NITRATE POLLUTION IN GROUNDWATER IN SELECTED DISTRICTS OF NEPAL

by

Madhu Chettri and Geoffrey D. Smith
Division of Biochemistry and Molecular Biology
School of Life Sciences, Faculty of Science
The Australian National University
Canberra, ACT 0200, Australia

ABSTRACT: A survey was made of the nitrate concentrations in groundwater from one hundred wells in the Patan and Bhaktapur districts of the Bagmati zone and the Chitwan district of the Narayani zone, Nepal. The former districts are urban and the latter is rural. Although the survey is small, it has demonstrated that there is a significant incidence of nitrate concentrations that exceed the World Health Organization's recommended limit for drinking water and that drinking-water supplies from many other wells are approaching this limit. A need exists for a larger study to determine how widespread the problem is. The primary cause is probably nitrification of nitrogen excreted by humans and to a lesser extent by animals inside settlements.

RÉSUMÉ: Un inventaire des teneurs en nitrates dans les eaux souterraines a été dressé à partir d'une centaine de puits des districts de Patan et Bhaktapur de la région de Bagmati et du district de Chitwan dans la région de Narayani, au Népal. Les premiers districts sont urbains et le dernier, rural. Bien que l'inventaire soit limité, il a été démontré qu'il existe des teneurs en nitrates dépassant les normes recommandées par l'Organisation Mondiale de la Santé pour les eaux potables, et que l'eau de nombreux autres puits, utilisés pour l'eau potable approche cette limite. Il est necessaire d'effectuer une étude plus détaillée pour connaître l'extension de ce problème. La cause première en est probablement la nitrification de l'azote de la pollution domestique et, à un moindre niveau, celle des animaux en étables.

RESUMEN: Se llevó a cabo una campaña de muestreo de las concentraciones de nitrato en el agua subterránea en 100 pozos localizados en los distritos de Patan y Bhaktapur, en la zona de Bagmati, y en el distrito de Chitwan, en la zona de Narayani, Nepal. Los primeros distritos son urbanos y el último rural. Aunque la campaña es reducida, se ha manifestado que hay una incidencia significativa de concentraciones de nitrato que exceden el límite recomendado por la Organización Mundial de la salud (OMS) para agua potable; asimismo, los suministros de agua potable de otros pozos se están acercando a dicho límite. Haría falta un estudio más completo para determinar la extensión del problema. La causa fundamental probablemente sea la nitrificación de residuos orgánicos humanos y, en menor medida, procedentes de animales.

INTRODUCTION

Nitrate contamination of drinking water is the subject of extensive research because of its potential human health hazard. The World Health Organization (WHO) has set a limit of 50 mg L^{-1} (or ppm) on nitrate in drinking water, mainly based on the formation of methaemoglobin in red blood cells as a consequence of nitrate conversion to nitrite by bacteria in the gastrointestinal tract (van Dijk-Looyaard and Montizaan, 1990). The WHO standard was originally set at 10 mg L^{-1} NO_3^--N, equivalent to 45 mg L^{-1} NO_3^- and has only recently been adjusted to 50 mg L^{-1}. Nitrate has also been linked with gastric and oesophageal cancer, because of the reaction of nitrate with amines in the diet-forming carcinogenic nitrosamines (Siddiqi et al., 1992; Forman, 1989, 1991), and implicated in diabetes (Kostraba et al., 1992).

Throughout the world, nitrate accumulation in groundwater has four major causes: (1) use of nitrogenous fertiliser in agriculture (Dudley, 1990); (2) input of organic nitrogen into soil, for example as a consequence of deforestation (Faillat and Rambaud, 1991); (3) biological dinitrogen fixation by microorganisms, thought to be the major origin in arid environments such as central Australia (Barnes et al., 1993); and (4) inputs of human and animal waste in village and urban environments (e.g., Wetselaar et al., 1993). Groundwater is the major drinking-water source in many parts of Nepal. The primary intention of this survey was to determine the extent of nitrate occurrences in groundwater in selected regions of Nepal, and to identify likely sources of nitrogen. The survey procedure does not represent random sampling, because the number of wells tested in each area was arbitrary.

GEOGRAPHY

Nepal is a Himalayan Kingdom. It is a landlocked country (147,181 km^2) that is situated between China on the north and India on the south (fig. 1). On the basis of topographic features, Nepal is divided into three regions, as shown in figure 1: (1) the Himalayan region, (2) the Hill region, and (3) the Tarai (plain) region. The Himalayan region is in the northern part of the country and constitutes 25 percent of the total area. Altitudes in this mountainous region exceed 3,000 m; above 5,000 m, the land is covered with snow. The Hill region is between the Himalayan and Tarai regions and constitutes about 50 percent of the total area. The Kathmandu valley is in this region. The Tarai region covers the southern part of Nepal and consists of low and level land; it constitutes the major agricultural region. The country is divided into 14 political zones, with 75 districts within these zones (Shrestha, 1991). This study was conducted in two of the zones, the Bagmati zone and Narayani zone (fig. 1).

The total population of Nepal is approximately 17 million, with a population growth rate of about 2.7 percent per year. The population density is greater in the Hill and Tarai regions than in the Himalayan region. The average Nepalese life expectancy is 54 years (1989 census).

Although Nepal is rich in water resources, many people do not have adequate drinking-water facilities. Reticulated drinking-water supply systems are limited to a few urban areas. People in the Hill regions are highly dependent on local streams, whereas most people in the Tarai region depend on groundwater. The water from all of these sources is consumed mostly unpurified, and such water is not regulated by any public health agencies (Khadka, 1993).

THE NEPAL SURVEY

Survey Regions and Locations of Wells

A survey was conducted in January, 1993, to provide initial information on nitrate exposure from groundwater. The first part of the survey was carried out in urban areas of the Patan and Bhaktapur districts of the Bagmati zone (fig. 2), where 19 wells were sampled. These districts are adjacent to the Kathmandu valley, which is also within the Bagmati zone. In Kathmandu, piped water is available, and therefore the use of well water is not common. Despite the availability of a piped water supply, many people in the Patan and Bhaktapur areas rely on communal and private well water as an alternative source when there is a shortage of water. Some families drink well water throughout the year, claiming that it is more reliable than the public water facility and that the well had been used by their ancestors for many years. In Patan, wells were tested in Hakha, Haugal, Mahapa, Dhapgal, and Shibahal. In the Bhaktapur district, the tests were conducted in Sinamanghal, Dhabukhel, Ghathaghar, Sukuldhoka, Chorcha, Golmati Chorcha, Tharphokhari, and Jela.

The second part of the survey was carried out in the agricultural (Tarai) region, where 81 wells were sampled, in order to make an urban/agricultural comparison. The main agricultural product of the Tarai region is rice; mustard seed, wheat, and cane are also cultivated. People there are entirely dependent on groundwater. In this context, the nearest agricultural region to the Kathmandu valley was selected, the central-eastern part of the Chitwan district in the Narayani zone (fig. 2). The selected rural villages are above and below the main road from Narayanghat to Megauli. This survey included household wells in the following villages: Meghauli, Dibyanagar, Gunjanagar, Shardanagar, Gaurigunj, Prembasti, Narayanpur, Kalyanpur, Yogyapuri, Thuloyogyapuri, and the urban centre of Narayanghat.

Hydrogeology of the Survey Regions

The hydrogeology of the Kathmandu valley, which includes the Patan and Bhaktapur districts, is summarized by Sharma (1981) and Khadka (1993). The area is underlain by fluvio-lacustrine deposits of Quaternary age. Detailed lithological data are presented by Khadka (1993) and show two aquifers, the upper one being an unconfined shallow aquifer. Its porosity is about 20 percent and its thickness is estimated to be about 10 m. Groundwater supplies are obtained from dug wells that tap beds of coarse-grained sand.

The hydrogeology of the Chitwan district has not been described in such detail. The general hydrogeology of the Narayani zone of the central Tarai region is described by

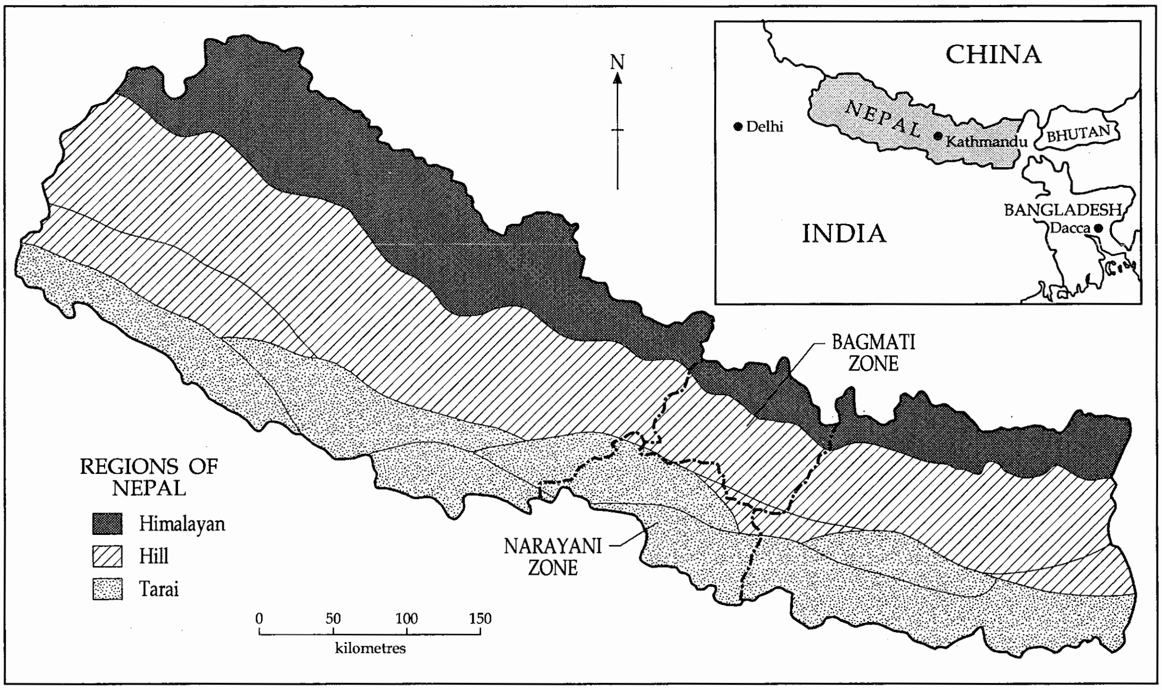

Figure 1. Locations of Nepal, its topographic regions, and the Bagmati and Narayani zones.

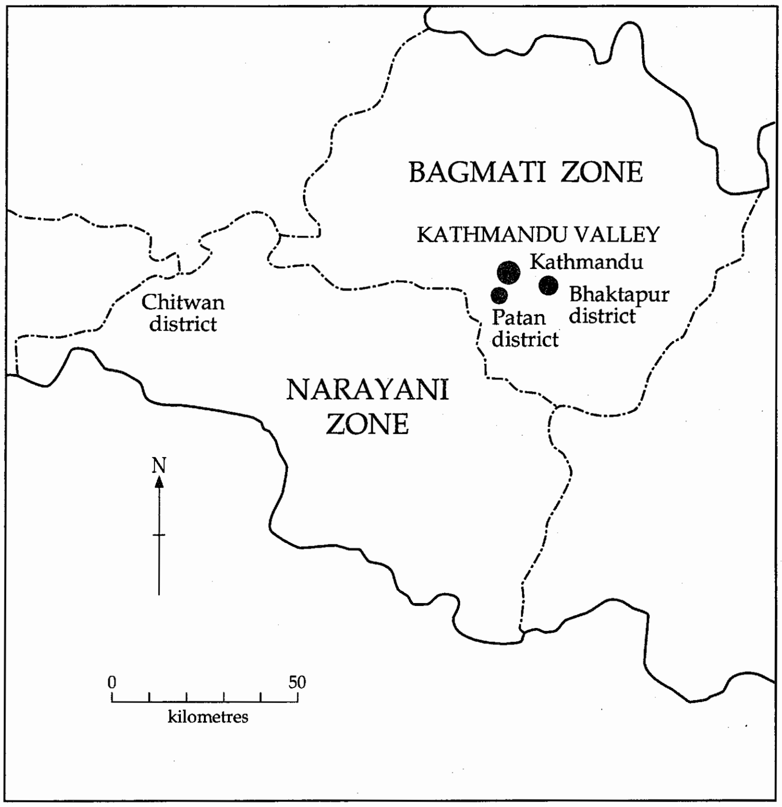

Figure 2. Locations of districts where sampling occurred, Bagmati and Narayani zones.

Sharma (1981). The Tarai plain is a part of the Indo-Gangetic basin, which is underlain by alluvium derived from the nearby mountains. The deposits consist mainly of sand, clay, and gravel. Samples were obtained from an unconfined aquifer that overlies a much deeper confined aquifer; depth to water is 10-15 m.

Methodology

Water samples were taken from household wells, and the nitrate concentration in the water was determined immediately at the site using the Merck Nitrachek method. This colourimetric method involves the determination of nitrite following the reduction of nitrate. This is a convenient method to use in the field and its accuracy is about ±20 percent. For wells with hand pumps, water for sampling was obtained after four to five strokes. The results at each location were recorded, along with depth to water (soil surface to the water table) and age, toilet proximity, soil type, fertilizer use, and the number of people using the well water (detailed results are available on request).

SURVEY RESULTS

The nitrate distributions obtained from the survey are shown in figure 4. In the Patan and Bhaktapur districts, 58 percent of the well samples had nitrate levels below and 42 percent of the well samples had nitrate levels above the old safe limit (45 mg L^{-1}) recommended by the WHO. In the Chitwan district, about 20 percent of the samples had nitrate levels that exceed the WHO recommended limit, and one percent contained nitrate concentrations greater than 100 ppm. In both regions, many other well samples had nitrate concentrations slightly below the 45 ppm limit. Concentration of nitrate in groundwater is greater in the urban areas than in the agricultural regions (fig. 3).

Most of the sampled wells in Patan and Bhaktapur are more than 100 years old. In Chitwan, the wells are less than 40 years old. The latter region has recent agricultural settlements. No correlation was observed between the ages of wells and nitrate concentrations (results not shown). For example, in the Patan and Bhaktapur districts, where almost all of the wells are more than 100 years old, a wide range of nitrate concentrations exists. In the Tarai region, no marked difference was observed in the nitrate concentrations in old and new wells.

Most depths to water are 9-10 m; a few wells are as deep as 18 m. Some studies have shown that the depth of the well is an important determinant of nitrate concentration; for example, in Iowa (USA), wells less than 15 m deep had higher nitrate concentrations than did deeper wells (Kross et al., 1993). In the present survey, a correlation between the depths of the wells and nitrate concentrations could not be made, because most of the depths to water (and, therefore, well depths) are similar.

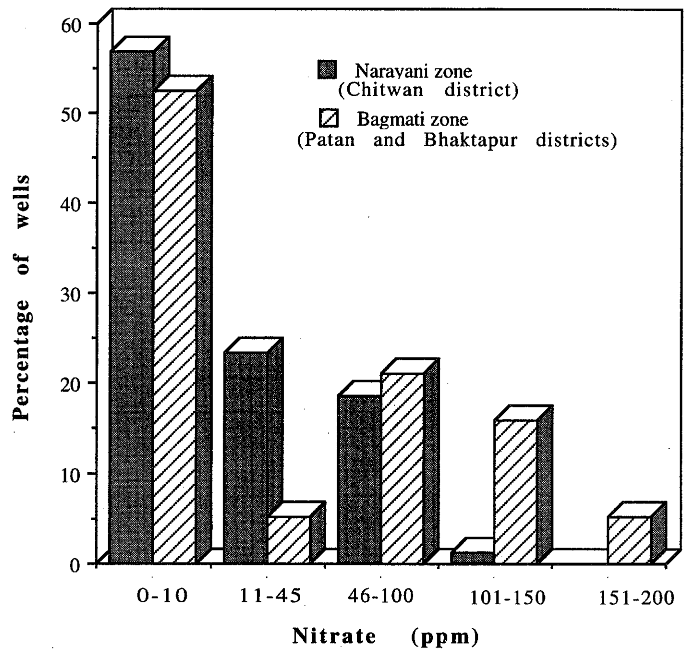

Figure 3. Distributions of nitrate concentrations, samples from wells in Bagmati zone (Patan and Bhaktapur districts; 19 wells) and in Narayani zone (Chitwan district; 81 wells).

POTENTIAL SOURCES OF NITRATE

In general, possible sources of nitrogen that lead to nitrate in groundwater are nitrogen fertilizers, soil organic nitrogen, sewage, and excrements from animals (Dudley, 1990). These are considered below.

Soil Type, Agriculture, and Fertilizer Use

The Patan and Bhaktapur regions have black soil that is rich in organic matter. In the Chitwan agricultural region, the soil is alluvial and is also quite rich in organic matter. Dudley (1990) has suggested that slow leaching of nitrate derived from organic matter in soil can lead to a steady rise in the nitrate concentration of some groundwater over long periods. In Nepal, this process could have contributed to nitrate build-up in groundwater, particularly in the Patan and Bhaktapur regions.

Fertilizers are not used in Patan and Bhaktapur, because the soil itself is relatively fertile. In villages in the agricultural Chitwan region, farming is traditional, and nitrogen fertilizers such as urea and ammonium sulphate are used only in small amounts on an irregular basis. Many farmers use animal manure. Because the survey results showed higher nitrate in the urban than in the agricultural region (fig. 4), it is concluded that the occurrence of nitrate in groundwater is not primarily due to nitrogen fertilizer application.

Sewage

Many families in the urban regions of Patan and Bhaktapur use septic tanks. Few households are connected to sewage systems. The distance between wells and the nearest septic tanks ranges from 5-50 m. No correlation was observed between nitrate levels in groundwater samples and distances from septic tanks within 15 m (results not shown). Septic tanks, however, must still be regarded as likely contributors to groundwater nitrate. More study is necessary to determine flow pathways from individual tanks to the water table and to well intakes. Nitrate derived from human origins can be many years old and most of the settlements in this area are 100-200 years old.

In the agricultural Tarai region, most of the villagers use pit systems, which are 6-90 m from the wells. A typical pit is a hole one m square and 4-5 m deep. Only a few households use septic tanks and others have no sanitary facilities; they use open field systems. In this region, no correlation exists between nitrate levels and distance from the pits (results not shown).

Livestock

Livestock in a village can also contribute to nitrate accumulation, depending on the nitrogen content of their feed. However, large numbers of animals were not observed and, therefore, animals probably do not significantly affect the concentration of nitrate in groundwater in the areas of the survey.

Other Factors

Rice and lentils are the staple diet of the Nepalese population. These vegetables are prepared by boiling, which increases nitrate concentrations. Similarly, boiling water is used for making tea, which is consumed by adults at a rate of 2-4 cups a day. In addition, vegetables known to concentrate nitrate, such as lettuce and spinach, are regularly consumed, along with chillies (fresh and dry). Research has shown that chillies contain high concentrations of amines, which react with nitrite to form nitrosamines, which are carcinogenic (Siddiqi et al., 1992).

DISCUSSION AND CONCLUSIONS

In the survey of wells in Nepal, 27 percent of samples of well water contains nitrate levels above the recommended WHO limit of 45 mg L^{-1}. The results from Patan and Bhaktapur (urban areas) and the agricultural villages in the Chitwan district provide a basis for comparing the nitrate concentrations in urban and agricultural regions. The results indicate that the concentration of nitrate is higher in urban areas than in the agricultural regions. Within individual settlements, a marked spatial variability in nitrate concentration was observed. Such variation within a settlement also has been reported in India (Jacks and Sharma, 1983) and Indonesia (Wetselaar et al., 1993). Because of the chemical and microbiological stability of nitrate in groundwater, any measured nitrate could have arisen over many years. It would, therefore, be of interest to examine the ages of the villages in which nitrate contamination occurs in groundwater to determine whether a correlation exists between nitrate levels and the ages of settlements. No correlation exists between the ages of wells and nitrate concentrations. Both old and new wells contain variable nitrate levels, although the ages of individual wells do not necessarily reflect the ages of the villages.

Unlike many countries where nitrogen fertilizers are the cause of nitrate pollution, no evidence exists of excess nitrogen fertilizer usage in the surveyed regions of Nepal. The nitrate concentration in well waters is probably, therefore, indicative of pollution mainly related to nitrification of nitrogen excreted by humans and to a lesser extent by animals inside the settlements. Septic tanks in urban areas and pits in the agricultural Tarai region may be the principal sources contributing to nitrate accumulation in groundwater. It is likely that, with increasing population growth, more wells will withdraw groundwater that exceeds the WHO limit. It is also likely that the nitrate levels in wells reflect the levels of faecal pollution of the water and confirm the need for improved sewage and water treatment.

Microbial nitrification from high levels of soil organic matter may be another possible factor contributing to the nitrate build-up over time. Many regions in Nepal have suffered from deforestation, and Faillat and Rambaud (1991) reported in an African study that deforestation has contributed to nitrate accumulation in groundwater. Whether such deforestation has affected nitrate accumulation in groundwater in Nepal is an unknown but possibly an important consideration. Accumulation of nitrate in this way would be expected to decrease with time as the organic nitrogen source diminished. Human activities, on the other hand, provide a continuing source of organic nitrogen.

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