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Role of Groundwater Protection Planning in Groundwater Governance: A Case Study from North India

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Abstract: In the present case study, impact of urbanization and industrial development on the shallow groundwater regime of Saharanpur town of Uttar Pradesh in India is examined with the aim of planning groundwater protection for better governance. The hazardous physicochemical and bacteriological parameters and heavy metals detected in the shallow aquifer include harmful pathogens like fecal coliforms, heavy metals like cadmium, chromium, nitrates and sulphates. An assessment of ground water vulnerability using the well known DRASTIC method has confirmed that the shallow groundwater in some central and southern localities of Saharanpur town fall in the medium risk zones. Further, using field data of 32 electrical resistivity soundings, the protective capacity of the unconfined aquifer is assessed in terms of a 'total longitudinal conductance' of the semi-pervious to impervious sediments overlying the unconfined aquifer. However, some areas aligned along a northwest-southeast and in the western parts of the town seem to have relatively higher protective capacity against infiltrating waste pollutants. A ground water protection planning map prepared by combining the DRASTIC map and the 'potentially hazardous pollutants' map has brought out the need to install eleven new groundwater quality monitoring wells in the town at locations near the line sources and point sources of pollution. This approach can be readily employed by the decision makers in framing sound guidelines for groundwater protection and governance.

Keywords: Groundwater Protection Planning, Case Study, Alluvial Aquifer, Uttar Pradesh.

INTRODUCTION

Ground water use has undergone dramatic expansion throughout the world over the past 50 years, with global abstraction rates increasing from an estimated 100-150 km^3 in 1950 to 950-1000 km^3 in the year 2000 (Shah et al. 2007). Through the construction of millions of private wells, there has been a phenomenal growth in the exploitation of groundwater in India in the last five decades (Garduno et al. 2011). As a result, 29 percent of the groundwater assessment blocks in the country are classified in semi-critical, critical, or overexploited categories with the situation deteriorating rapidly (Romani, 2006). The government has no direct control over the groundwater use of millions of private well owners, both in rural and urban areas. In part, this is due to the absence of a systematic registration of wells. Widespread groundwater pollution could further render the resource useless before it is exhausted. This poses a big challenge to the agencies responsible for groundwater development and governance in the country. In the present case study, the impact of urbanization and industrial development on the shallow groundwater regime of Saharanpur town (Fig.1) in the state of Uttar Pradesh (U.P.) is examined where a major percentage of the populace depend on the shallow groundwater for drinking. Earlier hydrogeological studies in and around Saharanpur area have been carried out by a number of agencies and workers (cf. Raghav Rao, 1965; Pandey et al. 1968; Bhatnagar et al. 1983; Barthwal, 1996). The U.P. State Groundwater Department (Saxena et al. 1983) have made an extensive water balance study of the Yamuna-Hindon interfluve which also included field evaluation of hydraulic characteristics of the aquifers and chemical analyses of the groundwater. Sriniwas and Singhal (1981, 1983) suggested an innovative analytical approach for estimating transmissivity of the alluvial aquifer in Saharanpur-Roorkee area from electrical resistivity data vide Mathew (1983). The approach was further extended to cover the anisotropic aquifers in the area by Singhal et al. (1998) and Sinha et al. (2009). Singhal et al. (2008) evaluated the groundwater vulnerability of the area using DRASTIC method suggested by Aller et al. (1987). In the present study, a groundwater resource planning map (GRPM) has been presented for groundwater protection planning in Saharanpur town using the chemical quality data

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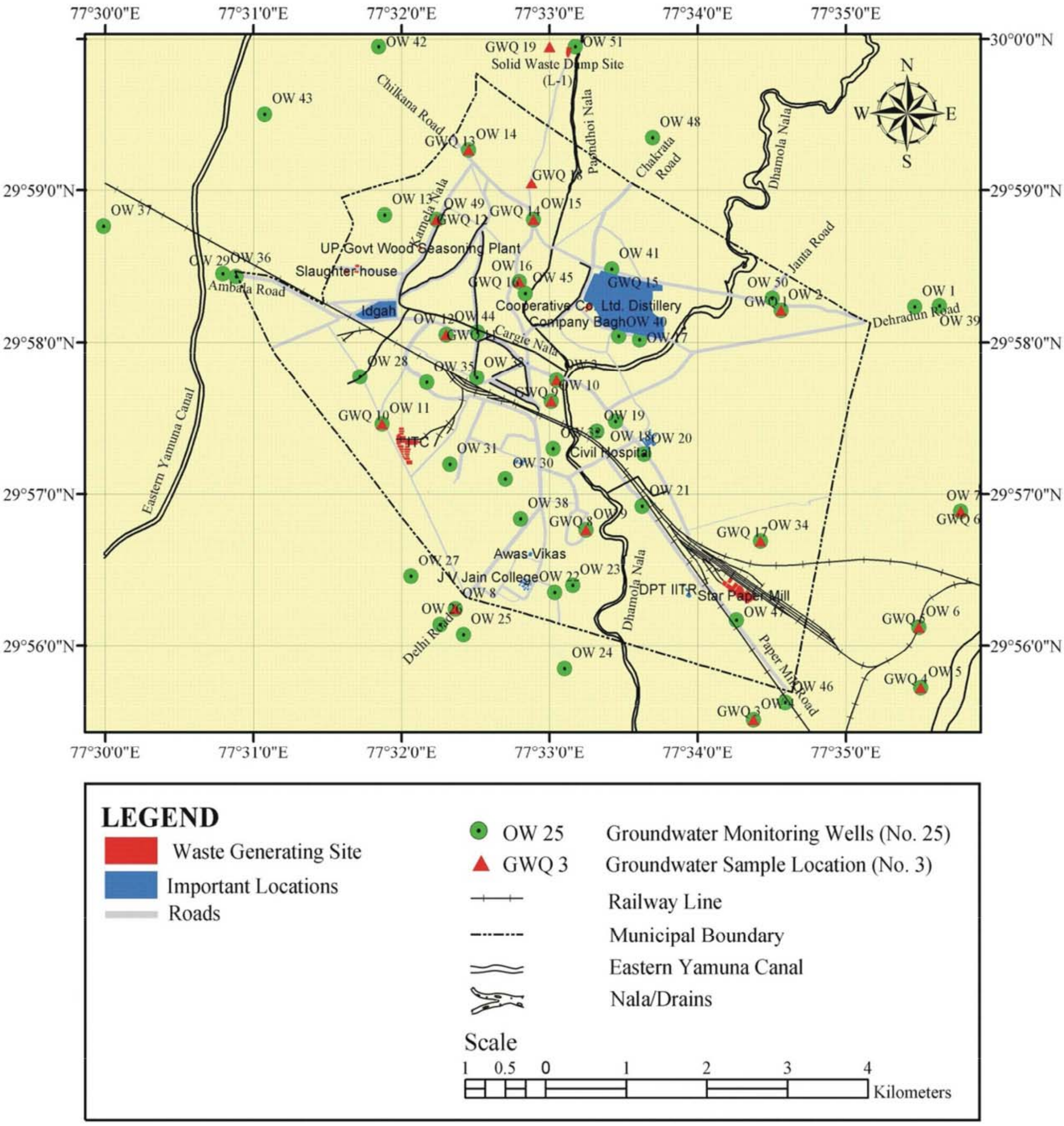

Fig.1. Index Map of Saharanpur Town

of the area generated by one of the authors (Sharma, 2007). Besides, the protective capacity of the vadose zone overlying the unconfined aquifer is also estimated in terms of a geoelectrical parameter called total electrical conductance.

Need for Groundwater Protection

There are various potential causes of quality deterioration in an aquifer and/or in any groundwater supply. These are classified by genesis and further explained in Table 1.

Rationale for Pollution Risk Assessment

The criteria (see Table 1) guide the type of pollution risk assessment to use. The commonly adopted approach (Foster et al. 2002) takes into account interaction between hazard from contaminant load and aquifer vulnerability to determine the risk of pollutants reaching the aquifer (Fig. 2). The risk can then be conceived as the interaction between:

- The aquifer pollution vulnerability resulting from the natural characteristics of both the aquifer and the strata separating it from the land surface and
- The contaminant load that is, will be or might be applied to the sub-surface as a result of human activity.

Adopting such a scheme, it is quite possible to have high contaminant load but no significant pollution risk, because the aquifer's intrinsic vulnerability is low, and

Table 1. Potential Causes of Quality Deterioration on an Aquifer/Groundwater System(After Foster et al.2002)

Type of Problem	Underlying Cause	Contaminants of Concern
Aquifer Pollution	Inadequate protection of vulnerable aquifers against manmade discharges and leachates from urban/ industrial activities and intensification of agricultural cultivation.	Pathogens, nitrate or ammonium, chloride, sulphate, boron, arsenic, heavy metals, dissolved organic carbon, aromatic and halogenated hydrocarbons, certain pesticides.
Well head contamination	Inadequate well design/construction allowing direct ingress of polluted surface water or shallow ground water.	Mainly pathogens.
Saline Intrusion	Saline (and sometimes polluted) ground water induced to flow into freshwater aquifer as a result of excessive abstraction.	Mainly sodium chloride, but can also include persistent manmade contamination.
Naturally occurring contamination (Geogenic)	Related to chemical evolution of ground water and solution of minerals (can be aggravated by manmade pollution and/or excessive abstraction)	Mainly soluble iron and fluoride, sometimes magnesium sulphate, arsenic, manganese, selenium, and other inorganic species.

vice versa. As the intrinsic vulnerability relates only to the properties of the aquifer with its overlying layers, and not to the properties of the potential contaminants (because these are numerous and highly variable), the approach is most helpful when dealing with persistent mobile contaminants not readily susceptible to attenuation.

For the purposes of developing groundwater protection and management policies, the assessments of aquifer vulnerability and contaminant load are presented in the form of a groundwater resource planning map (GRPM). This is derived by combining a groundwater vulnerability map (GVM) and a potentially hazardous activities map (PHAM, Fig. 3).

Evaluation of Aquifer Protection Capacity using Geoelectrical Parameters

Geoelectrical methods have often been used for estimation of aquifer properties, from field measurements of resistivity of aquifers (cf. Ungemach et al. 1969; Kelly, 1977). The geoelectrical methods are based on the analogy between the Darcy's law and the Ohm's law relating hydraulic conductivity with electrical conductivity. In a clay-free porous formation, fully saturated with water, the formation resistivity factor (F) is given as:

$$F = \rho_o/\rho_w \quad (1)$$

where ρ_o is the resistivity of the water saturated formation, and ρ_w is the resistivity of groundwater in the aquifer.

For a two layer geological formation, having thickness h_1 and h_2 and corresponding electrical resistivities ρ_1 and ρ_2, the average longitudinal resistivity (ρ_l) and transverse resistivity (ρ_t) are given by equations

$$(h_1 + h_2)\rho_t = h_1\rho_1 + h_2\rho_2 \quad (2)$$

and

$$(h_1 + h_2)/\rho_l = (h_1/\rho_1) + (h_2/\rho_2) \quad (3)$$

Based on the above approach, Maillet (1947) introduced the concept of transverse unit resistance (R) and longitudinal unit conductance (S) which can be expressed as

$$R = \Sigma_{i=1}^{n} \rho_i h_i \quad (4)$$

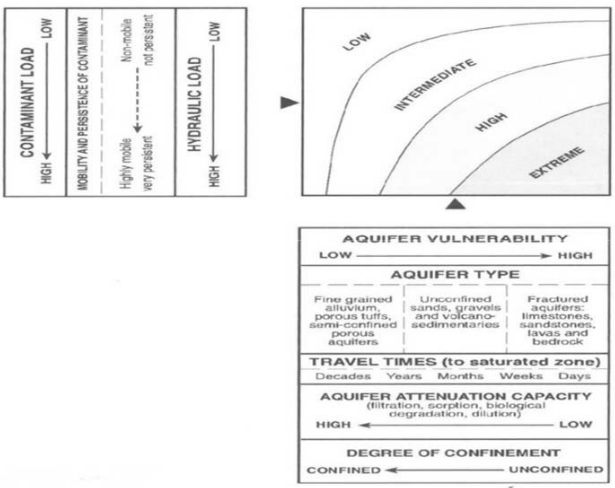

Fig.2. Conceptual scheme of groundwater pollution risk (modified from Foster et al.2002)

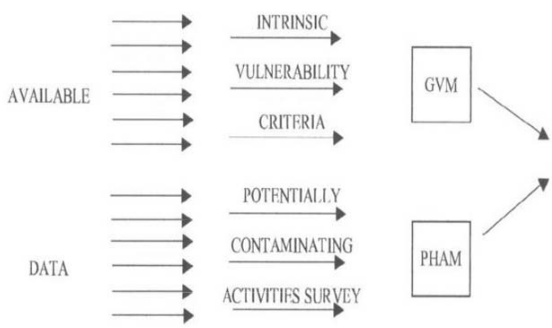

Fig.3. Evaluation of component parts of a groundwater resource planning map (GRPM)

$$S = \Sigma^{n}_{i=1} h_i / \rho_i \quad (5)$$

R and S are also known as Dar Zarrouk variable and Dar Zarrouk function respectively. These parameters play a significant role in the interpretation of resistivity sounding data.

Due to electrical anisotropy ($\lambda = \sqrt{\rho_t/\rho_l} > 1$) in electrical prospecting, a layer of thickness, h, average conductivity, σ, and anisotropy, λ, will be found to be exactly equivalent in its outside effects to an isotropic layer of thickness, λh and conductivity, σ_l (Maillet, 1947).

Figure 4 shows the layered model which assumes horizontal groundwater flow with vertical electrical flow in the transverse case and horizontal electrical flow in the longitudinal case.

After generalization, equations (2) and (3) can be rewritten as

$$\text{Transverse Resistivity } (\rho_t) = \frac{\Sigma^{n}_{i=1} h_i \rho_i}{\Sigma^{n}_{i=1} h_i} \quad (6)$$

$$\text{Longitudinal Resistivity } (\rho_l) = \frac{\Sigma^{n}_{i=1} h_i}{\Sigma^{n}_{i=1} h_i / \rho_i} \quad (7)$$

Sri Niwas and Singhal (1981 and 1985) and Sinha et al. (2009) explained the application of concept of transverse resistance in estimation of aquifer properties like transmissivity and hydraulic conductivity for homogeneous and anisotropic aquifers**.**

Arising from Eq. (5), the magnitude of 'total longitudinal conductance' of the unsaturated zone overlying an unconfined aquifer can be used for estimating degree of its protection from the pollutants infiltrating and percolating into an aquifer. The ability of the overburden to retard and filter percolating waste effluents is a measure of its protective capacity (Belmonte et al. 2005). The longitudinal conductance(S) gives a measure of the permeability of the confining clay/shale layers. Such layers have low hydraulic

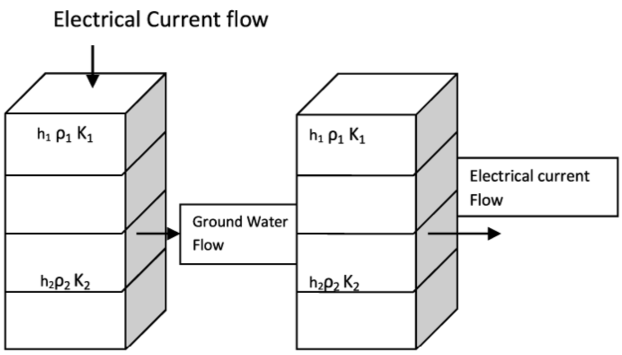

Fig.4. Layered Model showing transverse and longitudinal current flow.

conductivity and low resistivity. Protective Capacity (P_c) of the overburden layers is proportional to its longitudinal conductance(S) (Braga et al. 2006). So,

$$P_c = S = \Sigma^{n}_{i=1} h_i / \rho_i \quad (8)$$

Besides, for aquifers underlain by resistive basement rock (represented by H type field resistivity curves) the depth to the hard rock can be readily estimated by evaluating the total longitudinal conductance of the overburden by the asymptotic method (Bhattacharya and Patra, 1968).

Case Study of Saharanpur, North India

The present case study seeks to examine the impact of urbanization and industrial development on the shallow ground water regime of Saharanpur town, U.P., where the major source of water supply to the urban populace is from shallow hand pumps and deeper tubewells. The Saharanpur town of Western Uttar Pradesh is a sizable urban complex growing at a steady rate as a result of increase in population accompanied by spurt in industrial activity. The available data about the growth of Saharanpur town indicates that its built up area increased from 1110 hectare in 1973 to 2340 hectare in 2003. Further, the population grew more than four times in the last 60 years.

The area under study is a part of the Indo-Gangetic plain and lies in the upper part of the Hindon basin, bounded between latitudes 29°55' and 30°0' North and longitudes 77°30' and 77°36' East (Fig.1). The area is located in Saharanpur district of Uttar Pradesh, falling in the Survey of India topographic sheet No. 53G/9 (scale of 1:50,000). The investigated area is about 90 km^2.

There are various notable industrial units in the area such as a large paper mill, a tobacco company, distilleries, besides several card board manufacturing, electroplating, meat products and chemical units. These industrial units discharge waste effluents directly into the nearby drains, which finally meet the river Hindon. Further, the municipal effluents also carry sewage of the local residents and meet the river system adding to the waste load of the river.

Hydrogeological Features and Groundwater Quality

Lithologically, the water bearing formations in the study area are composed of fine to medium grained sands separated by clay horizons. Available data indicates that the water bearing formations in the Saharanpur town are sandy horizons separated by impervious clays occasionally impregnated by kankar (a nodular formation rich in $CaCO_3$) nodules. Based on lithological logs of seven tubewells and available water level data , two types of aquifer have been delineated in a geological fence diagram (Fig.5). The upper

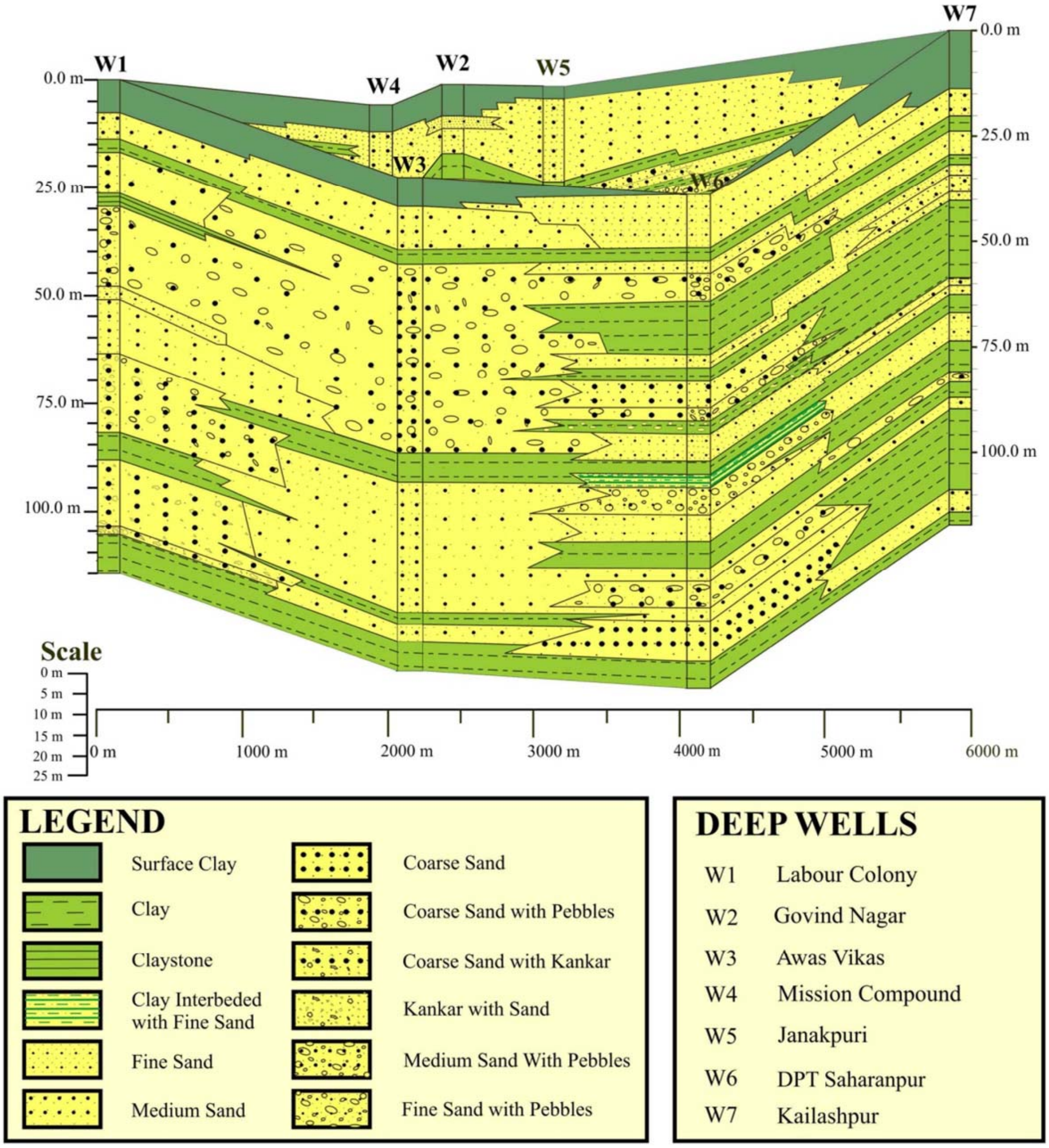

Fig.5. Geological Fence Diagram based on Tubewell data(well locations shown in Fig.12). (Sources: Saharanpur Municipal Corporation, IIT Roorkee)

one is a shallow unconfined aquifer which generally extends down to a depth of about 15 m below ground level (bgl). The deeper aquifers, are confined to semi confined in nature, occurring in depth range of 15 to 115 meters (bgl) separated by three to four aquitards at average depths of 15-36, 54-60, 80-90 and 95-120 meters bgl. Four to five aquifer zones have been tapped in a tubewell drilled recently in the southeastern part of the town in the premises of department of paper technology, IIT Roorkee in the Saharanpur campus upto a depth of 106 meters (Fig.5) as identified from the drill cuttings. The study of groundwater quality reveals that the groundwater is generally fresh with pH varying from 7.2 to 8.3 and EC ranging from 437 to 1448 micromhos/cm. The detailed analyses of physicochemical parameters, hazardous heavy metals and fecal coliforms present in groundwater during premonsoon period of 2006 is given in Tables 2A, B and C respectively. It was found that the total dissolved solids(TDS) in the groundwater of the area varied in the range of 224 to 954 mg/L and the hardness as $CaCO_3$ equivalent ranged between 228 to 760 mg/L. The nitrate and sulphate concentrations varied between1.7 to 80 mg/L and 114 to 297 mg/L respectively. Further, the chloride and total alkalinity ranged between 22 to 360 mg/L and 128 to 416 mg/L respectively. The ionic parameters in the groundwater were found to be mostly within permissible ranges except at a few locations. However, nitrate, sulphate and some heavy metals like cadmium, chromium and pathogenic bacteria were found to be present in the

Table 2A. Physicochemical Analysis of Groundwater, Pre-monsoon, 2006

Name of Groundwater Sampling Station	Ground-water Sampling Station no.	Temp °C	pH	EC (μ mhos/cm)	TDS	T.Alk	HCO_3	CO_3	Cl	SO_4	T. Hardness	Ca	Mg	NO_3	Na	K	Total-P	MPN/100ml	F.Coli/100ml
Mahipura	GWQ 1	26.7	7.5	615	371	128	127.62	0.38	35	223.85	346	86.4	31.56	1.75	17.8	ND	0.026	2	nil
ShekhpuraQadim	GWQ 3	25.6	7.4	1382	829	220	219.48	0.52	360	269.53	668	173.6	56.82	80.30	112.4	ND	1.913	14	4
Pairagpur	GWQ 4	25.8	7.4	1150	690	252	251.40	0.60	184	245.66	544	106.4	67.50	67.00	96.0	ND	0.293		
Hasanpur	GWQ 7	25.5	7.4	1448	954	266	265.37	0.63	177	174.06	326	84.0	28.16	62.70	122.8	ND	0.316		
Hakiquat Nagar	GWQ 8	25.1	7.5	715	421	416	414.76	1.24	71	206.16	490	158.4	22.82	11.20	56.3	6.7	0.012	2	nil
Govind Nagar	GWQ 9	26.1	7.8	843	514	330	328.05	1.95	121	232.49	434	105.6	41.28	41.80	71.6	6.1	0.126	2	nil
WazirVihar	GWQ 10	24.8	7.2	359	224	168	167.80	0.20	35	188.87	250	55.2	27.19	20.30	6.4	ND	0.436		
Patel Nagar	GWQ 11	26.5	8.0	815	473	216	213.99	2.01	203	113.57	430	73.6	59.73	3.59	29.5	ND	0.895		
SabarikaBagh	GWQ 12	28.2	8.2	437	273	198	195.00	3.00	27	282.28	336	56.0	47.59	8.65	10.4	ND	1.130	11	2
Munnalal Girl's Degree College	GWQ 13	26.4	7.5	963	579	260	259.30	0.70	154	270.76	588	112.8	74.30	50.80	69.3	2.3	0.067		
ArabiMadrisa	GWQ 14	26.8	7.8	651	432	206	204.78	1.22	57	297.10	340	80.0	33.99	43.50	48.3	6.3	0.998		
Company Bagh	GWQ 15	25.4	7.9	488	307	242	240.20	1.80	35	234.55	290	68.0	29.14	20.70	6.8	0.6	0.093		
ShahidGanj	GWQ 16	25.9	8.3	475	293	154	151.60	2.40	22	256.36	280	42.4	42.25	1.73	9.2	ND	0.109		
BIS: 10500		**-**	**6.5-8.5**	**-**	**500**	**200**	**-**	**-**	**250**	**200**	**300**	**75**	**30**	**45**	**-**	**-**	**-**	**Nil**	**Nil**

Note: ND = Not Detected

Table 2B. Heavy Metal Analysis Data of Groundwater (Pre-monsoon, 2006)

Name of Groundwater Sampling Station	Groundwater Sampling Station no.	Cd (mg/l)	Fe (mg/l)	Cu (mg/l)	Zn (mg/l)	Cr (mg/l)	Ni (mg/l)	Mn (mg/l)	Pb (mg/l)
Mahipura	GWQ 1	0.002	ND	ND	0.078	ND	ND	ND	0.03
Sheikhpura Qadim	GWQ 3	0.02	0.114	0.043	0.088	ND	ND	0.012	0.035
Pairagpur	GWQ 4	0.028	0.124	0.029	0.412	ND	ND	0.001	0.034
Hasanpur	GWQ 7	0.023	0.004	ND	0.078	ND	ND	ND	0.034
Hakiquat Nagar	GWQ 8	0.036	0.157	0.313	1.21	0.017	0.077	0.338	0.027
Govind Nagar	GWQ 9	0.006	ND	ND	0.088	ND	ND	0.002	0.035
Wazir Vihar	GWQ 10	0.056	0.248	0.169	0.744	0.072	0.003	0.088	0.033
Patel Nagar	GWQ 11	ND	0.029	ND	0.887	ND	ND	0.395	0.033
Sabari Ka Bagh	GWQ 12	ND	0.058	ND	0.102	ND	ND	0.003	0.035
Munnalal College	GWQ 13	ND	0.058	ND	0.554	ND	ND	0.018	0.035
ArabiMadrisa	GWQ 14	ND	ND	ND	0.122	ND	ND	ND	0.034
Company Bagh	GWQ 15	0.01	0.005	0.1	0.419	ND	ND	0.09	0.034
Shahid Ganj	GWQ 16	ND	ND	ND	0.351	ND	ND	0.08	0.01
BIS: 10500		0.01	0.3	0.05	5.00	0.05	0.20	0.10	0.10

Note: ND = Not Detected

Table 2C. Localities showing high number of Fecal Coliforms in groundwater, 2006 (BIS Standard : Nil)

Sample No.	Locality	Fecal Coliform/100 ml		Possible source	Drastic Index	Remarks
		Pre-monsoon-06	Post monsoon-06			
GWQ1	Mahipura	-	2	D/S of solid waste dump	148	Moderate pollution risk
GWQ2	S.M.Inter College	4	2	Near Confluence of Dhamola and Paondhoi drains	152	Moderate pollution risk
GWQ3	Shekhpura Qadim	-	2	Near Dhamola drains and d/s of waste sites	177	High pollution risk
GWQ4	Pairagpur	-	6	Proximity to Paper (mill) effluent drain	177	High pollution risk
GWQ12	Sabarika Bagh	2	-	Close to Kamela drain	152	Moderate pollution risk

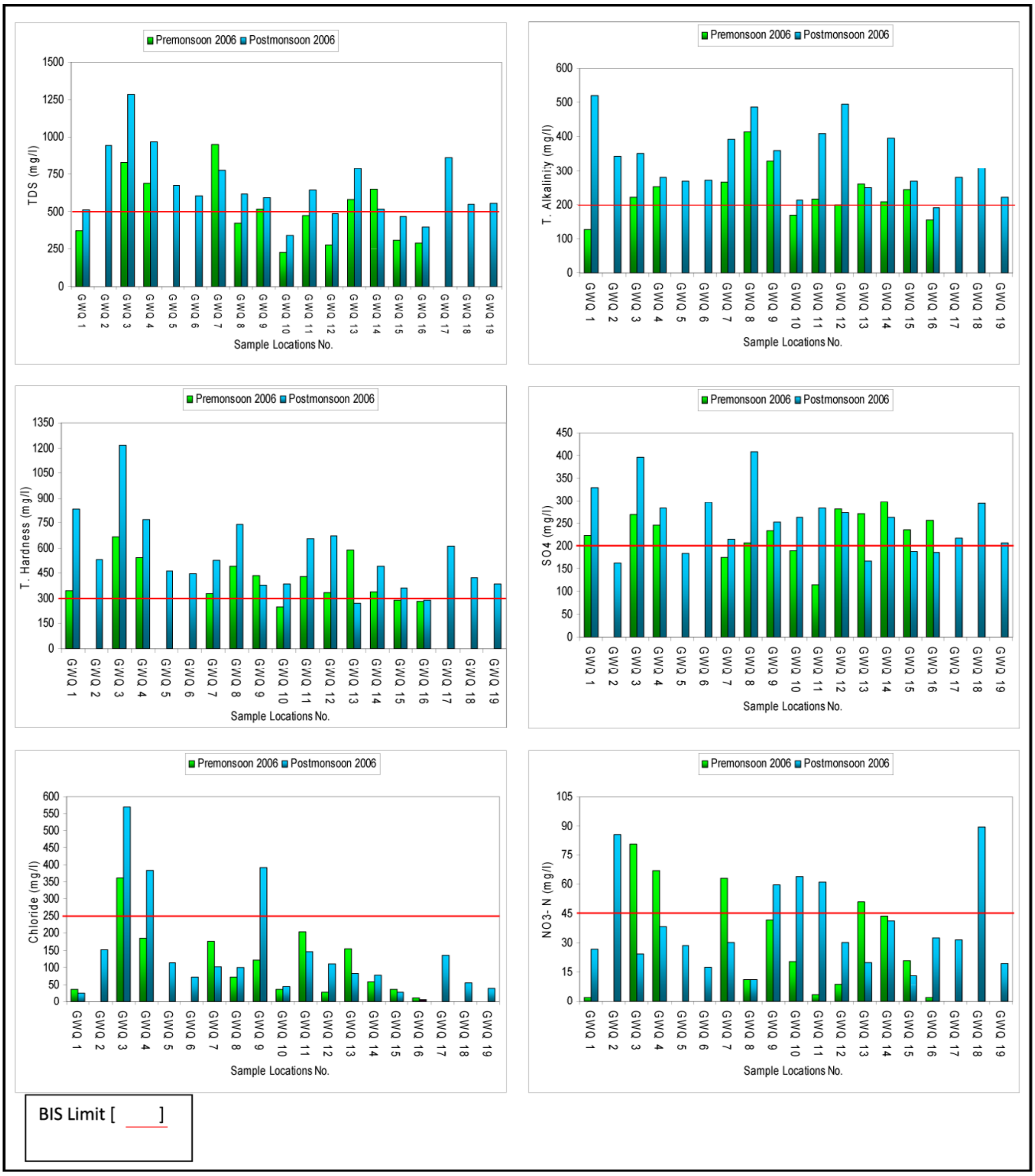

Fig.6. Bar Diagram Showing variation of Physico-chemical Parameters of Groundwater (Year 2006)

groundwater in high concentrations at a few localities as shown in Fig.6 to Fig.8. The pathogens too were found to exceed the permissible BIS(1991) limit at Mahipura (GWQ-1) on the northeastern periphery of the town, SM Inter college (GWQ-2) near the clock tower, Sabrika Bagh (GWQ-12) close to Kamela Nala (Fig.1) as well as Shekhpura Qadim (GWQ-3) and Pairagpur (GWQ-4) in the southern part of the area.

Risk of Groundwater Pollution and Vulnerability

Based on the hydrogeological setting of the study area, Drastic method of aquifer vulnerability assessment has been applied to find out its risk of pollution (vulnerability) in different parts of the Saharanpur Town (Fig.9) using the approach suggested by Aller et al. (1987). The parameters considered in this analysis included depth to water table, net groundwater recharge, nature of aquifer media, nature

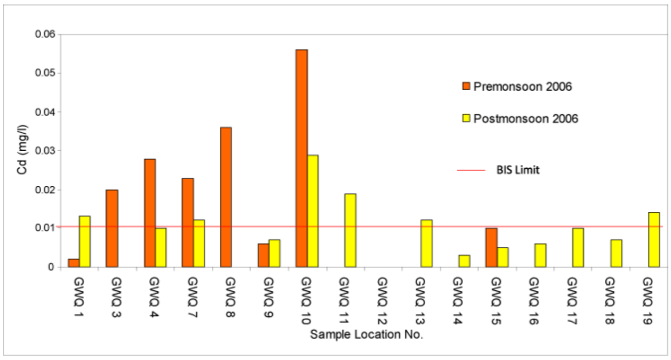

Fig.7. Plot of Temporal variation of Cadmium Concentration in Ground Water (Year 2006)

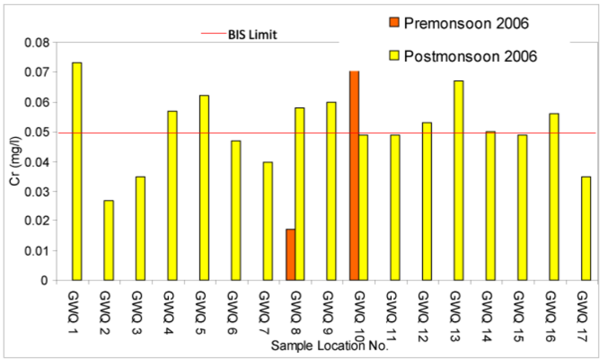

Fig.8. Plot of Temporal variation of Chromium Concentration in Ground Water (Year 2006)

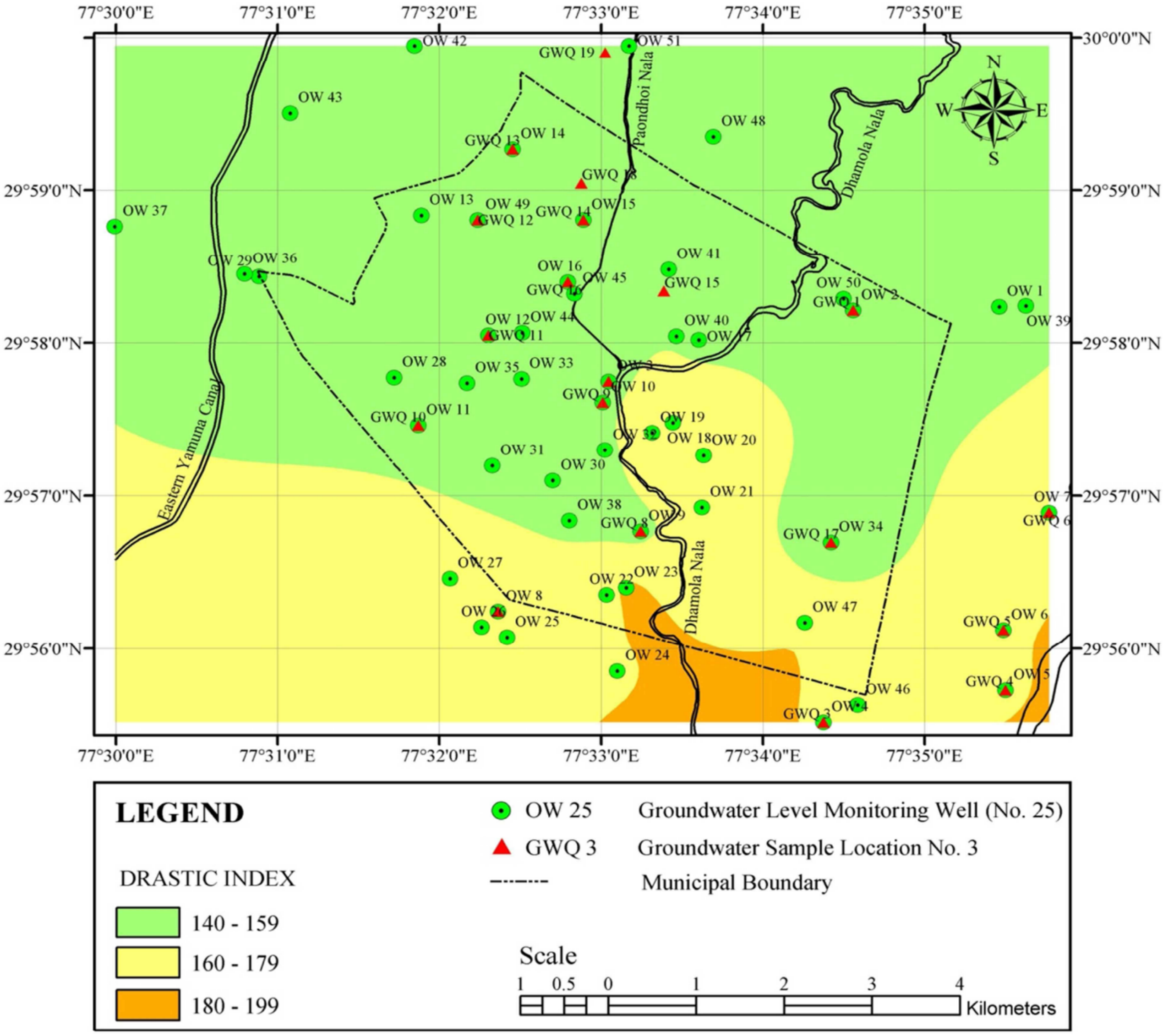

Fig.9. Groundwater Vulnerability Map of Saharanpur town

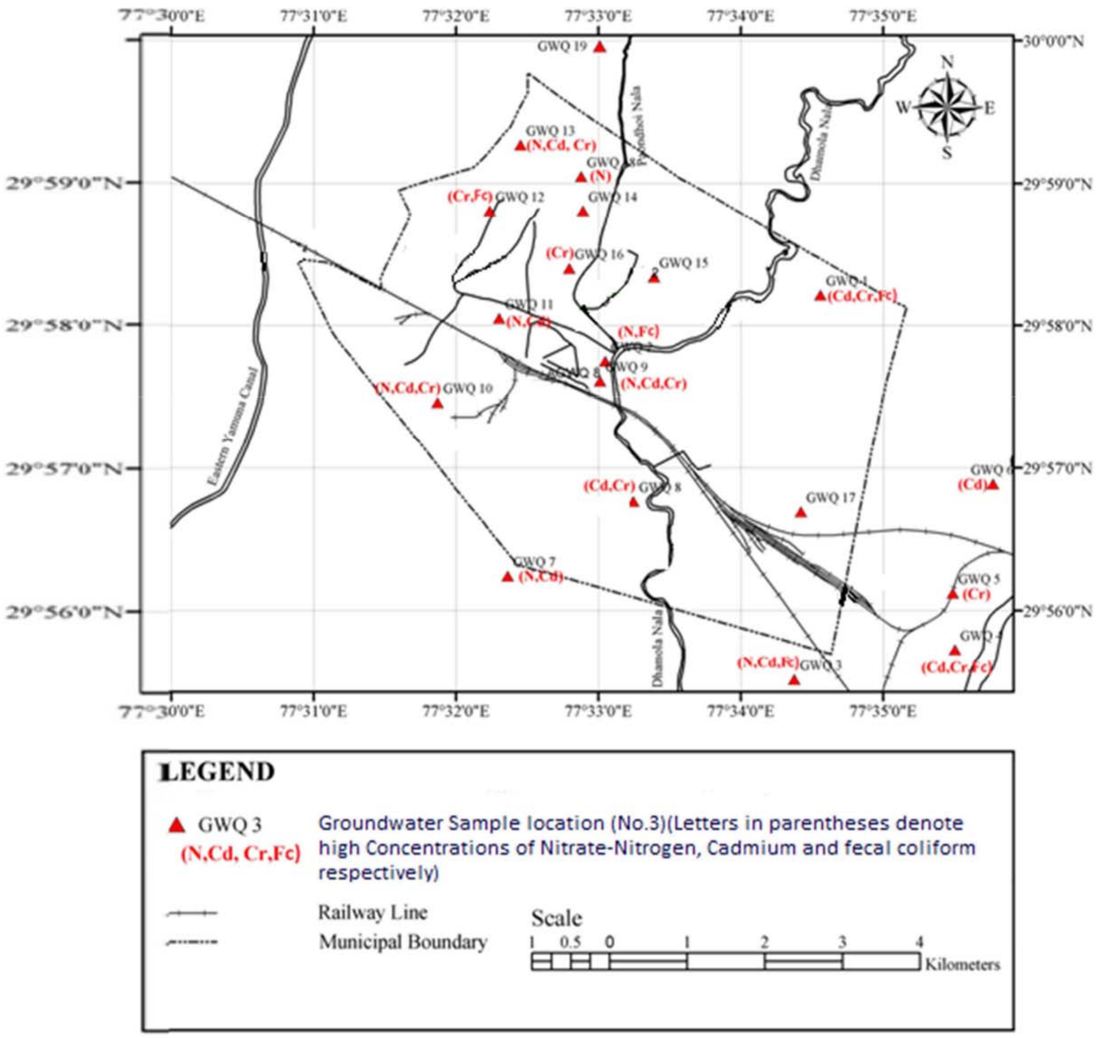

Fig.10. PHAM Map of Study Area Showing Groundwater Sampling Locations with Chemical Parametersand Fecal Coliforms exceeding permissible limits, in parenthesis (year 2006)

of soils, topographic zonation, impact of unsaturated zone and hydraulic conductivity of the aquifer. The calculation of the drastic index (DI) values indicates that although very high pollution risk zone (DI>200) is not present in the study area, the assessment has indicated that some central and southern localities of Saharanpur city are in medium risk (DI: 160-179) and high risk zones (D.I. >180) (Fig.9).

Based on the chemical quality of groundwater vis-à-vis possible sources of surface pollution, it has been inferred that the main sources of pollution are indicated to be point sources (outfalls of sewage, paper mill effluent etc.) and line sources. A groundwater resource planning map was generated (Fig.11) using ArcGIS softwarefor the town by overlaying the "potentially hazardous activities map" (PHAM, Fig.10) on the groundwater vulnerability map (Fig.9). It is quite likely that the localities inferred to be hydrogeologically more vulnerable for ground water contamination are also exposed to contamination by hazardous pollutants like fecal coliforms, cadmium, chromium and nitrate and thus stand greater risk of pollution than the areas with lower vulnerability. Such places need to be monitored for ground water quality more systematically and vigorously so that effective measures can be initiated for future protection of ground water.

Geoelectrical Investigations

In the present study, a total of 32 vertical electrical soundings (VES) were recorded in Saharanpur town with the help of DC resistivity meter (ABEM SAS 300B model) at selected sites shown in Fig.12. Out of these, IP soundings were also recorded at 12 VES points using SAS 1000 model with the VES being also repeated. The maximum current electrode separation (AB) was kept at 600 m. Preliminary quantitative interpretation of vertical electrical sounding

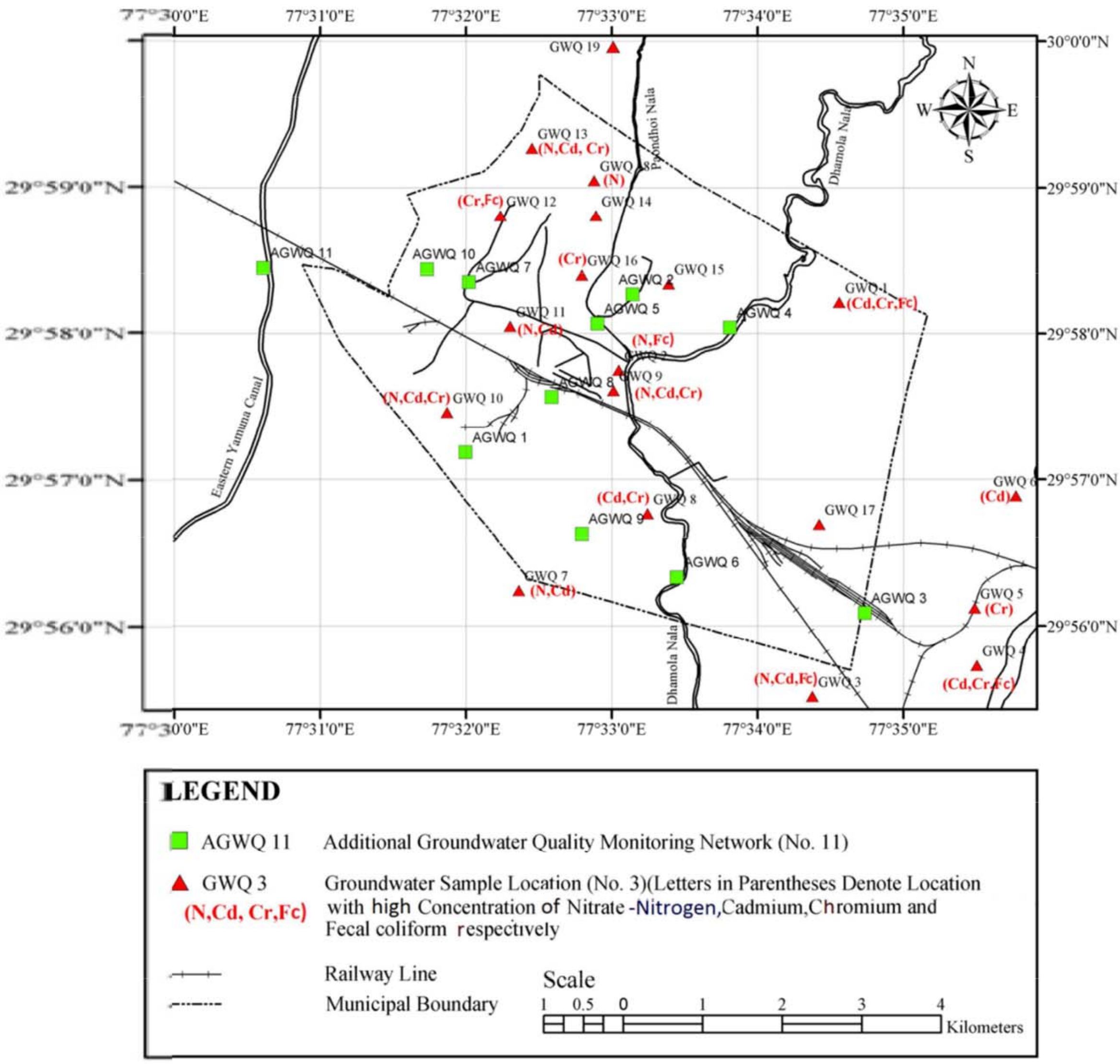

Fig.11. GRPM Map of Study Area

(VES) curves was attempted to interpret true resistivity and thickness manually by conventional curve matching technique using master curves and its auxiliary charts given by Orellana and Mooney (1966). For some sounding curves, the curve matching did not yield realistic interpretation. The results were then modified by using IX1D Interpex software (Version 3.36) and the software given by Zohdy (1989). In case the computed curve did not match with the field curve, the initial layer parameters were modified.

The interpreted geoelectrical data of the area was compared with the lithology of nearby wells and tubewells to fix the range of resistivity and IP for different geological materials, as under (Table 3).

The examination of the VES data was at first carried out at those sites where the lithologs of existing tubewells are available. It is observed that in general, there is a fairly good match of the observed depth of water table (in the shallow observation wells) vis-à-vis the layered earth model arrived at by quantitative interpretation. However, for arriving at the correlation of individual layers of sands and clays, use of IP sounding interpretation along with resistivity model has been of considerable help. Yet, it is observed

Table 3. Resistivity ranges for geological formations in the study area

Lithology	Resistivity range (Ohm-m)	IP (m-sec)
Clay	≤ 27	
Clay (sandy)	28-32	> 3 m-sec
Clayey sand	30-45	
Sand (fine grained)	37-49	
Sand (medium grained)	49-77	uncertain
Sand (coarse)	71-150	
Gravel	> 150	

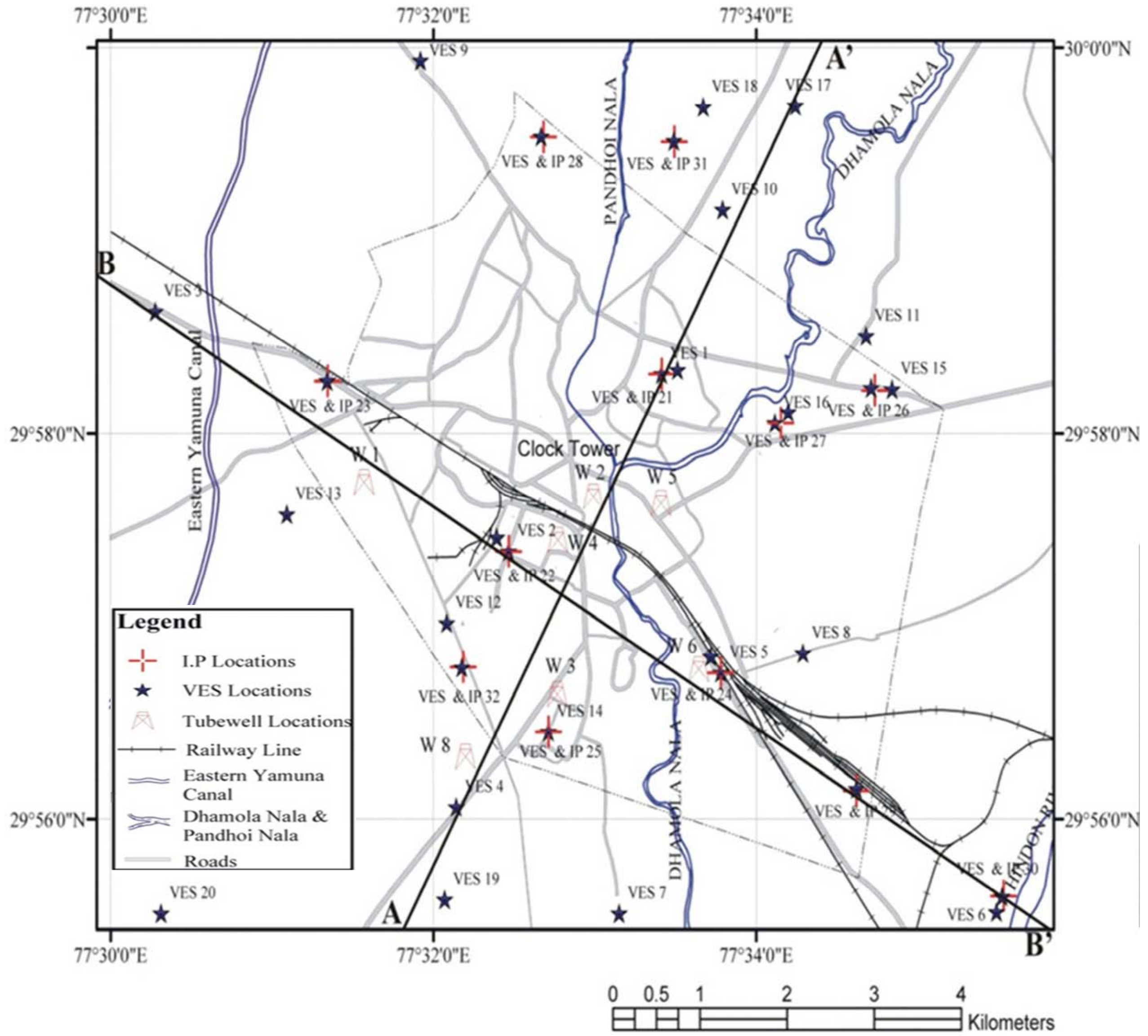

Fig.12. Location of Sounding points in Saharanpur Town

that it has been difficult to detect thin clay beds (aquitards) having thickness lesser than 3 m or so in the interpreted geoelectrical data. Based on the overall interpretation of VES (Fig.13) and IP data, a geoelectrical section has been presented along WNW-ESE direction (BB' profile, shown in Fig.12). The geoelectrical section (Fig.14)has indicated that in general, sandy formations dominate in the section. Further, a shallow clay layer is found to be present towards southeast with 17-22 m thickness (resistivity: 17-30 ohm-m) in VES-5, 29 and 30 from the depth of about 13 m bgl).

Protective Capacity of the Vadose Zone

Data of the vertical electrical resistivity/induced polarization soundings recorded in the study area was utilized to estimate the geoelectrical sections (in different parts of the area) with the aim of evaluating the total longitudinal conductance of the unsaturated formations overlying the unconfined aquifer of the area. It has been observed from the computations that the total longitudinal conductance of the unsaturated overburden above the aquifer varied between 0.03 mho to over 0.7 mho (Table 4).

Figure 15 shows the contours of total longitudinal conductance for the Saharanpur town which indicates that area towards central, western and NW parts possess highest longitudinal conductance near VES locations 9,22 and 23. This implies that these parts of the town offer relatively high protection to the underlying unconfined aquifer from the infiltrating pollutants. On the other hand, the localities towards south and southeast around the VES

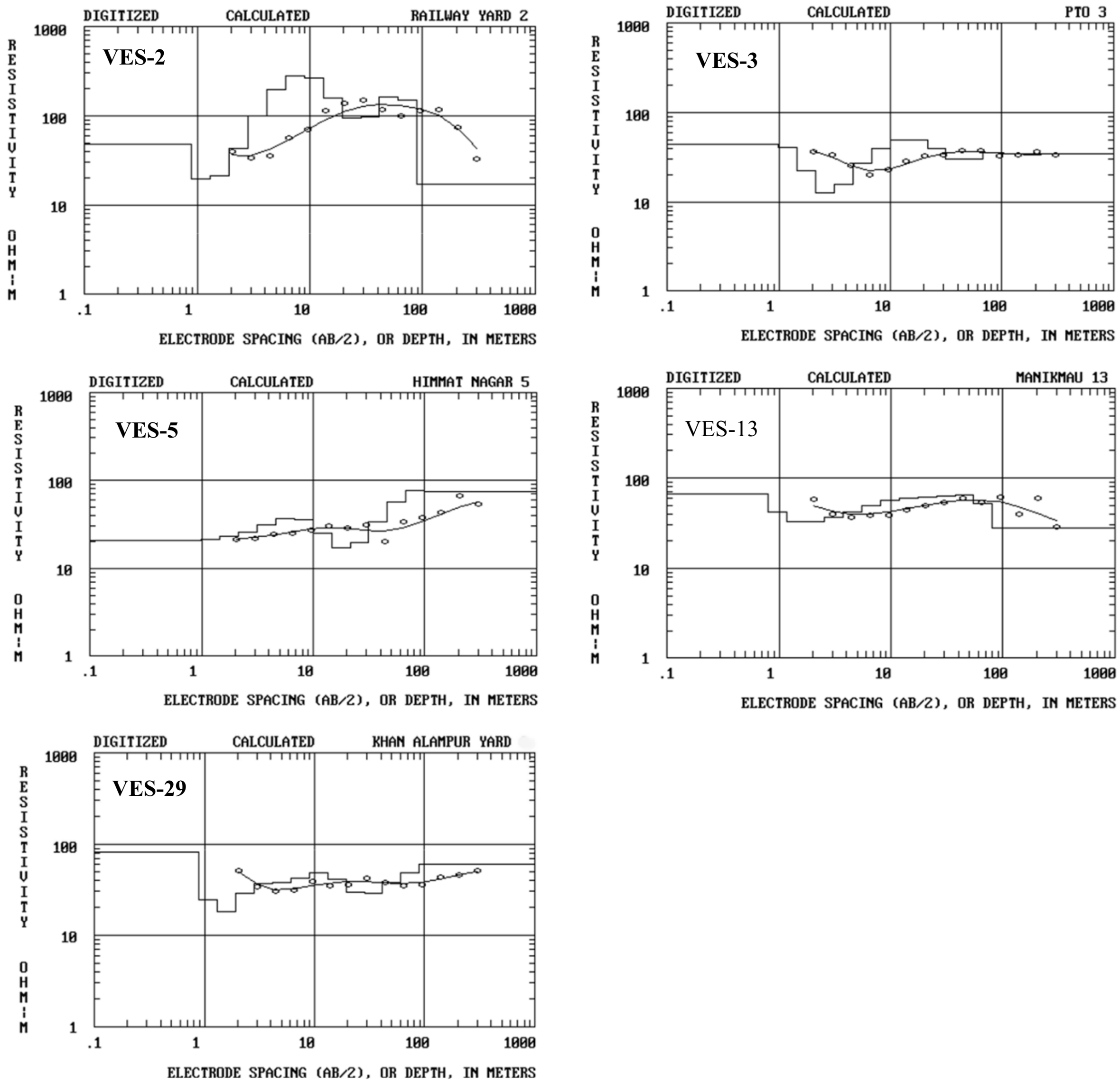

Fig.13. Selected VES Curves (along Section line BB', Fig.12)

Table 4. Data of Total longitudinal conductance (S) of unsaturated overburden in Saharanpur

S. No.	Locality name	VES no.	S
1	Company bagh	1	0.07989
2	Railway yard	2	0.17520
3	Ambala road	3	0.31364
4	ITI	4	0.09435
5	Himmat nagar	5	0.33310
6	Pairagpur	6	0.07596
7	Ramnagar	7	0.07275
8	Dabki junardar	8	0.14711
9	Halalpur	9	0.73607
10	Arya nagar	10	0.05745
11	Balmiki colony	11	0.43477
12	ITC	12	0.14910
13	Manikmau	13	0.25408
14	Awas vikas	14	0.14357
15	Mahipura	15	0.33469
16	Remount depot	16	0.03025

Table 4. Contd...

S. No.	Locality name	VES no.	S
17	Ganpati vihar	17	0.06348
18	Refinary colony	18	0.03987
19	Prem nagar	19	0.11974
20	Navada aquiduct	20	0.29387
21	Company bagh	21	0.07852
22	Railway yard	22	0.66353
23	Ambala road	23	0.67081
24	Himmat nagar	24	0.16227
25	New Awas vikas	25	0.13866
26	Mahipura janta road	26	0.18350
27	Remount depot	27	0.03481
28	Khata khedi	28	0.05198
29	Khan alampur yard	29	0.33589
30	Pairagpur	30	0.07781
31	Chowdhary vihar	31	0.06418
32	ITC	32	0.14762

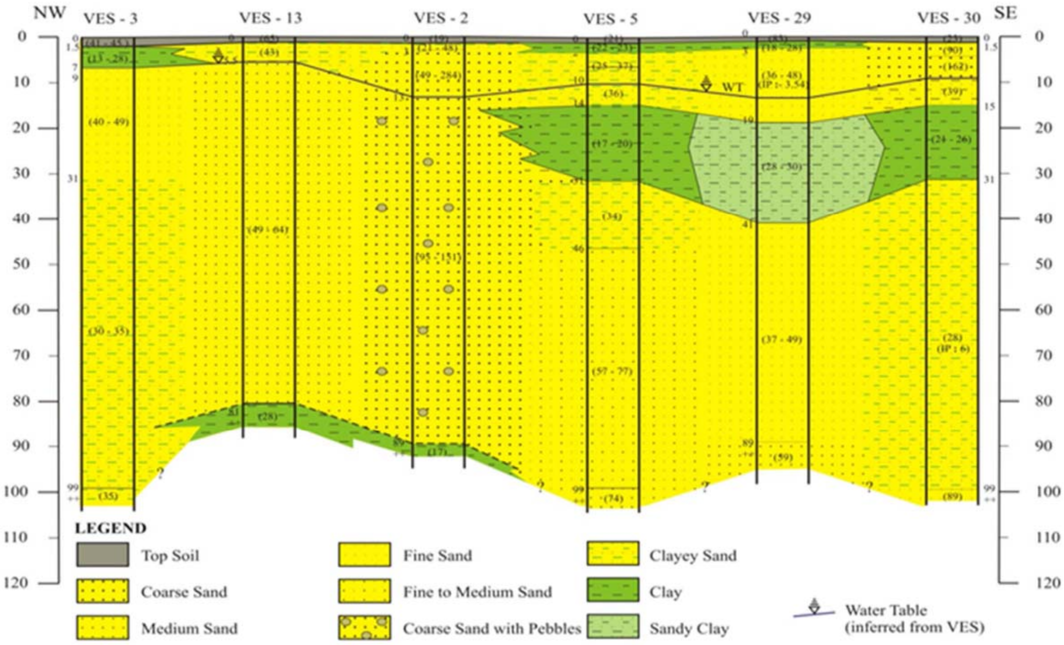

Fig.14. Geoelectric Section B-B'(section line shown in Fig.12)

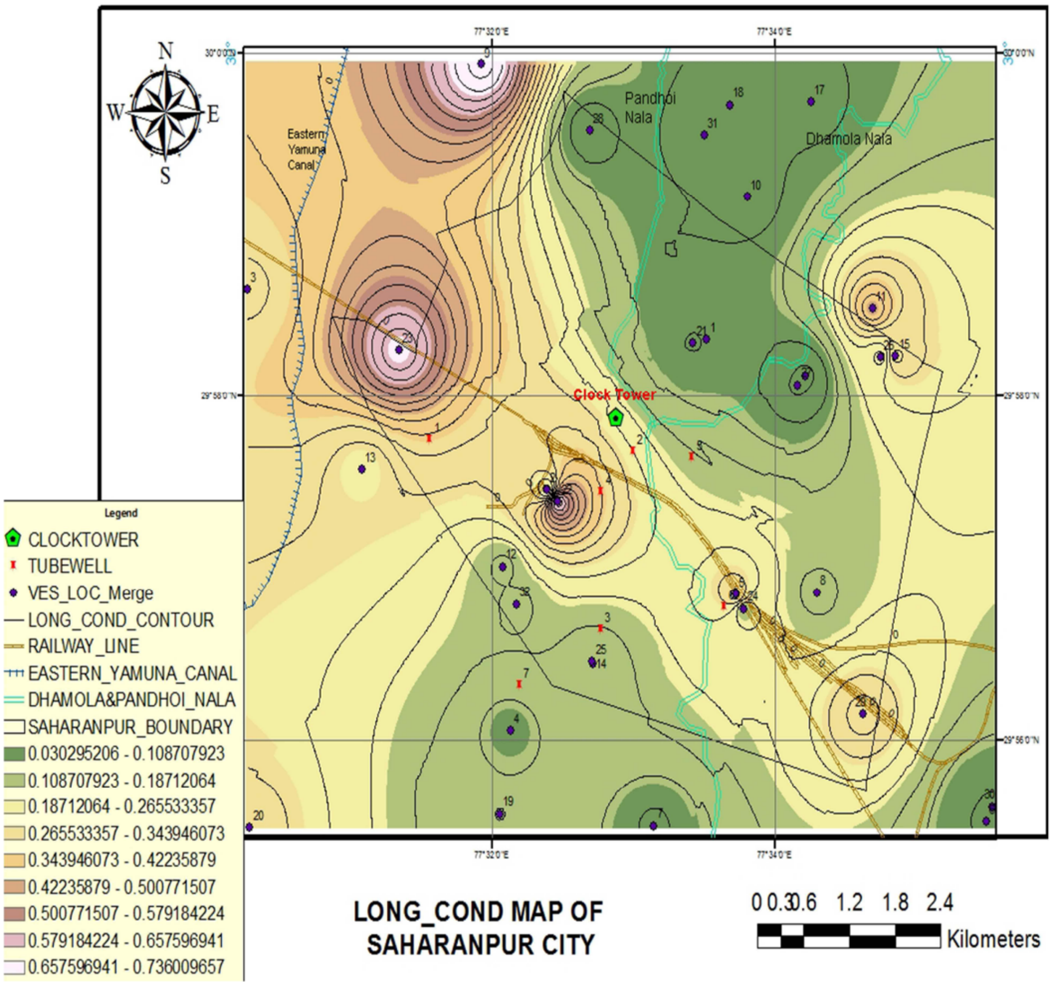

Fig.15. Total Longitudinal Conductance Map of Saharanpur Town

Table 5. Groundwater Pollution Monitoring Network Design incorporating criteria for AGWQ locations

Additional monitoring well Location	AGWQ No.	Target	Data/info	Methods/Criteria	Recommendations
ITC Cooperative Distillery Star Paper Mill	1 2 3	Monitor point Source pollution	Pollution sources map vulnerability map	One well for one point source of high risk, not protected, very large quantity, located at vulnerable area.	New sample location one well each near ITC outfalls Cooperative Distillery and Star Paper Mill (Fig. 1)
Dhamola (upstream) Confluence of Paondhoi (upstream) Dhamola (downstream) Confluence ofKamela drain with adjoining branch (near slaughter house)	4 5 6 7	Monitoring line source	Pollution sources map, ground water flow map.	-	One well each in the vicinity of Dhamola, Paondhoi and Kamela drains and one well downstream of their confluence
-	-	Monitor diffusive pollution	Vulnerability map, land use map, recharge map	Locate monitoring well in high pollution risk area (=high pollution load + high vulnerability)	No additional well required
Near Railway Station (Mission Compound Tube well) Near Govind Nagar Tube well Near Awas Vikas Tubewell Near HAV Inter College (just west of eastern Yamuna canal)	8 9 10 11	Monitor water supply sources	Capture zone of water supply well, pollution risk map.	-	One sample site each as under (Fig.1) 1. Near Govind Nagar Tubewell 2. Near Railway Station (Mission Compound Tubewell, 3. Near Awas Vikas Tubewell 4. Near HAV Inter College.
-		Set-up an integrated monitoring network.	-	Monitoring network map locations of all pollution monitoring wells; indicating existing wells and newly designed wells.	

sites 4, 7, 8, 14, 19, 24, 25 and 29) and the northeastern parts offer relatively lesser degree of protection to the unconfined aquifers from infiltrating pollutants. This can be easily corroborated by comparing the Fig. 15 with the Fig.9 and Fig.10. Such differentiation of the area on the basis of the aforementioned electrical parameter can prove to be of immense value in the groundwater management and especially for planning protection of groundwater resources.

Groundwater Resource Planning Map (GRPM)

Taking note of the possibility of ground water contamination in the Saharanpur town, an improved ground water quality monitoring network has been proposed in the present study, wherein eleven additional shallow tube wells (AGWQ) have been proposed for construction near the line sources and point sources of pollution for future ground water quality monitoring (Table 5 and Fig.11). Such a network will be of considerable help in planning a strategy for protection of the ground water resources of the town where the majority of the population depends on the shallow ground water for drinking. In the absence of an effective national ground water Legislation applicable in the state, a series of other institutional steps need to be undertaken for exercising greater restraints to be observed in day to day operation and management of the drinking water facilities in the town. In this context, the role of civic authorities and NGO's can be of considerable help (Singhal et al. 2008).Thus, it may be concluded that the technical information can be collated into a form which would be transparent and comprehensible to the stakeholders, so as to ensure that decisions regarding groundwater protection plan could be implemented by a single agency.

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