all values in ppm

Table 2. Physicochemical characteristics of water samples from nineteen ponds of Faipur city[a]

Parameter	Range	Parameters	Range
Temperature (°C)	27.00–31	Oxygen saturation (%)	24.91–213.53
Secchi disk transparency	4.75–33.75	BOD	31.20–67.60
Conductivity	0.91–5.10	COD	11.36–85.44
Total alkalanity	225.22–1226.22	Total hardness $CaCO_3$	25.64–77.94
Carbonate alkalinity	34.64–450.44	Calcium	7.39–26.71
Bicarbonate alkalinity	179.02–775.78	Magnesium	1.24–4.75
Total carbon dioxide	182.95–880.88	Nitrite nitrogen	0.02–1.09
Chloride	127.46–1594.50	Nitrate nitrogen	0.24–0.65
pH	7.96–9.23	Total orthophosphate	0.66–3.15
Dissolved oxygen	2.03–16.70	Total phosphate	1.70–6.06

[a] Source: Kanungo and Naik 1987

lytical results (Table 1) were compared with the drinking water standards proposed by the World Health Organization (WHO 1971).

The physical analysis shows that the color of the water sample collected from the quarry is pale brown with a pungent smell, whereas that collected from the dug wells has a peculiar saline taste, and the water from the tube wells is clear, without any smell or bad taste. The variation in chemical constituents is observed to be maximum in water from dug wells, rather than that from the tube wells (Table 1).

Earlier, Kanungo and Naik (1987) worked on the physiocochemical characteristics of the surface waterbodies. They found that (Table 2) these waterbodies have already eutrophicated and are progressing towards hypereutrophication due to pollution through sewage and urban waste disposal into them.

Comparing the analytical results, it is observed that water collected from the quarry, dug wells, and tube wells do not deviate much in concentration of chemical constituents. This indicates that there exists a connection for transportation of surface water to the groundwater system.

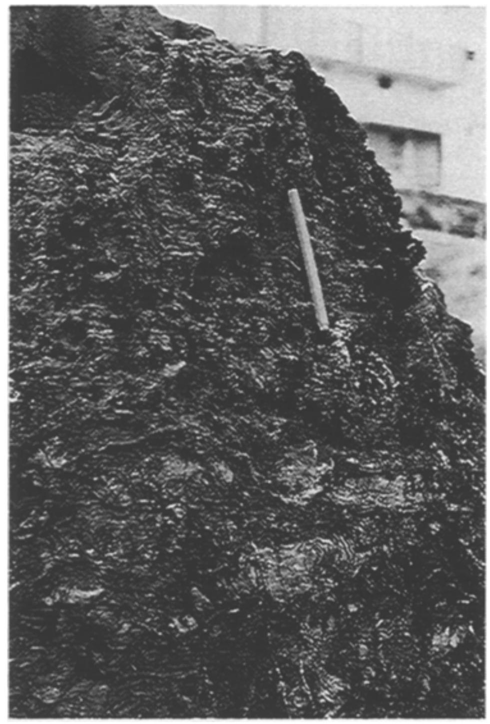

Fig. 3. Porous latsol developed over stromatolitic limestone

Transport of pollutants to the groundwater system

The analysis of water from different sources shows that the contaminants have entered into the groundwater system and are causing a threat to the life of the users. The dilution of a contaminant by nature's defense system minimizes the effect of pollutants, but in a karst region, with thin or no soil cover, the pollutants have direct access to the groundwater system without any check.

The Chandi limestone of the Raipur Group is the major aquifer that provides fresh water to Raipur city. It is covered with soil or laterite. The thickness of this cover varies up to 10 m. The laterite that is overlying limestone is highly porous (Fig. 3). The major joint patterns observed are vertical (NE–SW, NW–SE) and subhorizontal joints. Various karst features identified are grikes, klints, kareens, dolines, sinkholes, and solution-enlarged joints (Figs. 4 and 5). These karst features act as conduits and provide unchecked hydrologic communication of contaminated surface water with the aquifer.

Sources of pollution

During the course of study, four major sources contributing towards groundwater pollution were identified:

1. Domestic waste disposal: The prevailing practice includes direct disposal of domestic waste in the sewer line, which opens into the natural drainage system within the watershed area. Sewerage also is disposed into soak pits within the highly porous and permeable latsol capping over the limestone. Unregulated waste disposal in slums and areas of new urbanization without a planned sewerage disposal system leads to formation of cess pools, which are

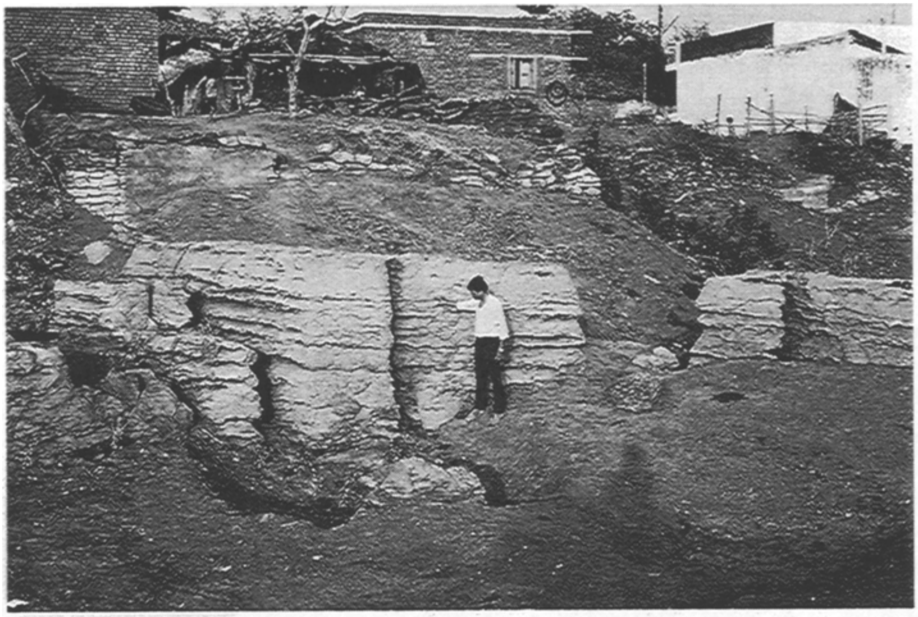

Fig. 4a, b. Development of typical karst features; solution enlarged joints **a** clefts and ridges **b** in stromatolitic limestone

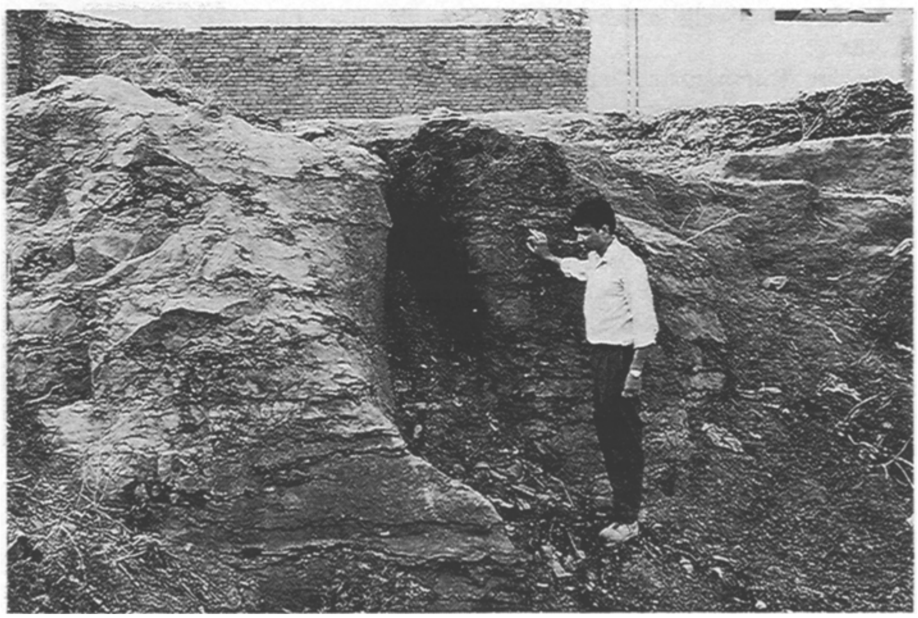

Fig. 5. Solid waste dump in solution enlarged joint

also potential contamination sources (Fig. 6). In all these systems, bacterial action digests the solid materials and the liquid effluent is discharged into the ground. Excessive concentrations of detergents, nitrate, and organic chemicals, bacteria, and viruses present the greatest threat to groundwater quality.

2. Water conservation structures: There are more than 35 water conservation structures in and around Raipur city. These are in the form of natural lakes and ponds, as well as artificially constructed stop dams. These structures act as artificial recharge sites. The inflow into these structures includes precipitation and surface runoff water. Surface runoff water carries with it dissolved and suspended constituents. Various contaminants identified are food wastes, animal feces, fertilizers, pesticides, grease and oil, and organic waste.

3. Landfills: There are more than 25 active and abandoned urban waste disposal sites in Raipur. At places, the disposal of waste is by dumping of garbage as landfills with incineration of combustible refuse in abandoned limestone quarries (Fig. 7). The current annual urban waste output exceeds 10 million tons. Along with the residential refuse, industrial, agricultural, demolition, and incineration waste are used as landfills. The landfill material includes paper products, food wastes, construction debris, septic tank sludge, plastic, glass, and chemicals.

Fig. 6. Direct disposal of domestic sewage into karstified limestone

4. Water wells: Domestic dug wells are of small capacity and tap the shallow water. Most of the dug wells have dried up due to lowering of the groundwater level. These dried up dug wells are, at places, used as community dumpholes. Tube wells for private and municipal water distribution are of higher capacity and tap deep-seated aquifers for domestic, agriculture, and industrial usages. The contaminants enter into the groundwater through a well due to well failure and because of improper well completion. Consequently, surface and groundwater percolation outside the casing, to the water table, may also occur.

Conclusion

By definition, pollution is defined to occur when contaminants are present to a degree that is judged to be harmful. The analytical results show that the concentration of various cations and anions exceed the normal range of drinking water standards. The water samples collected from the quarry and the dug wells, and tube wells adjacent to the quarry do not deviate much in concentration, which exhibits a positive hydrologic communication between the surface and groundwater. Karst features, such as solution-enlarged joints, grikes, and klints, act as conduits and play a major role in subsurface transport, thus polluting the aquifer.

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Fig. 7. Garbage disposal as landfills in an abandoned limestone quarry