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Groundwater pollution potential assessment through DRASTIC indices methodology - a case study for Banglore North Taluk (Bangalore Urban District)

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Abstract
Groundwater is one of the most valuable natural resources that many developing countries possess. Without improved management and closer protection, groundwater resource will suffer irreversible deterioration on a widespread basis. Innumerable large towns and many megacities derive a major component of their domestic and industrial water supply from aquifers. Approximately 65% of the total water supply is met by public supply system. The remaining 35% being individually supplied, almost exclusively from groundwater sources.

The urban runoff is highly polluted with domestic and industrial wastes that can have serious consequences for the receiving water bodies – surface and underground. In many parts of the tropics with a pronounced dry season or more generally arid climate, groundwater is also widely used as a source of primary or supplementary irrigation for agricultural development.

There is an urgent need for rapid surveys of groundwater utilisation, aquifer pollution vulnerability and subsurface contaminant load.

This situation prompted the authors to undertake a field-cum-office study of Bangalore North taluk (689 sqkm) for pollution potential assessment using DRASTIC indices methodology. This approach was originated in U.S during 1985 for assessing the levels of pollution in groundwater. It is a standardised system used for mapping groundwater pollution potential.

For the 25 grids of Bangalore North taluk, seven parameter values of DRASTIC model are applied with suitable weights and ratings and summed up to arrive at DRASTIC Indices (DI). These vary from 121-180. Higher DI value means, the area is more vulnerable to pollution. The vulnerability of different grid areas to pollution is presented on grid map of 0^0 2' 30" stretch.

INTRODUCTION

During the last two decades groundwater quality has emerged as one of the most important environmental issues confronting much of the world's populace. Increasing evidence of groundwater contamination in recent years, coupled with uncertainties regarding long term human health effects, has heightened pressure on public agencies to better manage groundwater resources. Because restoration of groundwater quality is such a formidable and cost prohibitive task, great emphasis is being placed upon protection of the resource, i.e., prevention of contamination. Sources of groundwater pollution are associated with a broad range of domestic, agricultural, industrial and commercial activities. Reports of serious incidents of groundwater pollution resulting from such activities as land disposal of hazardous wastes and chemical spills have aroused public concern, and field studies have established that many contaminants released into the subsurface are exhibiting sufficient persistence and mobility herein to cause unacceptable deterioration of the quality of valuable and often irreplaceable groundwater resource.

Considering a large number and variety of pollutants that may be released to the subsurface and the wide range of environmental situation (geological, hydrological, chemical and biological) they may encounter, it is apparent that a highly systematic approach must be followed in developing a capacity for predicting surface pollution potential and its control. The objective of the research is to provide methodologies that will permit accurate prediction of the effect of specific pollutants released into the subsurface from a particular source activity which will have on the quality of groundwater at points of withdrawal or discharge.

Perhaps, because it is so critical for public agencies to assess and map groundwater pollution hazard, spatial models designed to evaluate groundwater vulnerability to contamination have been more widely implemented. One such model, DRASTIC provides a systematic, standardised, nationally applicable method for assessing and mapping groundwater pollution potential (Aller et al., 1987-a).

The acronym. DRASTIC, is derived from the seven factors considered in the model:

Depth to water table (D)
Recharge (net) (R)
Aquifer media (geological characteristics) (A)
Soil media (S)
Topography (slope) (T)
Impact of vadose zone (unsaturated zone above water table, (I) and
Conductivity (hydraulic) of the aquifer media (C).

The model is formulated as an equation using a linear combination methodology.

Pollution potential (DI) = $D_rD_w+R_rR_w+A_rA_w+S_rS_w+T_rT_w+I_rI_w+C_rC_w$,

where, r is the rating and w is the weight for each factor.

Ratings and ranges for soil media and depth to water table, and assigned weights for DRASTIC factors are given in the form of tables by Aller et al (1987-b). The system has two major portions: the designation of mappable units, termed hydrologic settings; and the application of a scheme for relative ranking of hydrogeological parameters, called DRASTIC, which helps the user evaluate the relative groundwater pollution potential of any hydrogeologic setting. A hydrogeologic setting is a composite description of all the major geologic and hydrogeologic factors which affect and control groundwater movement into, through and out of an area. Once all the factors are assigned weights, that describe their importance in the pollution process, and the resultant numbers summed up. The proposed DRASTIC methodology has been designed to include only the hydrogeologic factors which influence pollution potential (Barber et al., 1994).

The main aim of the research work is to create a methodology that will permit the groundwater pollution potential of any hydrologic setting to be systematically evaluated with existing information.

STUDY AREA

Groundwater in many stretches of Bangalore urban district is contaminated. Contamination problems vary from region to region and are influenced by population density, intensity of industrial activity, hydrogeology of the region and the status and enforcement of regulations that can be used to protect groundwater.

Bangalore district (urban and rural) as a whole is an overpopulated district. The population of Bangalore North taluk is 9,09,971. The Bangalore Urban district comprises of Anekal taluk, Bangalore North taluk, Bangalore South Taluk and Bangalore North taluk alone covers an area of 689 sq km. The taluk lies between 12^0 55' and 13^o 15' North latitude and 77^0 21' and 77^0 45' East longitude (SOI Toposheet Nos. 57G/8, 57G/12 and 57H/5). The taluk extends north-south to 33 km with an average width of 38 km in east-west direction. National highways No. 4 to Bellary and No. 9 to Pune pass through this taluk. Bangalore city falls within the north taluk (Fig. 1).

Physical Features

Topography : The Bangalore North taluk is more or less level plateau lying between 839 and 962 m above MSL. In the middle of the taluk there is a prominent ridge running NNE-SSE. The highest point 962 m (Doddabettahalli) is on the ridge. The gentle slopes and valleys on either side of the ridge hold better prospects for groundwater utilization. The low lying area is marked by a series of tanks varying in size from a small pond to those of considerable extent, but all of them being very shallow. The largest one is Hesaraghatta tank with a water spread area of 776 ha, supplying drinking water to a portion of Bangalore city.

Temperature : Temperature is lowest during December and January with mean minimum and Maximum temperature of 15^0C and 26^0C respectively. Temperature increases gradually thereafter until the beginning of May with mean temperature in Bangalore varying between 22^0C and 34^0C.

Rainfall and Humidity : The Bangalore North taluk receives a mean annual average rainfall of 755 mm based on 18 years data measured over 9 raingauge stations. The average maximum relative humidity recorded was 78.3% during August, and minimum of 44.9% during March, the data being an average of 24 years (1970-94).

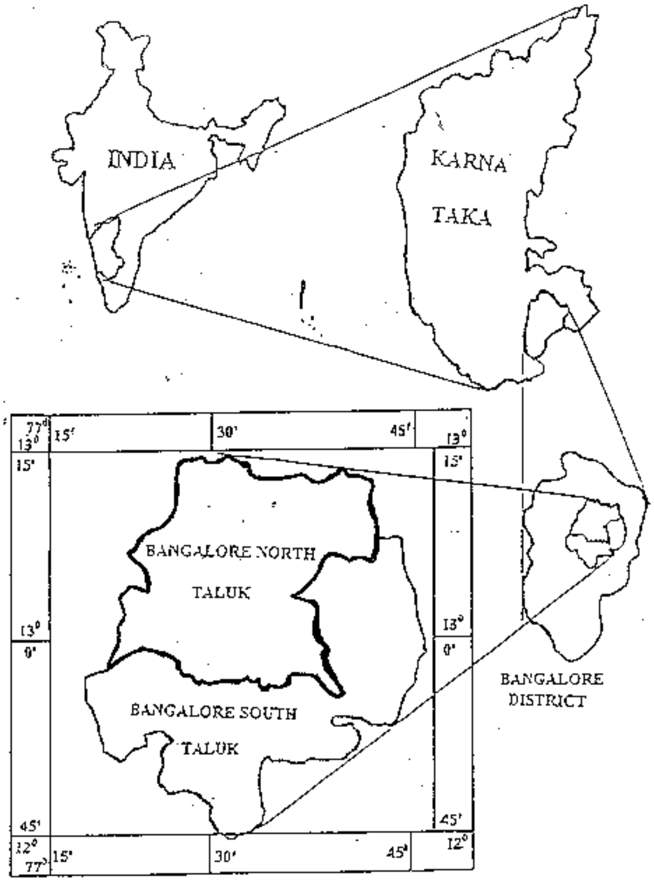

Figure 1. Location map of the study area.

Geology : The chief rocks occurring in the taluk are granites and gneisses. These are prominently exposed as a ridge running NNE and SSW almost along the middle of the taluk. The granitic gnenisses are criss-crossed by Pegmatite and aplitic veins, the rocks being highly jointed. Granites and gneisses are intruded by a number of basic dykes. Dykes are oriented east-west as well as north-south.

Soils : The soils of Bangalore North taluk consist of red loam, red gravelly sandy loam and lateritic soil. The red loam is red in colour and porous. Red gravelly sandy loams are generally shallow in depth with a thickness varying from 0.6 to 1.3 m, consisting of coarse particles of soil with gravel and pebbles. Lateritic soils are red to pale yellow in colour and confined to higher elevations.

Agriculture and Industry

Agriculture is still the main profession of the rural population. Farming is based on rising dry crops, viz., ragi, maize, gram, pulses, groundnut and others. Paddy and sugar cane are rarely grown in the taluk. There are 64 tanks and most of them are silted up. The details of agricultural land depending upon water supply from tanks, open dug wells and borewells are given below:

Served by tanks	:	912 ha
Served by open wells	:	818 ha
Served by bore wells	:	3361 ha

Of late, the farmers are rising cash crops like, vegetables, fruits, mulberry and flowers. Progressive farmers practice drip irrigation and sprinkler irrigation.

There are good number of major and medium industries established in the taluk. Many public sector units (PSUs) are also established in and around Bangalore city. These, to a great extent, contribute to the pollution of groundwater as well as soil.

Land Use and Land Cover

Land use refers to 'human activities for various uses carried out on land' and land cover refers to - natural vegetation, water bodies, rock outcrop of soil, artificial cover, etc. The spatial information on land use and other pattern of change are essential for planning, industrial locations, environmental studies, etc. For any developmental planning, categorization of land - grazing land, waste land, crop land, surface water bodies is quite essential. Table 1 presents the status of land utilisation in Bangalore North taluk.

Table 1. Land utilisation data of Bangalore North taluk.

Sl. No.	Particulars	Bangalore North taluk (ha)
1	Total geographical area	78411
2	Area under forest	1145
3	Barren land	2577
4	Land put to non-agricultural purposes	29988
5	Cultivable waste land	1387
6	Permanent pasture and grazing land	1972
7	Land under miscellaneous crops and other groups	3618
8	Current fallow land	16057
9	Other fallow land	974
10	Net area sown	20693
11	Area sown more than once	2510
12	Total cropped area	23203
13	Area irrigated by tanks	912
14	Area irrigated by open wells	818
15	Area irrigated by bore wells	3361

(Source : Bureau of Economics and Statistics, 1997-1998)

Utilisation of Groundwater

Groundwater in Bangalore North taluk occurs under water table conditions in the weathered zones of the hard compact rocks. Main source of recharge is through rainfall. The depth to water though dependent on topography, shows variation depending on the depth of weathering. Depth to water in the low lying area ranges from 0 to 3 m and some of the wells in the valleys start overflowing during rainy seasons. There are about more than

1,00,000 borewells of 15 cm dia in the taluk. They are mostly confined to higher elevations between 885 and 915 m. The depth of wells ranges from 27 to 106 m. The normal yield from borewells ranges from 37 to 150 lpm.

DRASTIC METHODOLOGY

DRASTIC is a groundwater pollution vulnerability assessment spatial deterministic model. The model consists of seven hydrogeologic key parameters to classify the vulnerability or pollution potential of an aquifer. The parameters are weighted with respect to their relative importance to the pollution potential of the aquifer.

In the model, 'r' refers to rating of the parameter ranges in the hydrogeologic setting and 'w' refers to weighting of the parameter. Ratings vary from 1 to 10. Fine textured soils are assigned a lower rating than soils having a coarse texture, like sand. Likewise, areas where depths to water table are deeper are assigned low ratings. Weights ranging from 1 to 5, are designed to indicate the relative importance of the seven factors with respect to one another. The D.I (Drastic Index) value obtained by the model is considered a relative indicator of pollution potential. Higher scores indicate greater vulnerability (Gajendragad, 1990).

The weights of DRASTIC parameters used in the present study are:
Depth to groundwater (D_w = 5); Recharge (R_w = 4); Aquifer media (A_w = 3); Soil media (S_w = 2); Topography (% slope) (T_w = 1); Impact of vadose zone (I_w = 5); Conductivity (hydraulic) (C_w = 3).

Table 2. Observation well data of Bangalore North taluk (meters).

Sl. No.	Observation wells	Pre-monsoon (Feb to May)		Monsoon (Jun to Sept)		Post-monsoon (Oct to Jan)	
		Max. level	Min. level	Max. level	Min. level	Max. level	Min. level
1	Byatarayanapura	12.26	11.35	12.40	10.95	12.18	10.12
2	Chikkabanavara	16.28	14.59	16.09	14.60	14.97	13.26
3	Chikkajala	7.05	4.92	7.39	6.97	6.27	3.85
4	Hesaraghatta	9.53	8.57	9.70	8.87	9.23	7.45
5	High court premisses	8.77	7.39	8.67	6.76	8.43	6.19
6	Rajanakunte	18.67	16.52	19.88	16.42	17.47	14.22
7	Thimmenahally	7.89	6.90	7.92	7.06	7.69	5.78
8	Thotagere	11.70	9.31	11.19	9.59	10.02	7.61
9	Yelahanka	11.56	10.36	11.76	10.36	11.70	9.52

(Source: Dept. of Mines and Geology, Bangalore)

Depth to water : Depth to water determines contaminant travel media before reaching the aquifer. The attenuation occurs as depth to water increases because longer time is required for pollutant to travel.

For Bangalore North taluk there are 9 village points (observation wells) from whom we have collected and analysed the water table fluctuation data, and are presented in Table 2.

The ratings used vary from 5 to 10. These values correspond to deeper depths (12-16 m) and shallower depths (<4 m).

Recharge : Net recharge is defined as the total quantity of water which is applied to the ground surface and infiltrates to reach the aquifer system. The rainfall data of 16 years have been used for six points within the study area. Ratings range from 1 to 9. By using water table fluctuation method the net recharge works out to 59.84 mm, for the entire area. The rating 1 refers to less than 20 mm and 9 refers to more than 81 mm.

Aquifer media : Aquifer media refers to the consolidated or unconsolidated rock which serves as an aquifer. Aquifer media with increasing pollution potential are classified as below:

Granitic gneiss
Weathered granitic gneiss
Fractured granitic gneiss
Weathered fractured granitic gneiss
Valley fills and recent sand dunes.

The ratings used in the analysis vary from 4 to 9.

Soil media : Soil has a significant impact on the amount of recharge which can infiltrate into the ground and hence on the ability of a contaminant to move vertically into the vadose zone. The pollution potential of a soil is largely affected by the type of clay present, grain size of the soil and organic material content. The types of soil encountered in the study area are: clay loam, loam, sandy loam and shrinking/aggregated clay. The ratings used in the analysis vary from 1 to 9. Here, these values correspond to lower infiltration to higher infiltration.

Topography : Topography refers to the slope and slope variability of land surface. Topography helps control the likelyhood that a pollution will runoff or remain on the surface in one area long enough to infiltrate. Topography is also significant because gradient and direction of flow often can be inferred for water table conditions from the general slope of land. Typically, steeper slopes signify higher groundwater velocity. Slope category vary from 0 to 18%. The ratings also vary from 10 to 1.

Impact of vadose zone : The vadose zone is defined as that zone above the water table which is unsaturated or discontinuously saturated. The type of vadose zone media determines the type attenuation characteristics of the material below the typical soil horizon and above the water table. The parameters affecting the range and ratings of the vadose zone media are - consumptive sorption and fracturing, path length and tortuosity as impacted by bedding, grain size, sorting and packing as influenced by sorting, packing and grain size, reactivity and potential for dispersion and consequent dilution. Ratings used vary from 5 to 9.

Hydraulic conductivity of the aquifer media : Hydraulic conductivity is controlled by the amount and interconnection of void spaces within the aquifer which may occur as a consequence of inter-granular porosity, fracturing and bedding planes. The ratings considered vary from 2 to 10, corresponding to <20 to >80 gpd/ft^2.

Based on the data relating to seven parameters, weights and ratings considered, DRASTIC Indices are worked out.

DISCUSSION OF RESULTS

The entire taluk is divided into 25 grids of $2^1/_2$ minutes square (Fig. 2). Each of the seven parameters of DRASTIC Indices are worked out using the D.I model. Based on the evaluated indices, the levels of probable pollution potential are presented in Fig. 3. The highest DI is 180 and the lowest is 121. The break-up of DIs is given below:

DI Values	No. of Grids	
121 - 130	3	(Least vulnerable to pollution)
131 - 140	5	
141 - 150	4	
151 - 160	5	
161 - 170	6	
171 - 180	2	(Highly vulnerable to pollution)
Total grids	25	

The two grids having DI values higher than 170 are considered alert zones and at any cost further dumping of wastes should be avoided. There are other six zones having DI values between 161 and 170 considered sensitive areas. Caution should be taken while utilizing these zonal areas for disposal of wastes, and are to be reserved for use only under unavoidable circumstances.

Of course, we do need some areas for disposal of wastes /pollutants and they are diluted during their pathways through soil pores before finally reacting the groundwater table. Such an exercise can be attempted in the three grid-zones, where DI values are least, viz., between 121 and 130. But unfortunately the three zones are within the urban limits of the city. Hence, areas having next higher DI values should be utilised for any waste disposal measures.

In peri-urban areas, surrounding the city limits, the conditions are more favourable for the transport of pollutants to reach groundwater table. Under the circumstances, steps are necessary to maintain hygienic conditions in the locality.

CONCLUSIONS

The DRASTIC methodology can be applied by an expert who has experience of valid comparative evaluation of relative groundwater quality status with acceptable results based on the readily available information for most of the region and which can be obtained and mapped with minimum cost and time.

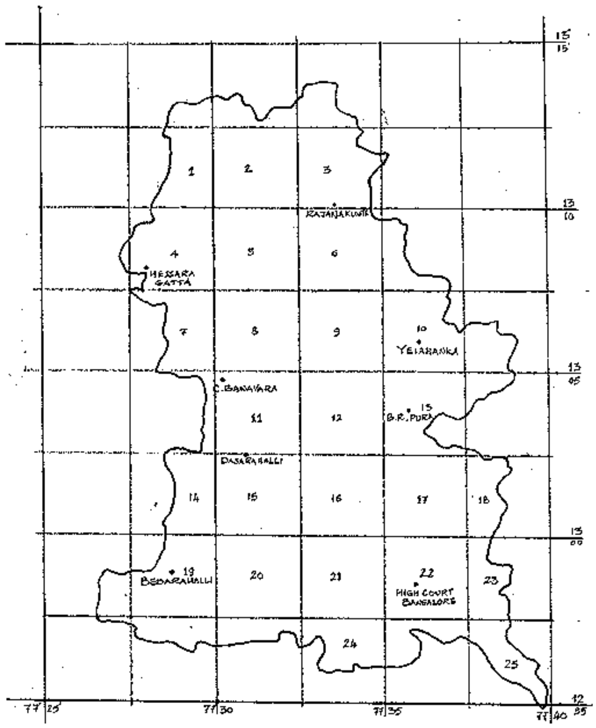

Figure 2. Grid map of Banglore North Taluk.

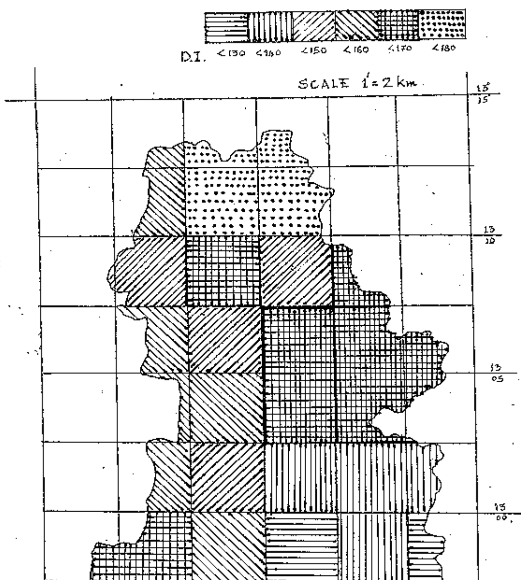

Figure 3. Pollution potential map of Banglore North Taluk.

Although the drastic model is able to consider physical, chemical and biological processes, the application of the model in the present study is restricted to the conservative behaviour of pollutants. Better results could be achieved by taking into account the location of the aquifer, infiltration capacity of the region, land-use pattern and actual pollution loads including those from agricultural and industrial pollutants.

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