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Catchment Pollution Potential and Pattern of Groundwater Quality

Ritu Ahlawat*
Department of Geography, Miranda House, University of Delhi, India

Abstract
Pollutants in groundwater can occur naturally or they can be introduced by various anthropogenic sources of pollution. Both point and non-point sources of pollution affect the quality of surface as well as ground water. As water infiltrates, solute concentrations are typically low. But after penetration their spatial extent follows a regional pattern that needs to be examined in detail. Hence, spatial pattern of important parameters of ground water quality obtained from secondary observation well data in case of Betwa river catchment has been presented in this paper. An overview of various sources of pollution from agriculture, industries and towns and their potential effect is also reflected.

Keywords*: Groundwater data network, spatial interpolation, solute concentration level, pollution potential, domestic pollution, agricultural pollution*

****Author for Correspondence*** E-mail: ritu.ahlawat@gmail.com

INTRODUCTION
Groundwater quality is affected by both point and non-point sources of pollution. The point source of pollution, contributed at a single point in significant amount, includes wastewater mainly from domestic and industrial use. The non-point or diffused pollution originates from the catchment area through movement of water. Pollutants originating from topsoil losses include soil, organic matter, plant residues, nutrient elements, organic chemicals, toxic elements and bacteria. Soil can retain, modify, decompose or absorb pollutants. A properly managed and balanced soil system does not represent a significant threat to water quality as the partially or untreated sewage is also being used for irrigation in the catchment. It is a good source of nutrients in the soil especially for nitrogen. Gardens, streets and storm-water drains generally containing sewage, sullage and other solid waste generated from domestic, commercial and industrial activities also add to it. But, it is difficult to estimate exact quantity of such pollution, because pollutant-soil interaction is very complex. Generally, soils of high clay and organic matter content exhibit high retention capacity for many pollutants. Due to their low permeability, erosion is primary transporting vector for pollutants. Sandy soils, on the other hand, have low erosion potential but their ability to retain pollutants is relatively low facilitating the pollutants to penetrate the topsoil and reach the ground water aquifers. The water pollution on account of agriculture is generally contributed by large amount of commercial fertilizer and pesticide use. The application of fertilizer increases the amount of pollutants that can be lost potentially from agriculture. The transport of fertilizers and residues from agricultural fields to the river occurs mainly during rainy season. The magnitude of their contribution to pollution load in river is directly related to amount of suspended particles in the runoff water and intensity of application of these chemicals. That is why it is difficult to quantify accurately. It has been estimated that 10-15% of the nutrients added to soil through fertilizers find their way to surface water system [1].

As many parameters are involved directly or indirectly in determining groundwater quality, various genetic algorithms have been devised to solve the multi-objective groundwater-monitoring problem [2]. Similarly, the classical linear programming model for determining optimum solution of the network design has now been made more practical through non-linear and mixed-integer programmes [3]. Even the specific minutest details like measurement scale and network sampling scale are now discussed in groundwater network [4]. In case of water quality investigations of both surface and ground water, the studies in India have assumed significance in the recent decade with the help of remote sensing data. A systematic approach has been made for the analysis of Ken graben area by integrating the remote sensing data with the hydrologic data to study the subsurface geological and geomorphological details and to demonstrate the aquifer geometry, ground water quality in the region. Ground water hydrogeological status has been inferred from an integration of the structural, lithological and vegetational information, DEM of the subsurface topography generated with the help of depth to bedrock contours. It enabled the delineation of the brackish ground water pockets that are in close agreement with the field investigation [5]. In the light of multiple studies regarding groundwater quality, a single objective study related to spatial pattern of important parameters at catchment level for one time-period has been presented in the present paper. Besides, an indirect estimate about possible sources of pollution that can affect groundwater quality has been made.

STUDY AREA

Betwa river, marked by diverse geological conditions and undulating topography ranging from alluvial plains towards north and Vindhyan plateau towards south, is selected for analysing the catchment and watershed-wise spread of groundwater pollutants. The spatial extent of catchment area lies between 22°20' to 26°0' N. latitudes and 77°10' to 80°20' E. longitudes in southern Uttar Pradesh and northern Madhya Pradesh (Figure 1).

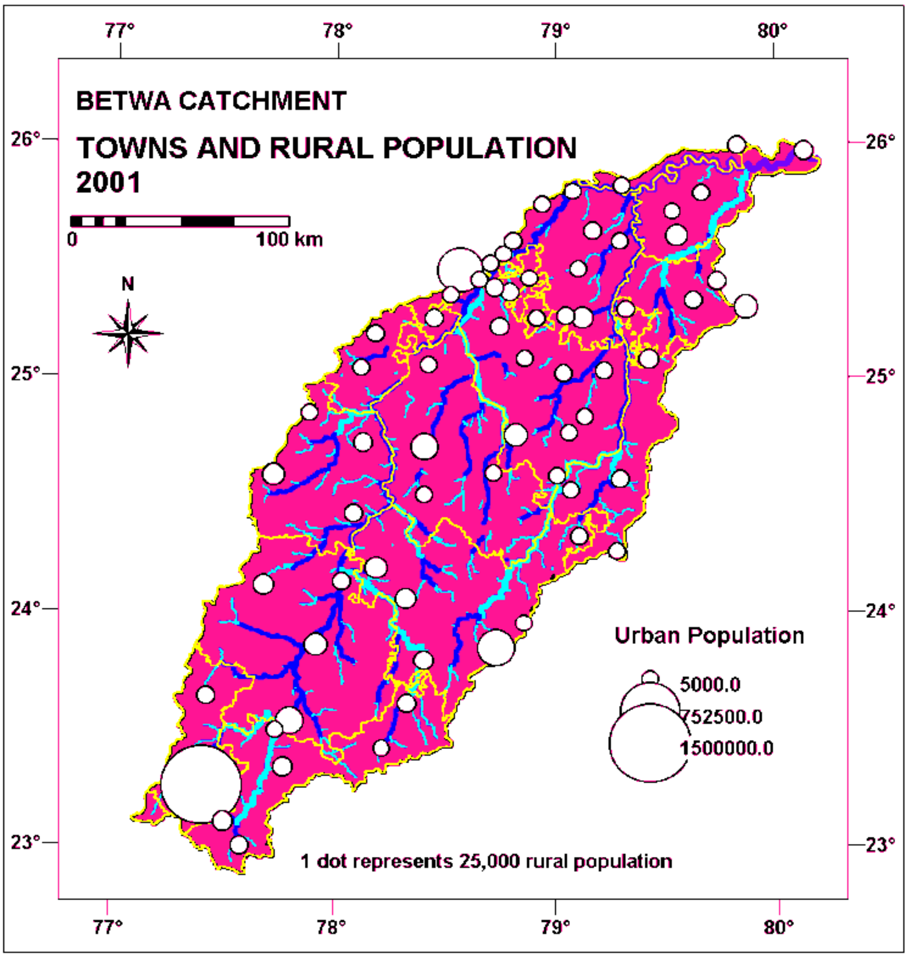

Fig.1: *Study Area.*

(Source: Author using ILWIS based on data from Census of India (2001) ***Final Population Tables CD****)*

The River Betwa finds its mention by the name *Vetrawati* in a numerous mythological *Granthas* and *Puranas* of Hindu religion. But, now the entire catchment of Betwa right from its origin to its confluence with Yamuna and its tributaries are subject to anthropogenic activities, which directly or indirectly affect the water quality. The River Betwa is the life-line for the region through which it flows and has an important role to play in the all round growth and development of the region. It serves as the source of drinking water to huge population of the region especially to Raisen, Vidisha, Basoda and Kurwai (Figure 1). It is the major source of irrigation for the area known for the production of high quality wheat, gram and soya bean in the country.

METHODOLOGY

The analysis is based on data collected from secondary sources. Ground water quality data for one season (May 2001) at hydrograph stations maintained by Central Ground Water Board was obtained from website www.IndiaAgristat.com [6]. Population data from reports and CDs of Census of India was used for rural and urban population growth. Fertiliser consumption data for all 14 district of Betwa catchment was obtained again from website www.IndiaAgristat.com [7].

Landuse and irrigation data were obtained Indian Agricultural Statistics volumes and website of Ministry of Water Resource respectively [8]. Survey of India toposheets, District Planning Map Series, Watershed Atlas of India were used for drawing base map of the region. Field visit was also undertaken at some of the sites in order to know the status of water quality.

First of all, hydrograph stations were located in each sub-catchment of Betwa river region. Then, ground water quality data of observation wells was formatted in MS- EXCEL and imported in GIS software - ILWIS for drawing attribute maps. Moving average interpolation method was used to calculate pixel-wise value of important parameters of water quality. Thereafter, resultant maps were compared with population data and fertiliser consumption in each region to know the pollution potential.

RESULTS AND DISCUSSIONS

Network of Water Quality Monitoring Stations in Betwa Catchment

There is still a paucity of both surface and ground water quality monitoring stations in the catchment. They have been established on main rivers only and on few lakes. The network of groundwater quality monitoring stations comprises of about 50 observation wells out of a total of 136 hydrograph stations in Betwa catchment. The gaps can be filled by monitoring of different parameters at potential sources of pollution. In Betwa river catchment, there exists only one CPCB station for monitoring surface water quality at Hamirpur. Other stations are maintained by state pollution control board. The upper Betwa sub-catchment alone has 8 stations at intake points of water supply, *viz.* Mandideep, Bhojpur, two in Vidisha and one near Raisen in upper reaches of Betwa; Rahatgarh on *Bina*, and one station each on *Jamni* and *Dhasan* river. It is suggested that a minimum of 5–8 more stations should be present in the Betwa catchment keeping in view the current rise in urban population and more land being brought under irrigated agriculture.

Pollution Potential in Betwa Catchment

The pollution potential in the catchment area is due to both point and non-point sources of pollution as reflected by concentration of pollutants at selected monitoring sites.

Point Sources of Pollution

Major domestic pollution sources are urban centres. The proportion of urban population has steadily increased over the decades reaching more than 3 million in 2001 (Table 1). The highest increase was in 1971–81 decade. As a result of increasing need for water to meet the domestic requirements and impact of resultant wastewater, discharge on the receiving waters have the cumulative effect of deteriorating the quality. The wastewater added from 70 urban centres in Betwa catchment have increased manifold. Although, there is only one million cities in the Betwa catchment, *i.e.* Bhopal but it contributes significantly towards pollution load. The other large cities are Jhansi and Sagar, located on boundary of catchment. As Sagar is situated far away from main Betwa as well as from its tributary - *Dhasan* in that region, therefore, its effect on water quality in Betwa catchment can be ignored. Jhansi, however, being very close to main middle Betwa, draws its water supply from it and has profound impact on water quality through its untreated sewage. Most of the other towns are also located very close to rivers.

Although, several industries have been established in the catchment area, a precise estimation of their contribution of pollution to the river could not be made due to wide variation in their discharges. Therefore, an analysis of the census data regarding most important industry along with number of industrial workers in each district reveals indirectly about nature and extent of industrial pollution. Most of the polluting industrial units lie in upper Betwa region around Bhopal. Mandideep, as fastest growing industrial centre, nowadays has witnessed the worst levels of critical parameters. A field survey conducted in this town also showed shocking results not only for human beings but also for cattles. The polluting industrial cluster around Ashoknagar for plastic bags is more harmful for groundwater quality as the town is away from main river/tributary. A central industrial belt around Jhansi and Tikamgarh region is another potential source of pollution. In rest of the towns, although, food-processing and *bidi* (forest-based household produce) industries predominate but the chemical used in processing and left untreated can become major source of groundwater pollution in near future. Therefore, a close and strict implementation of standards at these points needs to be enhanced by establishing independent regular monitoring sites.

The problem is further compounded by few treatment facilities in these small towns. The BOD load generation from smaller towns, estimated for different classes of towns according to per capita load adopted from CPCB classification, surpasses the total load from few big cities. Domestic pollution from rural population is, although not very harmful but a larger share of rural population (about 90%) in Betwa catchment may pose a significant threat particularly to groundwater quality. Hence, at least seasonal monitoring stations are required in large irrigated rural belts.

Table 1: *Watershed-wise Total Population (2001) and Fertilizer Consumption in Betwa Catchment.*

S. No.	Watershed	Total Urban* Population	Total Rural Population	Weighted Average Fertilizer Consumption (Tonnes)
1	Kaliasote	1,498,275	751,883	12,234
2	Upper Dhasan	298,715	3,279,558	19,011
3	Lower Dhasan	244,360	2,934,181	20,544
4	Lower middle Betwa	240,841	3,628,332	18,699
5	Upper Betwa	167,939	1,562,171	20,639
6	Bina	156,450	1,941,892	21,897
7	Narain nadi	----	1,502,573	19, 619
8	Jamni	129,279	2,492,838	15,.223
9	Newan nadi	---	862,445	25,294
10	Upper middle Betwa	98,214	2,760,108	21,036
11	Birma	88,802	1,150,399	10,095
12	Orr nadi	68,052	555,507	19,124
13	Kevtan nadi	---	1,275,109	23, 159
14	Naren nadi	---	862,445	25, 294
15	Kethan nadi	42,179	1,257,535	22, 588
16	Halali	----	1,562,171	14, 995
17	Baen nadi	24,302	1,149,507	17, 225
18	Sagar nadi	----	862,445	25,294
19	Uppermost Betwa	19,938	699,726	20, 222
20	Lowermost Betwa	14,941	502,386	15, 221

Source: Computed from Fig. 1 & 2 based on data from Census of India (2001). ***Town Directory; Final Population Tables.*** *Fertilizer Association of India (2002) (*Towns lying on catchment boundary are excluded)*

Non-Point Sources of Pollution

The non-point or diffused pollution originates from the catchment area through movement of water. In an unbalanced system, high pollutant loadings are associated with excessive nutrient applications, disturbed and unprotected lands, and unusual meteorological conditions especially in the ravinous irrigated belt of Betwa and *Dhasan*. The excess is in the form of runoff from animal feedlots, leachates from excessively fertilised and manured fields. The important sources of diffused pollution sources contributing to Betwa river catchment are agricultural and in-stream uses of water. The water pollution on account of agriculture is generally contributed by large amount of commercial fertilizer. Weighted average annual fertilizer consumption, calculated on *pro-rata* basis from district data, was found to be higher in watersheds lying in upper Betwa sub-catchments (Table 1).

The spatial variation in fertilizer consumption pattern is quite significant (Figure 2). The average amount in lower reaches, that have higher area under irrigation, is less than half of that in upper reaches. It may be due to less agricultural tract available in plateau region and, therefore, yield is enhanced by higher levels of fertiliser use.

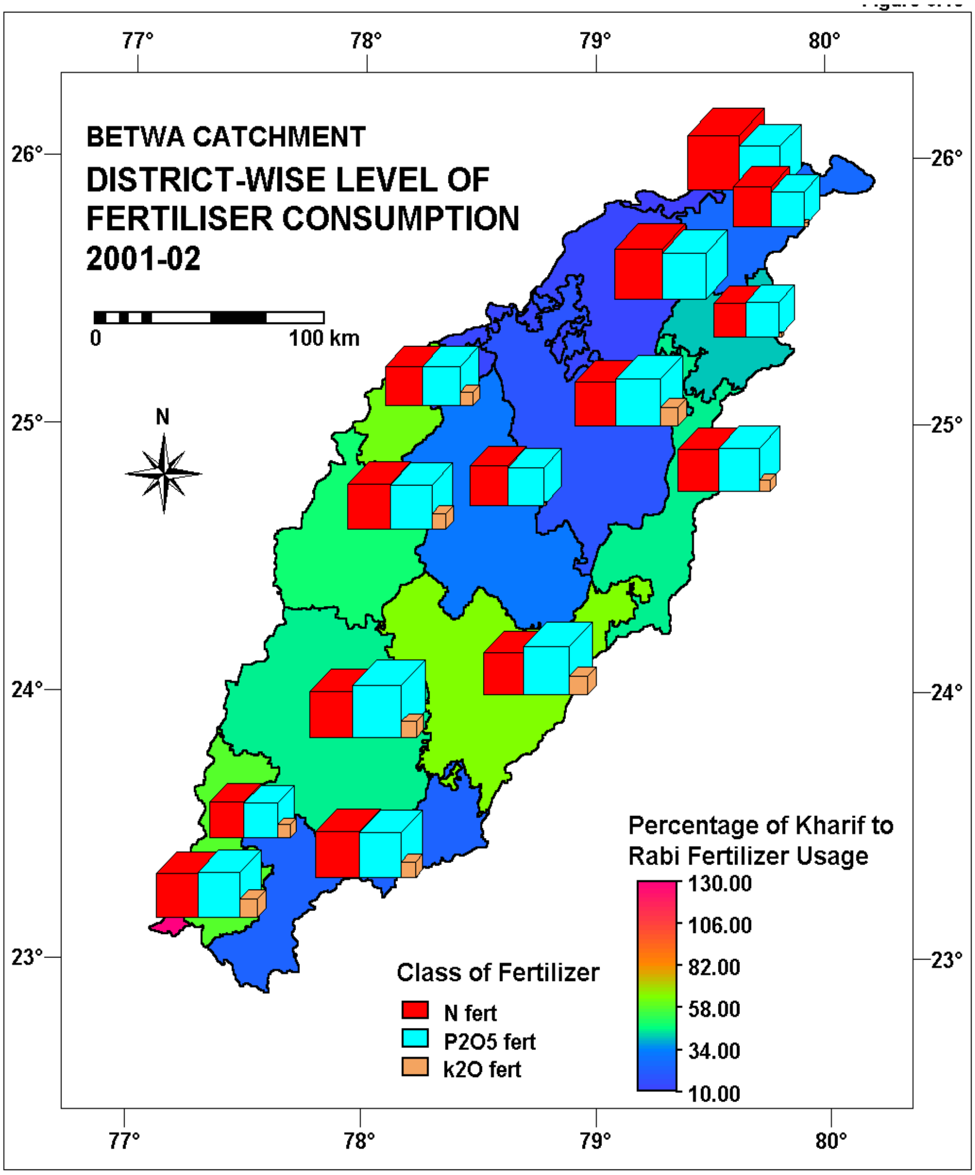

Fig.2: *Pattern of Fertlised Agriculture.*
(Source: Author using ILWIS based on data (2002) from Government of India, Fertilizer Association of India)

Spatial Variation in Groundwater Quality Parameters

Common groundwater solutes, usually present in concentrations above 1mg/l, include calcium (Ca^{2+}), sodium (Na^{+}), magnesium (Mg^{2+}), potassium (K^{+}), bicarbonate (HCO_3^{-}), sulphate (SO_4^{2-}), chloride (Cl^{-}) and silica (SiO_2). Secondary ions include iron (Fe^{2+}), nitrate (NO_3^{-}) and fluoride (F^{+}). A hydro-geochemical analysis based on observation wells data for May, 2001 revealed spatial variations in groundwater quality. From the detailed location-wise well data and their GIS based map interpolation (Figures 3a to l), a brief discussion on status of 13 parameters is presented as follows:

pH

pH of groundwater lies between normal range in the Betwa catchment. Its value of being more than neutral value of 7 at majority of places reflects slightly alkaline nature of groundwater. Only at one observation well near Vidisha, a pH value of 8 was observed. A slight variation in this range occurs towards western side (Figure 3a).

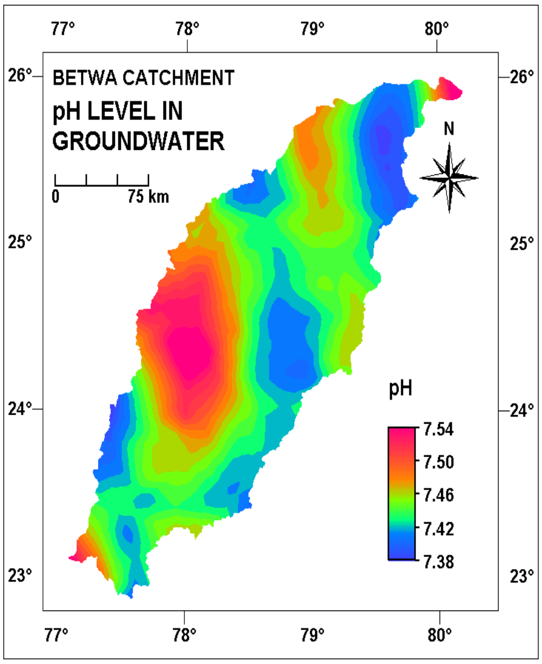

Fig.3a

Electrical Conductivity (EC)

EC values vary from 769 μ siemens in northern plains to 1621 μ siemens towards southeast. It shows close correspondence with geological structure. Higher values of EC are found in exposed area of Vindhyan scraps. Moderate to low values prevail in undulating Vindhyan sandstone and alluvium zone, respectively (Figure 3b).

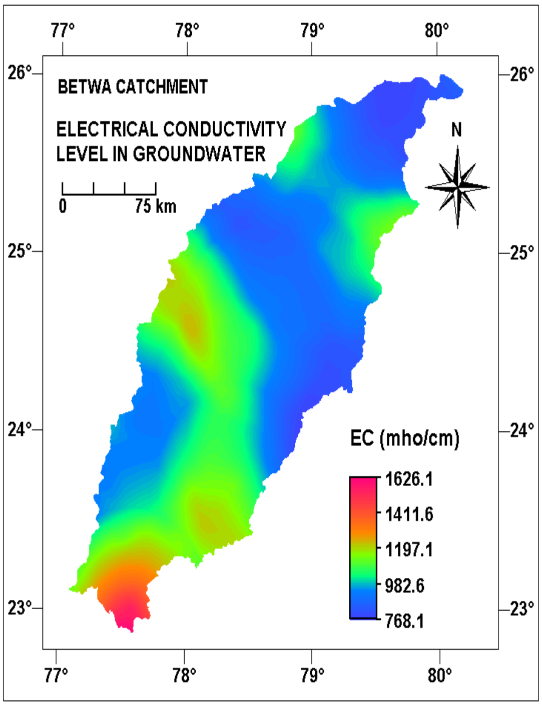

Fig. 3b

Chlorine (Cl)

In major parts of catchment chlorine concentration is well below the desirable limit. However, local maxims occur at places in uppermost Betwa, middle reaches of *Dhasan* and areas dominated by Bijawar series (Figure 3c). At about 12 wells, the chloride level was above 150 mg/l. It is at these crucial places that a careful and continuous monitoring is required in order to check the excess limit.

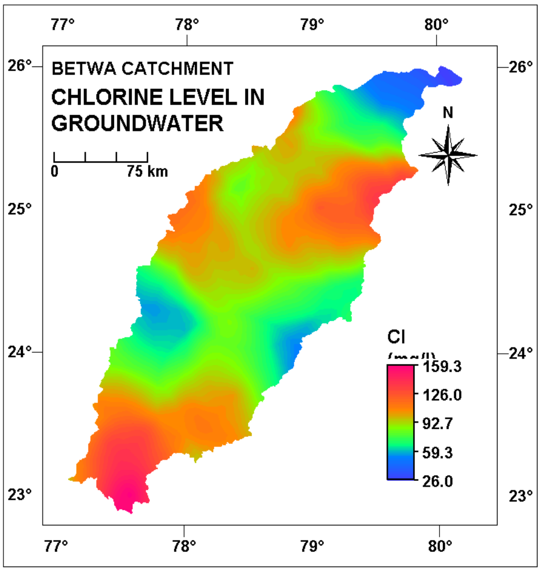

Fig.3c

Fluorine (F)

Fluorine amount in groundwater is within limits at most of the places. Two zones having relatively higher concentration have become quite distinct towards the south-eastern periphery of catchment and in the north central uplands (Figure 3d).

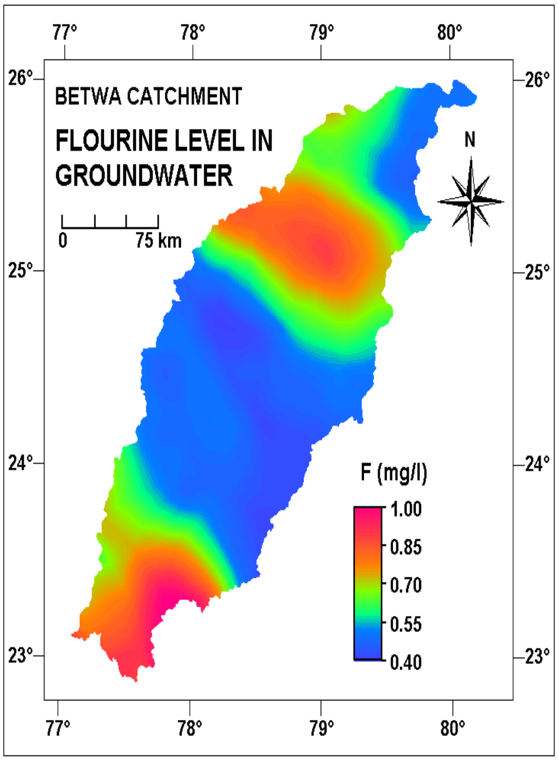

Fig. 3d

Carbonate and Bicarbonate (HCO_3)

Lowest bicarbonate concentration occurs in the middle reaches of entire Betwa catchment near the transition zone of Vindhyans and Bundelkhand gneisses, from where an increasing trend can be seen both north-eastwards and south-eastwards (Figure 3e). Highest values are found again in uppermost Betwa watershed. Most of the wells lying in catchment area of other tributaries, except *Halali*, in upper Betwa plateau region also have relatively higher concentrations.

Silicon Dioxide (SiO_2)

Silicon dioxide varies from 25 to 49 mg/l resulting into two zones of higher concentration on the eastern side (Figure 3f). There occurs a change in SiO_2 values over short distances. Thus, coverage of SiO_2 requires more observation wells in order to arrive at better spatial estimates.

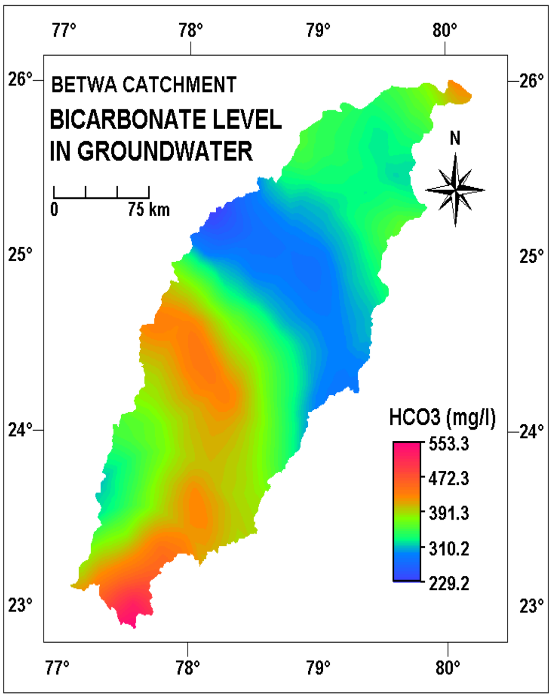

Fig.3e

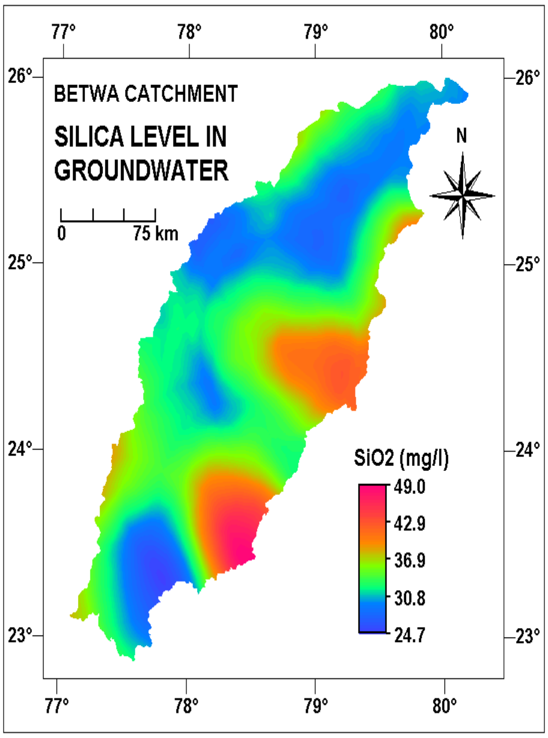

Fig.3f

Nitrate

In case of nitrates, the concentration is higher than the desirable limit at many places especially towards western fringe of middle plateau region and south-eastern periphery in higher reaches of *Bina* towards Sagar (Figure 3g).

Sulphate
Sulphate concentration is, in general, below desirable level except at Garutha. It may be due to some local quarrying activity. Lowest values occur towards northern plains and in middle reaches of catchment (Figure 3h).

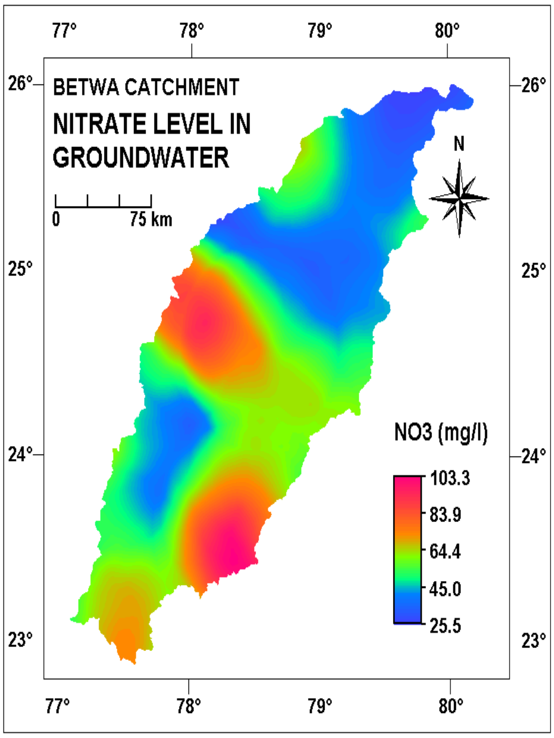

Fig.3g

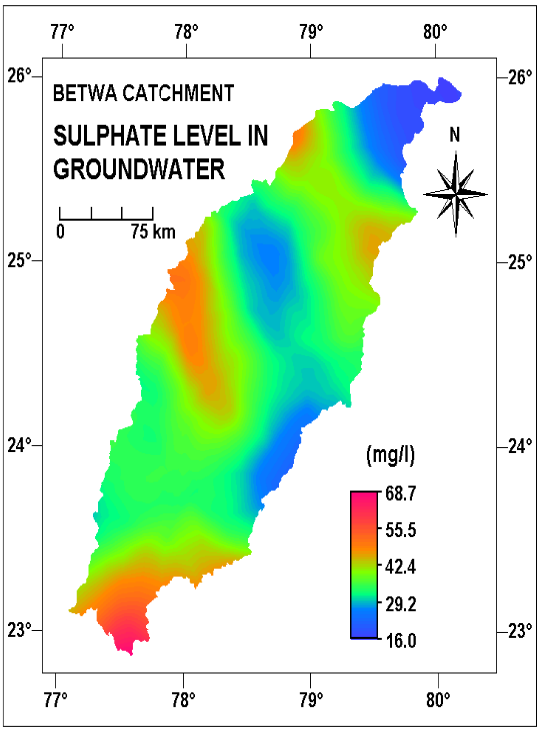

Fig. 3h

Sodium (Na)
To the contrary of spatial pattern in other parameters, sodium peak can be seen in central part of catchment, from where it declines southwards and northwards with a secondary ridge in lower *Dhasan* area of irrigated belt (Figure 3i).

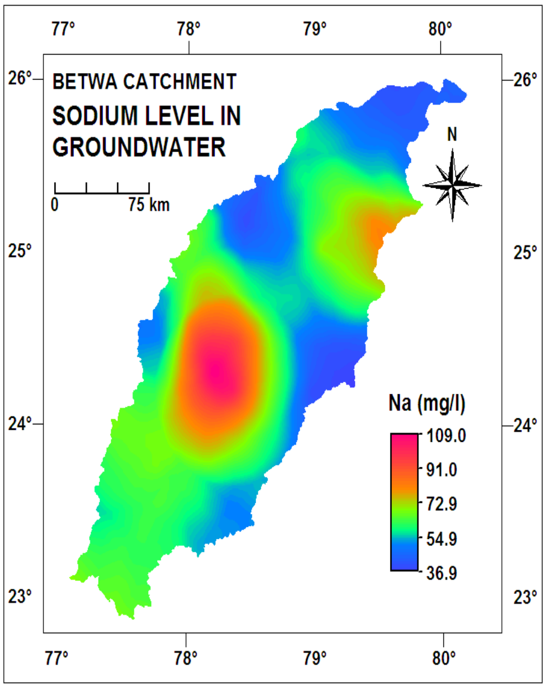

Fig.3i

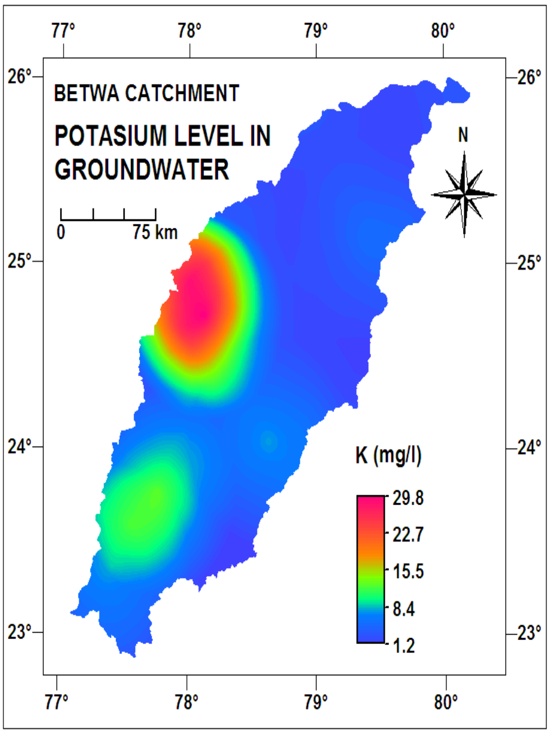

Fig. 3j

Potassium (K)
A very high concentration of potassium was observed at Chanderi as compared to much lower level at other places resulting into highest level of spatial variation among all parameters of groundwater quality in the Betwa catchment (Figure 3j).

Calcium (Ca)
Calcium concentration in most of the valley regions is lower. It is highest towards south-eastern part of catchment and along other areas in eastern and central belt (Figure 3k). At eight observation wells it even exceeded the maximum permissible limit of 200 mg/l.

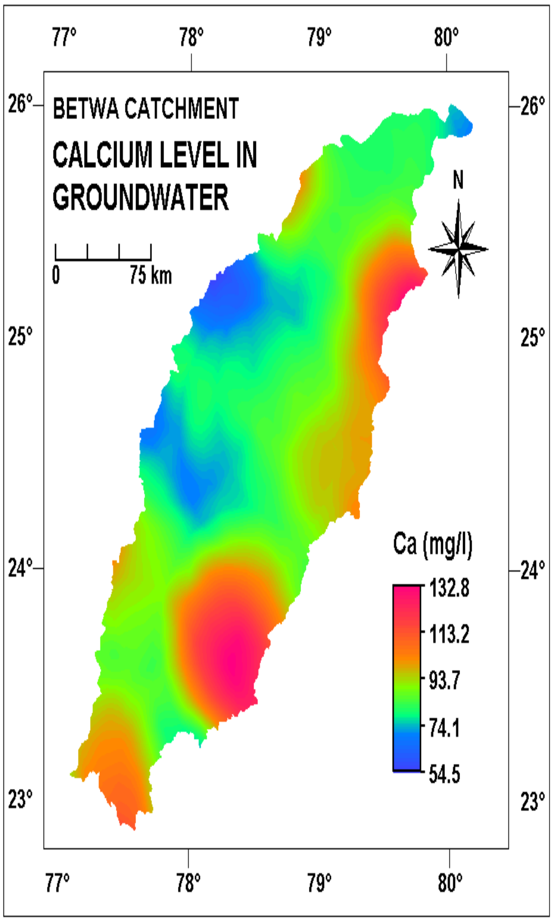

Fig. 3k

Magnesium (Mg)
Magnesium values in the catchment vary from as low as 2 mg/l (Pichhore) to more than 250 mg/l. A peak of Mg concentration is clearly visible in the southern tip of uppermost Betwa watershed. Slightly higher values occur towards mid-western parts (Figure 3l).

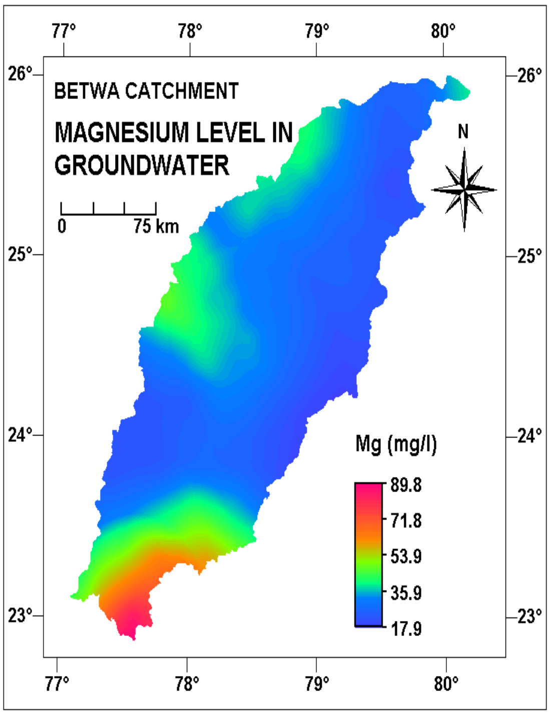

Fig. 3l
Fig. 3: *Spatial Concentration of Selected Groundwater Quality Parameters (May, 2001)*
(Source: By Author using ILWIS based on Well-wise Chemical Analysis of Shallow Ground Water Data of CGWB Groundwater Statistics (2002) from www.IndiaAgristat.com)

CONCLUDING REMARKS
Thus, like surface water, ground water also reflects a specific spatial pattern. However, individual well data may show high concentration at that point but limits of its spatial extent need to be examined well within reasonable standards. The potential path of their transport if mapped and modelled can, at least, provide ways for minimisation of pollution extent and its spread in the catchment. Further, monitoring of both surface and groundwater quality parameters is required at all towns having a population of more than 20,000 and sewage facility.

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