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NITRATE POLLUTION OF GROUND WATER AS RESULT OF AGRICULTURAL DEVELOPMENT IN INDO-GANGA PLAIN, INDIA

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ABSTRACT

In India one of the largest geohydrological province rich in ground water is the Indo-Ganga tract comprising of a uniform lithologic characteristic viz. Quaternary Alluvial sediments of varied thickness spread through an area of 27.8 million hectares of cultivable land. Climatologically humid tropics, with average annual precipitation of about 90 cm with generally two crops a year, it is under influence of moderate to heavy utilisation of fertilizer, mainly nitrogen based. Thoughthe problem of nitrogen pollution has not become alarming, the pointer towards a deteriorating situation in the shallow aquifer has been developed in the paper. Influence of natural and man-made conditions on existance and movement of nitrogen pollutants have been analysed and present quality monitoring system reviewed for the study area. Numerous wells totalling nearly a million perforate the basin and a concept of "mixing zone" has been introduced to develop a prediction model which can be simulated and perfected by ascribing different values to the parameters. The model has been tried through analysis of one year data i.e. 1978-79 for different parameters and amount of quality deterioration has been brought out.

INTRODUCTION

The Indo-Ganga alluvial plain stretches from Punjab in the west to west Bengal in the east and southeast. Hydrogeologically the belt (average 1500 km long and 300 km width) is bounded by high land region of the Himalayas in the north and the peninsular region comprising of Archaean Crystallines in the south (Fig.1). The plain, is under moderate to heavy utilisation of both industrial and natural fertilizer mainly nitrogen based. The basin is geohydrologically the richest province which is under moderate to heavy utilisation of ground water as well. Agricultural and fertilizer statistics have been utilised to analyse the magnitude of the problem of nitrogen pollution. The amount of fertilizer expressed in this paper is always in terms of equivalent of nitrogen. Because a large area of the states of Uttar Pradesh (U.P.)

and Bihar are covered by consolidated and semiconsolidated formations, any data referring to these two states exclude the following districts; Uttarkashi, Chamoli, Dehradun, Tehri Garwhal, Almora, Nainital, Pithoragarh, Pauri Garhwal, Jalaun, Hamirpur, Banda, Mirzapur, Jhansi, Lalitpur (for U.P.) and Chaibasa, Ranchi, Dhanbad, Hazaribag, Daltonganj, Santhalparganas and Gaya (for Bihar). The net area cultivated in 1978-79 in 4 states i.e. Punjab, Haryana, U.P. and Bihar are 4.175, 3.660, 14.440 and 5.552 million hectares respectively; corresponding figures of industrial nitrogen fertilizer applications are 410200, 161900, 724500 and 144100 tonnes (ref.10).

PRESENT SET UP FOR NITROGEN POLLUTION DETECTION AND OBSERVATION IN GROUND WATER

In India, the Central Ground Water Board (CGWB) is maintaining monitoring stations throughout the country to measure the conditions and trends of ground water quality and quantity in relation to standards and guidelines and is, to a great extent, representing the total spacial situation particularly in Indo-Ganga Valley. Its main objective is to collect ground water level data (5 times a year) and quality monitoring(once a year) for pH, HCO_3, SO_4, F, Cl, Na, Ca, Mg, K, total hardness. Regular monitoring on a national scale for ground water quality started in 1969 and with progressive increase in number of stations the status in Indo-Ganga Valley presently is as follows (ref.2).

	Punjab	Haryana	U.P.(Plains)	Bihar(Plains)
1969	1	4	39	30
1978	154	150	410	95

The monitoring of nitrogen level in ground water on a regular basis started rather recently. For monitoring the diffused and continuous pollution source like nitrogen, the frequency of observation (once a year) as well as the spacial distributions are well suited in Indo-Ganga plain setting.

Data of 276 samples for 1978 for U.P. show that number of wells with NO_3 concentration below 10, 20, 50 and 100 mg/l are 53.6%, 71.7%, 89.5% and 95.3% respectively (ref.9)

The median value of 0-10 mg/l group is 2.1 mg/l NO_3 and this is taken as representative average value in 1978. Similarly average value of river water (33 samples) in U.P. in 1978 shows 14 mg/l NO_3.

Historical data for nitrogen are lacking. Values of some of the old CGWB wells viz. well nos. 147, 207, 52, 203, 218, 153, 184 in U.P. show progressive increase in nitrogen concentration (ref.2, 8, 9). Also Handa reported in 1975 following concentration in ground water (ref.6).

State	No. of samples	Remarks
Punjab	125	88% had less than 20 mg/l NO_3
U.P.	193	99% had less than 20 mg/l NO_3
Bihar	179	88% had less than 12 mg/l NO_3

Comparing this with 1978 U.P. values it is seen that percentage of well with 20mg/l NO_3 has gone down by 27% within a span of minimum 4 years. Adyelkar (ref.1)

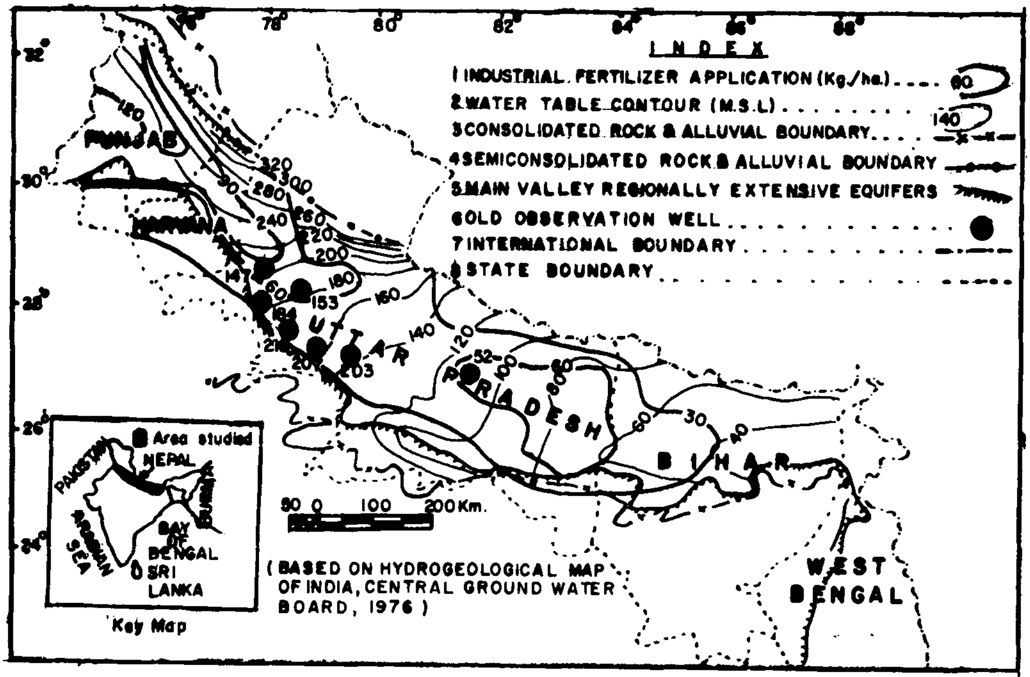

Fig.1. Hydrogeological map showing industrial fertilizer application (1978-79).

reported that 87.5% out of total 104 samples had less than 20 mg/l NO_3 in Bihar during 1978-80. This is less than what Handa reported even for 12 mg/l NO_3 concentration. Though scanty, the above data manifest progressive deterioration in quality.

INFLUENCE OF NATURAL AND MAN-MADE CONDITIONS ON EXISTANCE AND MOVEMENT OF NITROGEN POLLUTANTS IN GROUND WATER

Nitrate is a stable end product of entire nitrification process and constitute almost all the nitrogen in leached water. Once formed this is quite mobile in soil and ground water and acts almost like a tracer in the ground water reservoirs (ref.5). Pollution of nitrogen in ground water is primarily influenced by the movement of percolating water, its initial concentration and the amount of nitrogen available for leaching. The following factors are important in present area:

1. Natural conditions: (a) Climate and precipitations; (b) Surface water; (c) Geomorphology, land use and hydrogeology. 2. Man-made conditions: (d) Application of industrial and natural fertilizer; (e) Type of crops, its nutrient removal capacity; (f) Irrigation both from surface water and ground water.

(a) Influence of climate and precipitation

The distance that NO_3 can move downward depends on amount of water entering the soil. The more rainfall that occurs the deeper the pollutant is expected to penetrate. Average values of rainfall (50 years average, in mm) and potential evapotranspiration (in mm) are Punjab 625 and 1500, Haryana 625 and 1550, U.P. 986 and 1495, Bihar 1203 and 1480 respectively.

(b) Influence of surface water

Nitrogen concentration in rain water is negligible. Most of the rivers and most part of the rivers in the Indo-Ganga basin are effluant in nature and are not contributing, in a general way, to ground water pollution through influent seepage. However extensive canal networks criss-cross the area and these are contributing to ground water. Amount of ground water recharge due to canal seepage are 0.5, 0.2, 1.2 and 0.5 million hectare-meter per year for Punjab, Haryana, U.P. (the entire state) and Bihar (the entire state) respectively (ref.4).

(c) Influence of geomorphology, land use and hydrogeology

The Indo-Ganga plain occupies the depressed zone between mountaneous region (Himalayas) in the north and Peninsular Shield area in the south. The area is covered by alluvial soil and the litho faces forming the alluvium is fluvial type consisting mainly of coarse to fine sand alternating with some clay layers. The geomorphological configuration of the basin is such that for shallow ground water, the flow is inward into the basin all along the high land fringe area in north and south. The average master slope of ground water is about 16 cm/km and the average velocity in shallow unconfined aquifer varies from 0.5 to 50 m per year. This velocity is sluggish and the basin practically acts as sink for receiving nitrogen pollutants.

Both shallow unconfined aquifer (less than 50 m) and deeper confined/unconfined aquifers exist in the basin. The unconfined aquifer which usually extend almost from below the soil layer is extensively tapped for drinking water wells and shallow, low-duty, small diameter irrigation tubewells (average yield 20 to 50 m^3/hour). The deeper aquifers are extensively tapped by heavy-duty, large-diameter, irrigation tubewells (average yield 100 to 200 m^3/hour). The water table varies between 2 to 10 m below ground level, average annual fluctuation being about 4 m and average maximum draw down of the tubewells is of the order of 6 m. In major part ground water flows from west to east (fig.1). The valley is perforated with more than 7,50,000 number of tubewells which makes the ground water movement and also intermixing in the upper part of the aquifer more artificially controlled due to pumping effect.

(d) Influence of fertilizers

Both industrial and natural fertilizer (in the form of rural and urban compost) are applied in moderate to heavy amount in the present areas. The main types of industrial fertilizer manufactured and utilised in India are, Urea (46%N), Ammonium Sulphate (20.6%N), Ammonium Sulphate Nitrate (26%N), Calcium Ammonium Nitrate (25%N), Ammonium Chloride (25%N). From industrial fertilizer application record and future projection (ref.10) it is estimated that a total of 5127 million kg. of N has been applied between 1974-75 upto 1978-79 in an area of approximately 27.8 million hectares and this will be 26,235 million kg. of N in between 1974-75 and 1987-88. Fig.1

gives the zones for application of industrial fertilizer (1978-79 data). Total nitrogen application in the basin, both from industrial and natural fertilizer, and calculated in terms of kg. per hectares of cultivable land for 1978-79 is given in table 1.

TABLE 1

Amount of industrial and natural fertilizer applied (in kg/h) and net area irrigated from surface and ground water sources (in million hectares)

State	Industrial Fertilizer	Natural Fertilizer	Total	Surface water source	Percentage	Ground water source	Percentage
Punjab	96.3	304.1	402.4	1.426	44.3	1.792	56.7
Haryana	44.2	106.2	150.4	1.126	59.3	0.774	40.7
U.P.	50.2	356.7	406.9	2.732	37.9	4.484	62.0
Bihar	25.9	121.7	147.6	0.897	46.1	1.050	53.9
Average	54.6	222.2	276.8	1.545	43.0	2.025	57.0

(e) Influence of crop

Production of field crops occupy the foremost place in the area, wheat and rice being the two leading crops in the basin. Among cash crops, ground nut, cotton and sugar cane occupy the leading position. Total annual food grain production is of the order of 40 million tonnes. The type and variety of crop effects nitrogen losses to ground water through leaching. The average nutrient removed by main crops (averaging both summer and winter demands) varies from 175 kg/h in high yielding variety of wheat to 92 kg/h in high yielding variety of paddy (ref.10).

In practice it is very difficult to apply fertilizer in proper quantity and proper time of the plant growth. Untimely application of fertilizer when the crop is not in greatest need will lead to leaching of nitrogen to soil and then to ground water. It can be assumed that 10 to 30 percent of the fertilizer nitrogen applied would be leached out of the root zone as nitrate in deep percolation water (ref.7).

(f) Influence of irrigation

For irrigation water returning to ground water some degree of nitrogen pollution has taken place because in the process the percolating water picks up nitrogen from applied fertilizer. Present area is irrigated from both surface water sources and from ground water sources almost at 43:57 basis as per table 1.

PREDICTION MODEL

The objective of the present study is to determine quantitatively, the level of nitrogen pollution that is taking place in the ground water system and to evaluate the future trend. Since shallow aquifers in the region are predominantly used for drinking water supply to teeming millions and this is going to be much more extensive under rural water supply schemes in next two decades, the study is highly significant in monitoring health hazard.

To achieve this objective a simple model is visualised assuming following conditions (a) Total recharged water through net cultivated area comes from 3 different sources having different nitrogen concentrations viz. (i) infiltration from rainfall; (ii) infiltration (i.e. return flow) from irrigational surface water; (iii)infiltration (i.e. return flow) from ground water irrigation (b) The nitrogen applied through fertilizer cannot be fully utilised by the crop-soil sub-system and some percentage (10%) of this is available for leaching to ground water; (c) The model assumes no change in aquifer storage after a stipulated time period corresponding to one year cycle of cropping rotation, fertilizer application, natural and artificial recharges and discharges etc. Though within this cycle the aquifer is subjected to storage fluctuations shorter duration changes in nitrogen concentration as well as storage variability has not been considered; (d) Natural movement i.e. velocity of ground water flow is extremely slow. Numerous tubewells perforate the basin and they create an artificial condition, by mechanical dispersion, of intermixing of the pollutant in the uppermost part of the aquifer. Thus a concept of mixing zone has been introduced in the model.

In present case the zone of mixing has been decided on an analogy from "design of housing pipe length for tubewells". This is taken as a zone (volume) of equivalent thickness of aquifer comprising of yearly water level fluctuation range plus the maximum limit of draw down shown by majority of the tubewells in the area; the combined value being about 10 m. The final nitrogen concentration (Ci+1) is a product of mixing of the percolated water with the already existing ground water in the mixing zone with average 30% aquifer porosity (table 2); (e) One year cycle has been taken in the present model i.e. application of fertilizer, irrigation water etc. for 1978-79 (upto March, 79) will manifest its effect after final mixing in April, 1980.

Fig.2 shows the interaction of the system and explains the model. The system parameters are as follows (letter in brackets indicate the dimension of the parameters) A=Net area cultivated (L^2); V_R=Amount of precipitation (L^3); V_S=Amount of surface water for irrigation (L^3); V_g=Amount of ground water for irrigation (L^3); F=Amount of fertilizer in terms of nitrogen (M); a=Percentage of fertilizer available for leaching (fraction); n=Porosity of the aquifer (fraction); l=Mixing zone (L^3); I_1,I_2, and I_3=Infiltration from precipitation, surface water and ground water respectively (fractions), C_1=Concentration of nitrogen in precipitation water (M/L^3); C_2=Concentration of nitrogen in surface water (M/L^3); C_3=Concentration of nitrogen in ground water applied for irrigation (M/L^3); C_i=Initial concentration of nitrogen in ground water in mixing zone (M/L^3); C_{i+1}=Predicted (or optimal) concentration of nitrogen in ground water after a stipulated time period in mixing zone (M/L^3); $f_1=I_1V_R$; $f_2=I_2V_S$; $f_3=I_3V_g$.

Thus mathematically the model is expressed as follows:

$$C_{i+1} = \frac{[C_1f_1+C_2f_2+C_3f_3+f_4] + [l.n-(f_1+f_2+f_3)]C_i}{l.n}$$

A glance at table 2 will reveal that for nitrogen pollution in the present area rows 9 and 11 are most important. Row 11 assumes complete mixing of pollutant upto 10 m thick zone in one year. Table 2 gives 1978-79 data analysis for the model.

TABLE 2

1978-79 data analysis for the model (per hectare per year)

1. State	Punjab	Haryana	U.P.	Bihar
2. Recharge from rainfall in m^3	1249.8	1250.0	1972.1	2405.9
3. Recharge from surface water in m^3	818.7	914.8	611.2	404.3
4. Recharge from ground water in m^3	458.7	282.0	361.1	192.2
5. Total recharged water in m^3	2527	2447	2944	3001
6. Amount of N in rain water in mg	----- N e g l i g i b l e -----			
7. Amount of N in surface water in mg	$2.456x10^6$	$2.744x10^6$	$1.834x10^6$	$1.213x10^6$
8. Amount of N in ground water in mg	$0.229x10^6$	$0.141x10^6$	$0.180x10^6$	$0.096x10^6$
9. Amount of N through leaching @ 10% in mg	$40.24x10^6$	$15.04x10^6$	$40.69x10^6$	$14.76x10^6$
10. Proportionate amount of ground waterin 10 m thick mixing zone with 30% porosity value in m^3	27473	27553	27056	26999
11. Amount of N in this ground water (row 10) in mg (0.5 mg/l NO_3-N)	$13.74x10^6$	$13.78x10^6$	$13.53x10^6$	$13.49x10^6$
12. Total amount of N in mg, rows 6+7+8+9+11	$56.67x10^6$	$31.71x10^6$	$56.23x10^6$	$29.56x10^6$
13. Final concentration of NO_3-N after one year, in mg/l	1.89	1.06	1.87	0.90

Note:- Average 3 fold increase in concentration.

Recentdata of ground water draft has been utilised (ref.3) where 90% amount has been assumed to have been used in irrigation. Surface water draft is calculated on proportionate basis of area irrigated. As regards, rates of infiltration, average 20% has been taken as rainfall infiltration (ref.4) and same value is assumed for ground water return flow (with 0.5 mg/l NO_3-N). Average rate of 40% has been taken for surface water return flow (with 3 mg/l NO_3-N).

To prevent health hazard the study manifests the possibility of management by control on V_s, V_g and F. Management on I_1, I_2, I_3, C_2 and C_3 will also be possible to prevent excessive pollution.

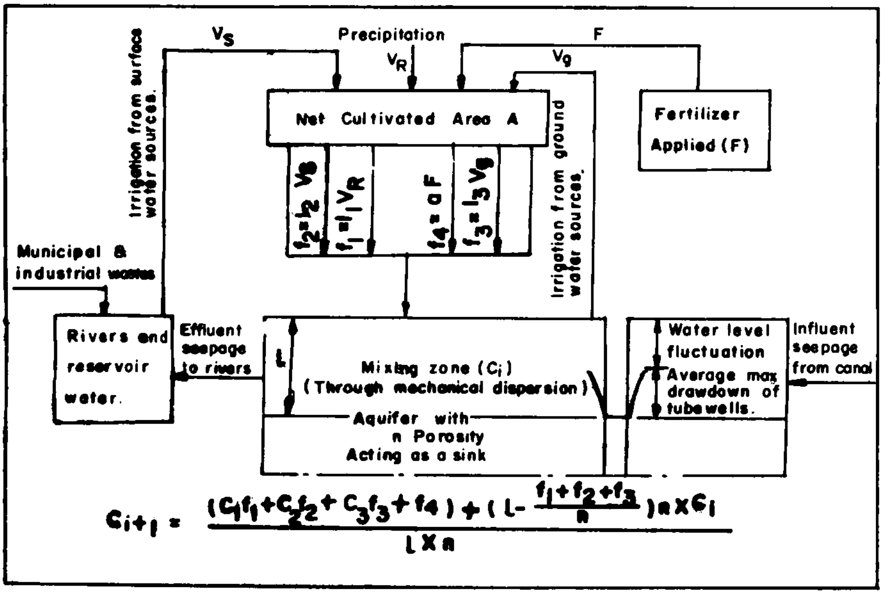

Fig. 2 Interaction and the parameters in the system and the model.

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