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Effects of irrigated agriculture on groundwater quality in North-West Bangladesh

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Abstract

The emerging problem of groundwater contamination due to agricultural land use changes with increased use of fertilizers and pesticides has created a need for information which can be supplied by properly designed groundwater quality monitoring programmeme. The effective design of such monitoring programmemes and subsequent use of data obtained depends upon an understanding of spatial and temporal variability of groundwater quality parameter concentrations. Herein an attempt is made to assess the spatial and temporal variability of groundwater quality based on available data in northwest region of Bangladesh. Data from about 40 observation wells in the northwest Bangladesh were used in this study. Results of investigation on nine parameters are presented and compared to standards, criteria and other guidelines for assessing groundwater quality. These initial results suggest that parameter concentrations are well within permissible limits. To assess the parameter concentration values at the regional level and to examine if statistically any significant difference in values exists between the periods 1977-83 and 1992-94, data series from all the wells were combined. Empirical distributions were compared and chi-square tests were employed. Also selected parameter concentration variation with depth was looked into in a regional scale. To evaluate the differential effects of agricultural practices, hydro geologic and climatic factors, site specific analyses were also performed using data for five representative well locations, one in each district in the study area. Spatial variability appeared to be more pronounced than temporal difference. At present the quality of groundwater in the northwest region of Bangladesh may be considered adequate for domestic and agricultural use. However, this observation is based on limited time series that were available at the time of this study. Obviously there is a time lag between the activities on the land surface and concomitant deterioration of groundwater supplies. Degradation of groundwater quality may not be readily apparent given the extent of current monitoring activities. Suggestions and comments made should be considered as tentative only and need to be verified by more exhaustive studies and research.

INTRODUCTION

Recently increasingly more attention is being focused on the possible impacts of irrigated agriculture on groundwater quality. This is of particular concern because groundwater is the predominant source of domestic water in rural areas of Bangladesh. Most private wells in these areas are shallow and susceptible to contamination. These wells are generally not tested for water quality; thus unsafe levels of contamination may go undetected. The northwestern region is the most important agricultural area in Bangladesh. This area is among the leading producers of rice. Since early 1960s the irrigated area has increased markedly, especially with the introduction high yielding variety (HYV) rice. The aquifer systems underlying this area are some of the most productive groundwater reservoirs in the country. Soil, water, and climatic resources make the region ideally suitable for intensive agriculture. Although annual rainfall averages about 160 cm, rainfall distribution in most years is such that crops experience water stress. These drought conditions, along with the vast groundwater supply in the region, have led to multiple cropping with several fold increase in the irrigated area in the last 15 years.

Irrigation trends between 1981 and 1990 show that the total area served by combined use of surface and groundwater in the country increased by about 75 percent from 1.73 to 3.03 million ha. Area irrigated only by groundwater increased by 557 percent from 0.27 to 1.78 million ha in the country, and in the northwest this increased by 838 percent from 89 thousand ha to 0.84 million ha. Figs. 1 and 2 show respectively the trend of irrigation increase in the five northwestern districts by combined use of surface and groundwater and only by groundwater for the period 1981-1990. Cultivation of HYV rice requires increased use of fertilizers to achieve economically viable yields. This crop is less resistant to pests and requires relatively heavy application of pesticides. Use of chemical fertilizers and pesticides also increased significantly as shown in Figs. 3 and 4.

The purpose of this paper is to evaluate the impact that irrigated agriculture might have on the groundwater quality in the northwest Bangladesh. The study area comprises five greater districts of Rangpur, Dinajpur, Bogra, Rajshahi, and Pabna, and is situated between longitudes $88^0 10'$ and $88^0 50'$E and between latitudes $23^0 30'$ and $23^0 38'$N. This region was selected for study because the number of tubewells and the level of groundwater use is generally higher than other areas. The region is adjacent to the Indian states of Bihar and West Bengal and forms a hydrologically distinct area bounded on the south by the Ganges-Padma river and on the east by the Brahmaputra-Jamuna river. The soils of the northwest region occur on an almost level topography except the Teesta River flood plain, which occur in a catenary sequence on a landscape of broad ridges and depressions. Most of the soils in the region have heavy textured clay and clay loam subsoils. The ridges of the Teesta River flood plain are generally light textured, grading from sandy to silty soils and the depressions consist of mainly silty soils. The major physiographic land types are recent alluvial flood plain and pleistocene terraces. These pleistocene terraces are known as Barind tracts. Abundant groundwater supplies occur throughout the region in a shallow unconfined aquifer. The potential recharge ranges from a maximum of 2290 mm to a minimum of 1170 mm (UNDP, 1962). Groundwater recharge can be attributed to rainfall between May and September. At the end of monsoon, the water table is located approximately 1 to 2 meters below the ground surface in floodplain areas, but is deeper in the Barind Tract. Water table recedes by 2 to 4 meters in response to pumping during the dry season.

Land Use Changes and Agricultural Pollutants

Physiographic features of the region, in particular a high water table, frequent flooding, high recharge rates, and the unconfined nature of the aquifer, suggest the presence of a relatively high potential for groundwater contamination and degradation. Anthropogenic factors in tandem with these physiographic features also influence the potential for groundwater contamination and degradation. Severe water quality problem may arise from deep percolation below irrigated areas, carrying high salt loads and increased nitrate concentrations to groundwater (Law, 1987; McCutcheon, 1992; Detay, et al., 1989, Guerrera, 1981). Irrigation increases recharge rates and the soil-water velocity, thus increases the amount of leaching that occurs and the speed at which contaminants may reach groundwater (Meeks and Dean, 1992). Irrigation also increases the area under cultivation during the dry season, a time during which most land previously remained fallow. In turn this has led to an increase in the land area on which farmers apply fertilizers and pesticides.

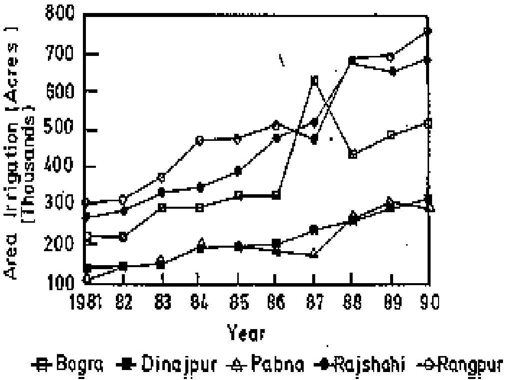

Figure 1. Trend of irrigation by surface and groundwater in the study area (1981-90).

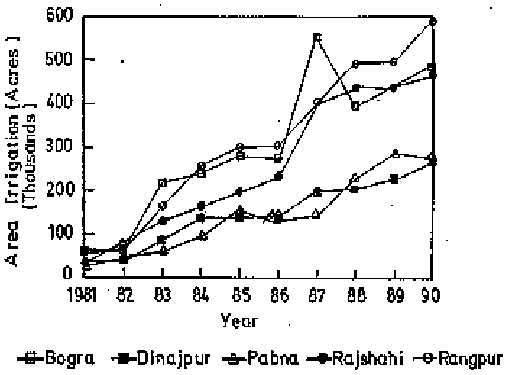

Figure 2. Trend of irrigation by groundwater in the study area (1981-90).

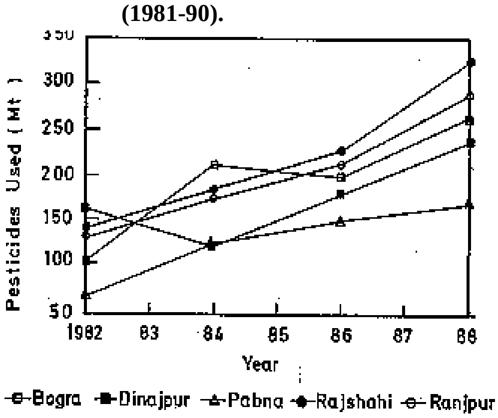

Figure 3. Trend of fertilizers used in the north-west area (1981-88).

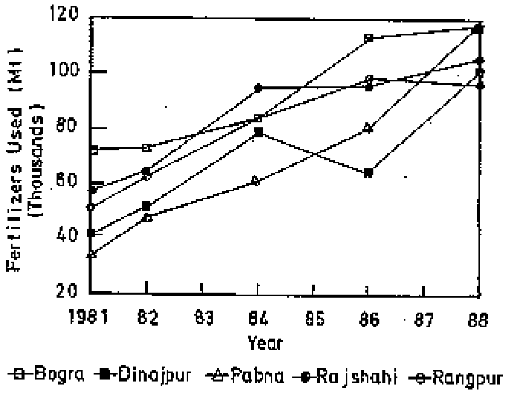

Figure 4. Trend of pesticides used in the north-west area (1981-88).

The Water Resources Planning Organization (WARPO, 1987) estimated a 30 percent increase in pesticide use per cropped ha of HYV rice by the year 2005. The use of urea, the principal nitrogenous fertilizer, has more than doubled between 1981 and 1988. This corresponds to an increase in use from 145 thousand tons in 1981 to about 346 thousand tons in 1988. The use of tripple super phosphate increased more than three times between during this period that is from 48 thousand tons to 150 thousand tons. Likewise fertilizer and pesticide use also increased from 600 tons to 1300 tons between these years. Fertilizer and pesticide application cause greater amounts of nitrates (and other soluble constituents) and pesticide residues to leach from the root zone and reach underlying groundwater.

ASSESSMENT OF GROUNDWATER QUALITY

A water quality criterion may be defined as “that concentration, quality, or intensive measure that, if achieved or maintained, will allow or make possible a specific water use” (McCutcheon et al 1992). There are several sources of standards and guidelines for assessing water quality. In Bangladesh general guidelines were prepared by the Department of Environment and, irrigation water related guidelines by the Bangladesh Agricultural Development Corporation. FAO, WHO, USEPA and EEC published widely accepted criteria. In addition to health and environment, poor water quality can have a detrimental effect on crop yield and sustainable use of agricultural land.

Water Quality Data

Bangladesh Water Development Board (BWDB) started groundwater quality monitoring activity in 1960. Water samples are presently collected from about 117 tubewells and piezometric wells in dry season throughout Bangladesh. Of these, approximately 40 observation wells are located in the northwest region, however all the wells were not sampled every year. Sampling and analysis of water have undergone gradual changes over the years. During the period 1977-1983, BWDB collected samples several times during a year. Initially, samples were analyzed in the Central Testing Laboratory, now known as the Bangladesh Standards and Testing Institute Laboratory, Dhaka within one to four weeks of collection. Due to this time lag between sample collection and testing in the laboratory, representative water quality results might have not been obtained. Starting in 1992, BWDB began collecting only one sample a year. In 1993 BWDB began to analyze water samples in their own laboratory. Concentrations of nineteen parameters are determined. Iron, magnesium, carbonate, bicarbonate, pH, carbon dioxide, total dissolved solids, total hardness and temperature are measured in the field with a spectrophotometer. Other parameters are measured in the laboratory at Dhaka using titration methods. For this study available groundwater quality data for about 40 wells in hard copy were collected from Groundwater Circle II of BWDB. Data on nine parameters, such as chloride, nitrate, TDS, pH, SAR, sodium, iron, calcium and magnesium were found to be more or less complete than other parameters and were selected for analysis. Data were entered into computer, consistency check and organized in proper format for further analysis.

METHOD OF ANALYSIS

Analyses performed herein seek to determine whether or not changes in the concentration of selected groundwater quality parameters have occurred. An inspection of the available data revealed that the data for the 1977-83 and 1992-94 period were found to be more or less complete. From a statistical viewpoint, all water quality constituents are considered random variables, and statistical analysis can help ascertain whether or not there has been any incidence of unsafe level of groundwater contamination due to fertilizer and pesticide applications on agricultural land. Long-term mean values of water quality variables were obtained combining the data from all wells in the region. Empirical distributions of data for the two periods 1977-83 and 1992-94 were compared and chi-square tests were performed to evaluate the difference between the two periods. Also data were evaluated according to spatial difference and temporal trends over time. For this part of analysis data from five selected wells, one from each district, were employed. Mean values of water quality parameters were computed and compared to evaluate spatial variation. T-tests were performed to evaluate the difference between the two study periods. Finally to see the long-term trend, plots of groundwater quality versus time were produced for each of five sites.

RESULTS AND DISCUSSION

The overall chemical nature of shallow groundwater in irrigated areas is the result of climatic, anthropogenic, and hydrogeologic factors. For the sites under study, the climatic inputs are fairly similar. Human induced impacts include method and frequency of irrigation and types of crop grown. Resultant difference in water quality should be most readily discernible from long-term means of chemical properties.

Summary Statistics

Computed mean and standard error for selected parameters based on combined data for all wells are presented in Table 1. A comparison of values with the standards shows that concentrations of all parameters are within the permissible limits except that of iron. Mean concentration of iron for 1977-83 and 1992-94 periods are respectively, 3.82 mg/1 and 3.58 mg/1 compared to the permissible limits of 0.30 mg/1 for drinking water and 5 mg/1 for irrigation purpose. It meets the irrigation water quality standards, but exceeds the drinking water standard. In Bangladesh the main sources of iron in groundwater are iron-rich sediments which were deposited by the Ganges, Brahmaputra and Meghna Rivers in the part of geologic time. As groundwater moves very slowly under flat gradient through these sedimentary deposits its iron contents tends to increase. Moreover, the northwest region is confined on the south by the Ganges river and on the east by the Brahmaputra-Jamuna river. So the iron content in groundwater is likely to be more. Water becomes problematic which iron concentration exceeds 5 mg/1.

Table 1. Mean and standard error of selected water quality parameters for the indicated periods

Water Quality Parameter	Mean with Standard Error		
	1977-83	1992-94	Two Periods Combined
Chloride (mg/1)	25.92±1.28 (n=570)	22.90±2.87 (103)	25.47±1.17 (674)
Nitrate (mg/1)	3.30±0.746 (n=404)	3.06±0.46 (103)	3.25±0.60 (507)
TDS (mg/1)	246.99±6.04 (n=555)	262.85±17.32 (103)	249.48±5.77 (658)
PH	7.64±0.04 (n=554)	7.12±0.088 (103)	7.56±0.040 (657)
SAR	2.56±0.13 (n=496)	0.59±0.05 (103)	2.22±0.11 (599)
Sodium (mg/1)	42.85±1.06 (n=488)	16.49±1.90 (103)	3.26±1.02 (591)
Iron (mg/1)	3.82±0.35 (n=555)	2.31±0.47 (103)	3.58±0.30 (658)
Calcium (mg/1)	26.58±0.896 (n=490)	61.93±4.62 (103)	32.73±1.22 (593)
Magnesium (mg/1)	16.94±0.61 (n=485)	79.20±6.91 (103)	27.86±1.63 (588)

Difference in Parameter Concentration Between Two Periods

Ideally one would like to examine whether there is a statistically significant difference of parameter concentrations between two study periods 1977-83 and 1992-94. The computed mean concentrations have a relatively small standard error, which indicate that the water quality had not changed greatly between the two periods. This was in agreement with the general conclusion of BWDB (1991) that groundwater quality was adequate for all purposes except in coastal areas where groundwater is typically saline. However, such conclusions were based on sporadic sampling and insufficient information. Because groundwater travels slowly, locally poor groundwater supplies may not be detected in a gross level assessment. It is worthwhile to examine if the samples for the two periods are statically same or they are significantly different. To verify this hypothesis, empirical distributions of parameter concentrations for the two periods were plotted for visual comparison. Such a plot for nitrate is shown Fig.5, which shows that frequency of non-zero nitrate concentrations appeared to be much higher in the 1992-94 sample. This could be attributed to the increasing use of fertilizers in agriculture. Empirical distributions for TDS and chloride showed a closer overlap between the two samples suggesting that no significant changes in TDS and chloride concentrations have not occurred between the time periods. A significantly large percentage of wells had lower sodium concentrations during the 1992-94 period than 1977-1983 period.

Then a quantitative test, such as chi square test was employed to see if the frequency distributions of groundwater quality data were identical for the two periods. Computed chi-square values were 388.19, 31.61, 80.94 and 487.77 respectively for nitrate, TDS, chloride and sodium. These exceeded the critical values of 12.592 for nitrate and TDS and 16.91 for chloride and sodium at a significance level of 0.05. This suggests that the frequency distribution of data collected in the 1990s is statistically different from that collected during the 1970s and 1980s and specifically it shows an increase in nitrate, TDS and chloride concentrations but a decrease in sodium concentration between 1977-83 and 1992-94 periods.

Vertical Difference

Variation of nitrate, TDS, chloride concentration with depth of sampling was tested graphically and by linear regression. A scatter-plot of nitrate concentrations against depth is shown in Fig. 6, which shows a somewhat decreasing trend with increasing depth. This is in general agreement with the findings of Spalding and Exner (1980) in Nebraska, USA where in a gravelly, unconfined aquifer, groundwater quality improved with depth. Linear regression equations of the form $y_i = a + bD_i$ were also obtained relating parameter concentration, y_i with depth, D_i . The regression equations respectively for nitrate, TDS, chloride and sodium are given below.

$$y_i = 7.64 - 3.13D_i \quad (1)$$
$$y_i = 242.11 + 0.01D_i \quad (2)$$
$$y_i = 30.81 + 0.42D_i \quad (3)$$
$$y_i = 44.52 + 0.036D_i \quad (4)$$

Based on t-statistic computed slopes (coefficients of D_i) for nitrate and sodium only were significant at a significance level of 0.05. This suggests that the depth of the well does have an effect on these parameter concentrations. The slope for nitrate was negative suggesting a decreasing trend with depth and that for sodium was positive indicating an increasing trend with depth. But the low R square values of 0.62, 0.20, 0.26, and 0.53 respectively for the above regression equations indicate that only a small fraction of the variation is explained by the equations, and that therefore, much information that might explain the difference in parameter concentration between sites is missing and probably could not be captured by sampling. However, increase of sodium concentration with depth agrees with the results obtained by Close (1987) in New Zealand, where concentrations of Na, Ca, Mg, and EC tended to be higher with depth in irrigated area.

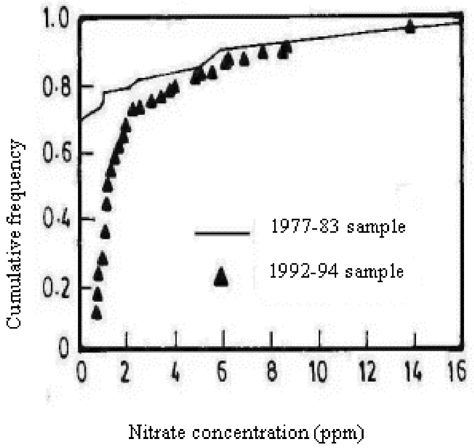

Figure 5. Cumulative frequency of nitrate concentration.

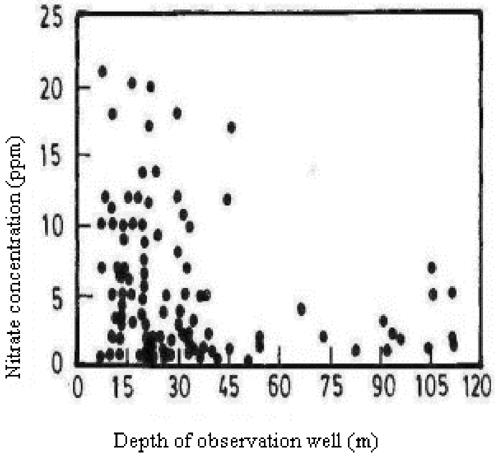

Figure 6. Nitrate concentration with well depth.

SPATIAL AND TEMPORAL VARIATION

Five wells, one located in each district of the northwest region, were selected for this analysis. Inspection of means and standard errors of parameter concentrations at five well locations, as presented in Table 2, reveals spatial variation. Such variations are likely due to small-scale horizontal geological variations and local variations in the aerial application of fertilizer. Nitrate may be denitrified in anaerobic stagnant water, which may cause a large variation spatially (Bjerg and Christensen, 1992). However parameter concentrations were within the standard values except iron and magnesium. Iron concentration exceeded the permissible limit at all locations while magnesium exceeded in flood plain areas of major rivers. Chloride, TDS, pH, sodium and magnesium showed minimum values in upland areas and maximum values at locations near Brahmaputra river, indicating an increasing trend near major rivers. As expected sodium absorption ratio (SAR) was lower near major rivers because of higher concentration of calcium and magnesium at these locations. SAR values at all locations were well below the irrigation standard. Time series plots of parameter concentrations exhibited a gradual change over time at some sites, but showed too much scatter and fluctuation to identify any trend. There were large variations over short periods indicating that factors other than irrigation influence the value of the observed parameters. In general, this variation obscured any slight monotonic trends present in the data.

Also t-tests were performed to evaluate the concentration difference of chloride, nitrate and TDS in two periods 1977-83 and 1992-94 at each of the five selected wells. The hypothesis that mean values of parameters in two periods are the same was tested at a significance level of 0.05. Computed t-values for chloride, nitrate and TDS in Well 14 exceeded the critical t-values showing a significant change in mean concentration. This location falls in the Teesta River flood plain having high cropping intensity and shallow and highly permeable aquifers. Temporal variations, long-term or seasonal, in groundwater quality may be significant in such aquifers due to variations in flow direction, recharge, geochemical processes or artificial interference at the land surface (Bjerg and Christensen, 1992). Moreover Teesta flood plain consists of many ridges and depressions, where runoff from agricultural watersheds is likely to accumulate chemical residues.

Table 2. Mean and standard error of water quality parameters for five selected wells

Well no	Nitrate	Chloride	TDS	Sodium	SAR	Iron	Calcium	Magnesium
4	3.6 ± 1.9	16.3 ± 8.6	120.6 ± 16.4	25.5 ± 4.5	2.4 ± 0.5	3.7 ± 1.1	11.5 ± 2.3	9.1 ± 3.3
14	7.2 ± 2.4	30.5 ± 5.2	225.8 ± 24.5	31.3 ± 4.4	1.3 ± 0.4	1.9 ± 0.7	33.4 ± 9.3	18.5 ± 7.6
23	0.2 ± 0.1	23.5 ± 4.6	181.6 ± 16.4	37.6 ± 5.3	1.6 ± 0.3	2.6 ± 0.7	27.9 ± 2.2	18.7 ± 4.9
27	0.5 ± 0.2	52.9 ± 14.7	425.8 ± 59.4	37.5 ± 6.7	1.2 ± 0.2	0.9 ± 0.3	55.7 ± 11.7	58.1 ± 16.6
39	1.2 ± 0.4	31.6 ± 6.9	380.6 ± 32.1	32.6 ± 4.4	1.5 ± 0.4	10.9 ± 3.1	71.3 ± 12.6	56.7 ± 20.6

Well 4 located at Tkurgaon, 14 at Rangpur, 23 at Gokul, Bogra, 27 at Nawabganj, 39 at Nagarbari ferry, Pabna

CONCLUSION

The potential for groundwater degradation is an area of study that needs attention. This study is based on readily available data collected by Bangladesh Water Development Board. While the results presented in this paper do not provide any conclusive evidence of large-scale deterioration as evaluated by selected parameter concentrations, it has opened up some perspective on what further work is needed. Parameter concentrations in groundwater have been known to fluctuate with the water table. This is particularly important for shallow unconfined aquifers like those found in Bangladesh. Depth integrating and multiple samples during the year are needed to identify the variation with depth and seasonal patterns in groundwater quality. Beginning 1992, BWDB collects only one sample a year from a well without regard to the date on which sampling occurs. Meaningful analysis becomes complicated by this lack of information. Depending upon the purpose monitoring programme can be designed (i) to evaluate the quality of drinking water, (ii) to assess the combined effect of multiple non-point sources at the regional level, and (iii) to identify contamination from point sources. In Bangladesh not many point sources pose a threat to groundwater; therefore first two should be the most important objectives of monitoring programs. An evaluation of the purpose of existing monitoring programs could provide additional clarification about what changes are needed.

Reconnaissance-level investigation should be undertaken to identify, evaluate, and respond to any irrigation-induced water quality problems. Future programme design should incorporate and consider the information needed to evaluate the vertical, spatial, and temporal variations in groundwater quality. It is both efficient and appropriate to direct monitoring efforts to those areas most susceptible to contamination or degradation. Research is needed to identify, develop, and validate appropriate methods for prioritizing monitoring sites.

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