GIS FOR POINT-SOURCE POLLUTANT DISPERSAL ANALYSIS

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ABSTRACT

Point-source pollution due to H-acid - a dye intermediate, leaching into subsurface from a factory storage facility in Bichhri in Rajasthan, India, led to groundwater and soil contamination since 1988. Satellite data, soil and groundwater sampling and their integration with resource maps of the region in ARC/INFO GIS, enabled the study of H-acid dispersion in soil and groundwater which had adverse impact on land use/land cover and the life of the residents.

Application of GIS for overlay of maps of various themes, viz., land use/ land cover, hydro-geomorphology, groundwater potential, soil types, land capability and H-acid conc. in soil and groundwater, enabled the assessment of magnitude of H-acid contamination in the area. Significantly, H-acid conc. in soil extracts of surface and subsurface soil by far, exceeded the concentration level in ground water; H-acid conc. was 4000 - 7000 mg/kg in soil extract while it ranged between 2 - 50 mg/l in groundwater in 1998.

GIS map-union using plots of H-acid conc. in groundwater with hydro-geomorphology of the region, indicated the magnitude of aquifer contamination. Areas with varying H-acid concentration levels were delineated; it was noted that over 3.1 Km^2 was contaminated with < 1 mg/l while 0.02 Km^2 was polluted with 500 mg/l. This analysis has facilitated in the estimation of cost of ameliorative measures necessary for cleanup. Fortunately, since 1998 the H-acid conc. has declined both in soil and groundwater owing to the passage of several hydrological cycles, as indicated by the gradual return of agricultural activity in the region.

1.   INTRODUCTION

1.1   Location and natural resource base of study area

Bichhri village, the focus of this study, is located at $24^0 35^{'}$ N and $73^0 46^{'}$ E, app. 16 Kms towards the Southeast of Udaipur city in the State of Rajasthan in India. The region lies in a transition belt between hot arid climate in west and sub-humid climate towards the east with a mean rainfall of 581 mm. Koppen's climate classification defines the area as BShw, i.e., warm semi-arid steppe type with mean annual temperature over 18^0C. This typical climate is a result of its location near the Tropic of Cancer and the periphery of the Great Indian *Thar* Desert, which is moderated by the large water bodies located around Udaipur City, within the region.

Geologically, the region belongs to the Archean Shield of the Deccan Plateau consisting of well-foliated, highly contorted and faulted Gneiss Basement Complex. The region belongs to Aravalli hill system and local geomorphology indicates denuded slopes and plain which is nearing peneplanation. The region forms a water-divide where the western streams drain into Sabarmati river which flows into the Arabian Sea and the eastern streams drain into east-flowing rivers flowing into the Bay of Bengal. The drainage density within the region varies from 0.5 to 0.7 Km/Km^2. Five large earth-excavated tanks dot the Udaipur city, moderating the climatic rigour.

Groundwater occur and circulate mainly through the weathered zones and weak planes like joints and fissures in Quartzite while in Phyllite and Schist, it occurs in fractured bedding. The water-table varies from 5 to 30 m below ground level and the yield from wells vary from 15 to 150 m^3/ day. Natural vegetation vary from deciduous to sub-

tropical evergreen forest and rainfed agriculture is predominant in this region with small scattered pockets of irrigated agriculture.

1.2   Genesis of environmental contamination

In 1987, an agro-chemical industry named the Hindustan Agrochemical Limited (HACL) was setup in Bichhri village, which commenced production of a dye intermediate, H-acid (8 amino 1 napthol 3 - 6 disulphonic acid). As the earth excavated storage facility were unsuitable for the storage of highly corrosive H - Acid, an organic non-bio-degradable chemical with pH of 1.5 - 2.0, it soon percolated downward and contaminated the soil and groundwater, resulting in severe coloration of groundwater with acrid taste and odour, turning it unsuitable for human consumption, domestic use, livestock watering and irrigation. Several health-related problems, viz., eruption of skin diseases, respiratory problems among people and increased livestock mortality, had been attributed to H-acid contamination of groundwater and fodder.

To get a comprehensive view of status of contamination of groundwater and soil and its impact on agricultural production and consequent changes in land use since 1988, satellite data from Indian Remote Sensing Satellite, IRS-1A and 1B LISS-II sensor, were analysed using ERDAS Imagine (Ver. 8.3) Digital Interpretation Software. The information was mapped and superimposed over maps of soil and groundwater contamination on ARC / INFO GIS platform (Cowen et al 1995, Hofman & Kobus, 1996) .

1.3.   Ecological and socio-economic consequence

The environmental impact of H-acid contamination was severe in 1992 leading to popular unrest necessitating intervention by civil authorities. Incidents such as two cases of infant mortality, increased incidence of health-related problems, lack of drinking water in the vicinity and higher livestock mortality, all triggered a social unrest in Bichhri in 1990-92. Since then, however, the situation has been steadily improving due to a gradual fall in H-acid conc. through various hydrological cycles leading to leaching of H-acid from soil surface to lower levels of soil profile and fall in H-acid conc. in groundwater due to hydrological dilution. Although groundwater is still severely coloured, the H-acid conc. is falling and agricultural activity is regaining.

2.   MATERIAL AND METHODS

To assess the impact of H-acid contamination on agriculture and environment, satellite data were analysed for detection of change in land use / land cover pattern using visual interpretation and digital technique with ERDAS - Ver.8.3 (ERDAS 1997). For *apriori* information on land use pattern, LANDSAT-5 TM data was taken; Standard FCC comprising of Band 2 (0.52 - 0.60 μm), Band 3 (0.63-0.69μm) and Band 4 (0.76-0.90μm) was visually interpreted and mapped providing baseline information on Bichhri, prior to the occurrence of HACL disaster. For assessment of post-disaster scenario, digital data of Indian Remote Sensing Satellite - IRS-1A LISS-II of 1992 and IRS-1B LISS-II of 1998, were digitally analysed using ERDAS Imagine. IRS Geocoded image on 1:50,000 scale with a spatial resolution of 36.75 m comprising of Band 2 (0.52-0.59μm), Band 3 (0.62-0.69μm) and Band 4 (0.77-0.89μm), were found suitable for the study of land use / land cover changes in the region (NRSA 1987). An overlay of land use / land cover in the following pattern - 1998 over 1992 and 1992 over 1986 - indicated changes in land use owing to contamination of groundwater and soils. These maps besides other theme maps viz., land use / land cover, hydro-geomorphology, groundwater potential, soil types, land capability and H-acid conc. in soils and groundwater, were used in ARC / INFO GIS for creation, overlay and analysis of various aspects of pollution (ESRI 1993).

Contaminated groundwater were analysed for 14 - 16 physico-chemical parameters to determine their quality for human consumption, livestock and irrigation, while soil was assessed for suitability for agriculture (Anon. 1991, CPCB 1998). To assess the degree of contamination, soil quality was compared with standards for agricultural soils given by FAO (1983), German (Grenzwerte, 1994) and Dutch governments of 1993. Groundwater quality was assessed for drinking purpose and compared with Drinking Water Standard of India (Anon. 1991) and the German standard (Bundesgesetzblatt, 1990); while irrigation water quality was compared with standard given by FAO (1973, 1986) and USDA (1954). Significantly, it was noted that although water quality for both purposes was not poor, the occurrence of H-acid in it, made it unsuitable for any use.

3.   DISCUSSION:

Water quality analysis indicated that some of the physico-chemical parameters, viz., EC, dissolved solids, Ca, Mg, Na and SO4 levels were higher when compared with the Indian (IS-10500 : 1991) and German Drinking Water Standard (Bundesgesatzblatt, 1990; Malina ,1996; USEPA 1990; WHO, 1984). A map-union in ARC/INFO GIS enabled the estimation of spatial spread of H-acid conc. in groundwater in 1992, in areas with varying groundwater potential within Bichhri. It was noticed that H-acid conc. varied in different parts of the aquifer; while an area of 3.01 Km^2 had a concentration level of <1 mg/l, over 0.02 Km^2 area had a conc. of 500 mg/l. By 1998, the H-acid conc. had declined drastically with a maximum conc. of 50 mg/l over an area of 0.04 Km^2 and 3.4 Km^2 of aquifer with H-acid conc. ranging from 2- 40 mg/l. Table.1 indicates the advantage of using GIS for assessing the magnitude of H-acid contamination on groundwater aquifer.

H-acid contamination (1992)		H-acid contamination (1998)	
Groundwater potential category	Area contaminated (Km^2)	Groundwater potential category	Area contaminated (Km^2)
Poor	0.1	Poor	0.01
Poor - Moderate	1.7	Poor - Moderate	1.5
Moderate - Good	2.4	Moderate - Good	1.9

Table 1: Decline in contamination hazard to groundwater at Bichhri.

Soil quality for agricultural purpose was assessed using The Netherlands Standard for Soils and the German Standard (Grenzwerte, 1994) and the trace metal and micro-nutrient content as recommended by FAO (1983). It was noted that most of the soils were in good state barring those found in the vicinity of HACL factory, except for the H-acid concentration which made the soils highly toxic for agricultural purpose. Analysis using GIS indicated that the magnitude of H-acid conc. in soil extract of surface and sub-surface ranged from 4000 - 7000 and 4000 - 6000 mg/kg respectively. In groundwater, H-acid conc. ranged from 1- 500 mg/l of water in 1992 and 2-50 mg/l in 1998 (Fig.1).
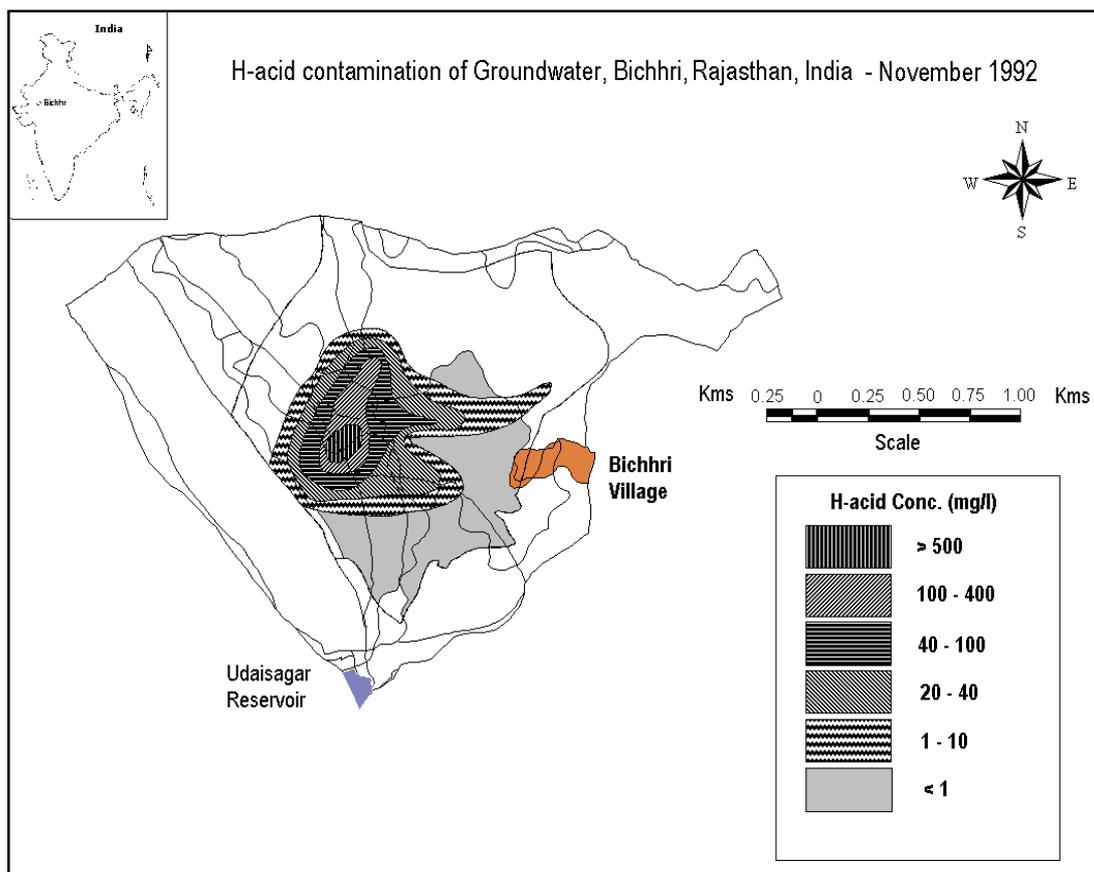

Figure 1. H-acid contamination in groundwater samples from Bichhri village near Udaipur city in November, 1992 .

Map-union of H-acid conc. in surface and subsurface soil in 1998, with a map of groundwater potential of Bichhri, highlighted the H-acid hazard to the aquifer through natural leaching (Fig.2). It was noticed that areas with both - poor

to good groundwater potential were severely affected with H-acid conc. ranging from < 4000 to 7000 mg / kg in subsoil to 4000-6000 mg/kg in surface soils (Fig.3). A union of maps of spatial spread of H-acid conc. in groundwater with that of groundwater potential in Bichhri in 1992, indicated the magnitude of H-acid contamination in groundwater. It was seen that H-acid conc. varied in different parts of the aquifer as mentioned earlier. By 1998, however, the H-acid conc. declined drastically; maximum H-acid conc. in well water was noted as 50 mg/l in an area of 0.04 Km^2. Total area of 3.4 Km^2 of aquifer was estimated to be affected by H-acid conc. of 2- 40 mg/l.
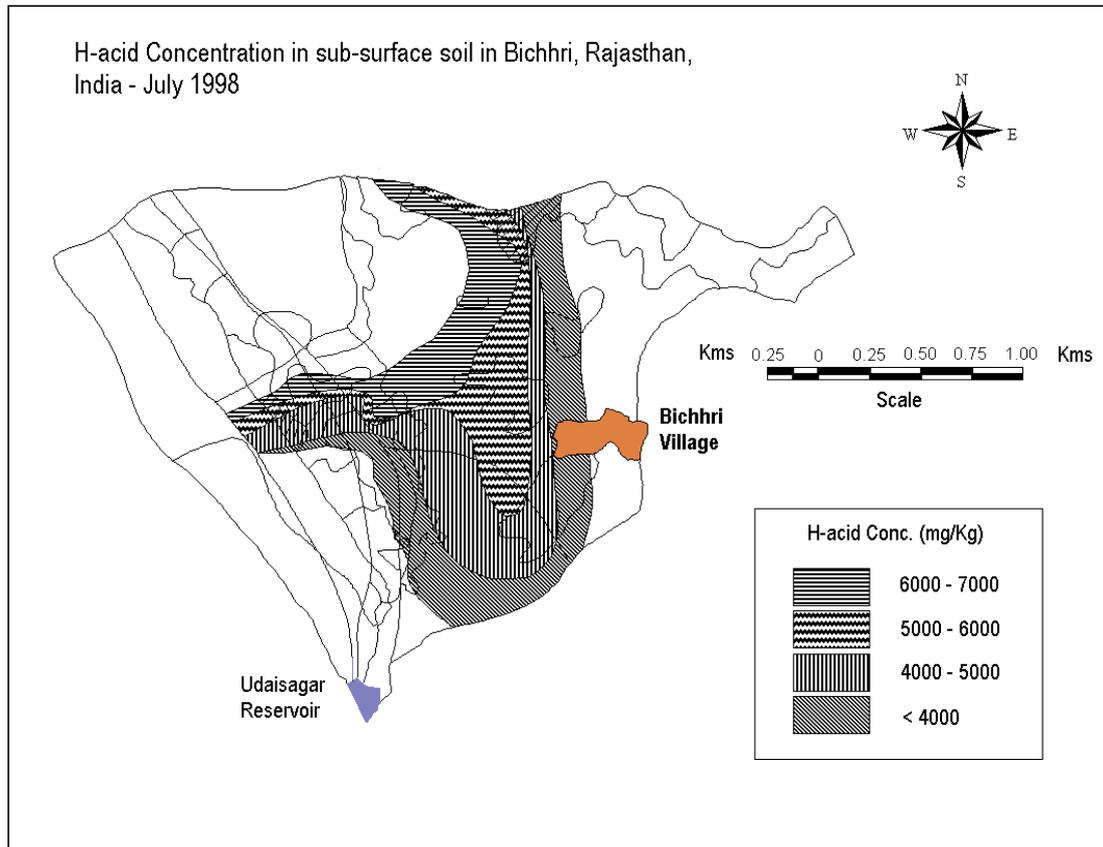

Figure 2. H-acid concentration in sub-surface soils from Bichhri village in July 1998

Digital Interpretation of IRS - 1A and 1B LISS - II data of 1992 and 1998 and a subsequent map overlay in GIS, indicated the land use dynamics in the region as a consequence of contamination. It was noticed that cultivation associated with onset of monsoon *'Kharif'* improved marginally between 1992 and 1998. In 1992, *Kharif* cultivation was confined to an area of 0.22 Km^2 which marginally increased to 0.31Km^2 in 1998. The effect of groundwater contamination was obvious in case of post-monsoon season cultivation *' Rabi' ,* where groundwater is the only source for irrigation. In 1992, an area of 0.36 Km^2 was cultivated under *Rabi* , which increased to 2.0 Km^2 in 1998, owing to the decline in H-acid conc. in water. Spatial extent of fallow land fluctuated proportionally with H-acid conc. in groundwater. Analysis depending on map overlay of Land use/land cover of 1992 and 1998, highlighted some disturbing trends. Owing to contamination agricultural land first fell fallow for over five to seven years. This was followed by encroachment on marginal land, such as open scrub and unreserved forest, which until then had acted as bio-reserves. Human encroachment on these fragile ecosystem, would further aggravate the ecological debacle.

4. CONCLUSION

Dispersal of contaminant from a point-source and its impact on agriculture, socio-economic life of rural people in Bichhri and on the livestock, could be assessed with ease, using satellite data from Indian Remote sensing satellites and ARC/INFO GIS. Map overlay and union provided statistics regarding the spatial extent of soils and groundwater contamination, which in turn, has facilitated the estimation of cost of ameliorative measures to be undertaken. Temporal assessment of soil, groundwater and land use/ land cover have indicated the fall in H-acid concentration levels in groundwater and soils; however, H-acid traces are still to be found in soils and groundwater in Bichhri which makes them unsuitable for any use.
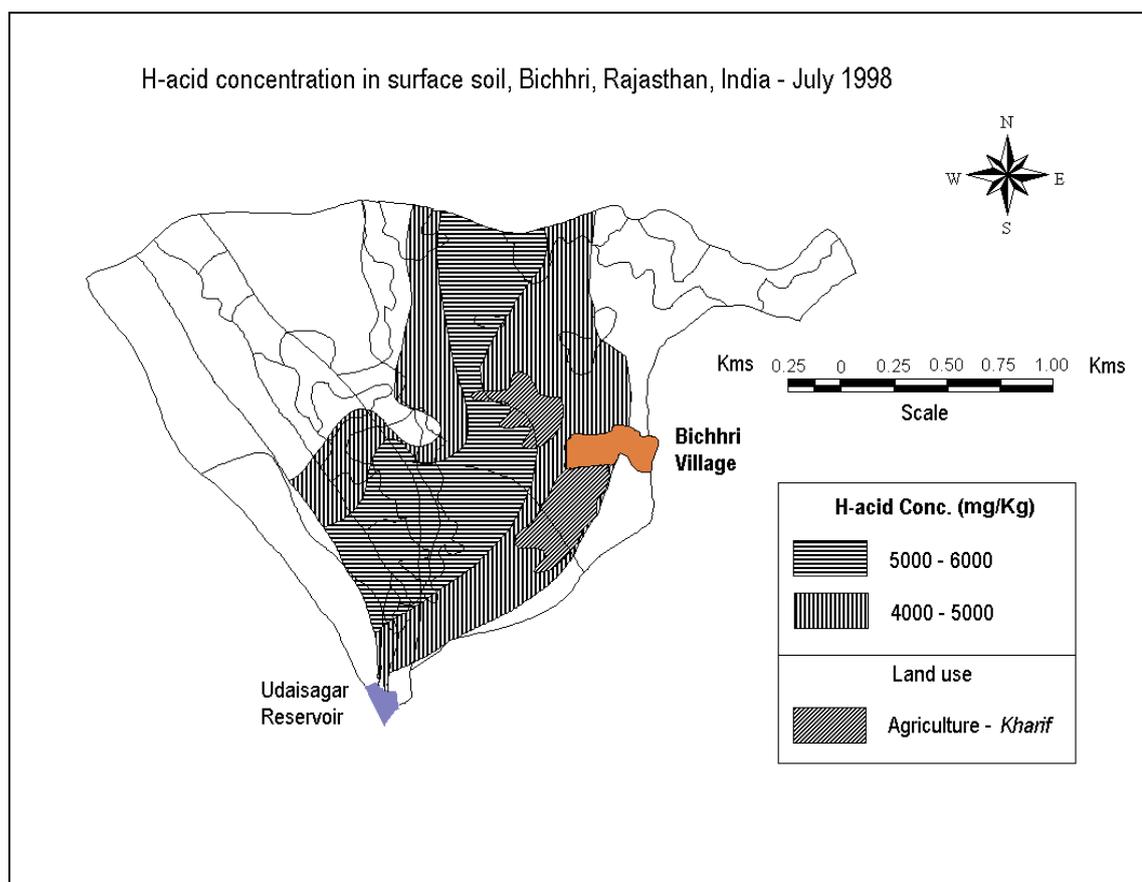
Figure 3. Impact of H-acid contamination of soil on agriculture in Bichhri, July 1998

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