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SUITABILITY OF GROUNDWATER FOR DRINKING PURPOSE IN BHIWANI DISTRICT, HARYANA: A SPATIO-TEMPORAL ANALYSIS

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Abstract

Increasing threat to groundwater quality due to human activities has become a matter of concern during recent period. Groundwater quality problems today are mostly caused by contamination and over-exploitation of groundwater. The situation has become more critical in arid and semi-arid regions of the world due to scarcity of water. It necessitates developing innovative methods and viable strategies to protect this vital natural resource. Present study highlights hydro-geochemical characteristics of groundwater, its quality and determinants using multi-site groundwater quality data for the years 1992, 2000 and 2010 in Bhiwani district of Haryana. Groundwater quality index (GQI) calculated in accordance to the World Health Organization (WHO) standards, reveals that about 75 per cent groundwater water observation wells of the district fall in the category of poor water quality. The analysis of Gibbs Diagram reveals that groundwater observations predominantly fall in evaporation dominance, whereas Piper Diagram shows that water chemistry of study area is dominated by alkaline earth with strong acid.

Introduction

Groundwater is a vital resource for meeting the requirements of different sectors of economy like agriculture, industry and domestic. It has played a vital role in India's economic development and ensuring its food security. The relevance of groundwater in development processes in India can be realized from the fact that about 85 per cent of Indian rural domestic requirements, 50 per cent of its urban water requirements and more than 50 per cent of irrigation requirements are being met by groundwater resource. However, rapid pace of industrialization, agricultural development and urbanization has resulted over-exploitation and contamination of groundwater. Over utilization of groundwater has led to depletion of this precious resource and decline in groundwater levels to the extent of almost inaccessibility in some cases. Contamination of water sources by agriculture, industries and even by domestic use has contributed towards deterioration of groundwater quality. Globally, the sustainability of groundwater is being threatened owing to water overdraft, declining well yields, drying up of springs, stream flow depletion and land subsidence due to over-exploitation (Shah et al., 2000; Zektser, 2000). Saidi et al. (2009) pointed out that the groundwater quality is generally affected by contamination originating from intensive irrigated agriculture. While Vasanthavigar et al. (2010) opined that groundwater quality depends upon the quality of water recharged,

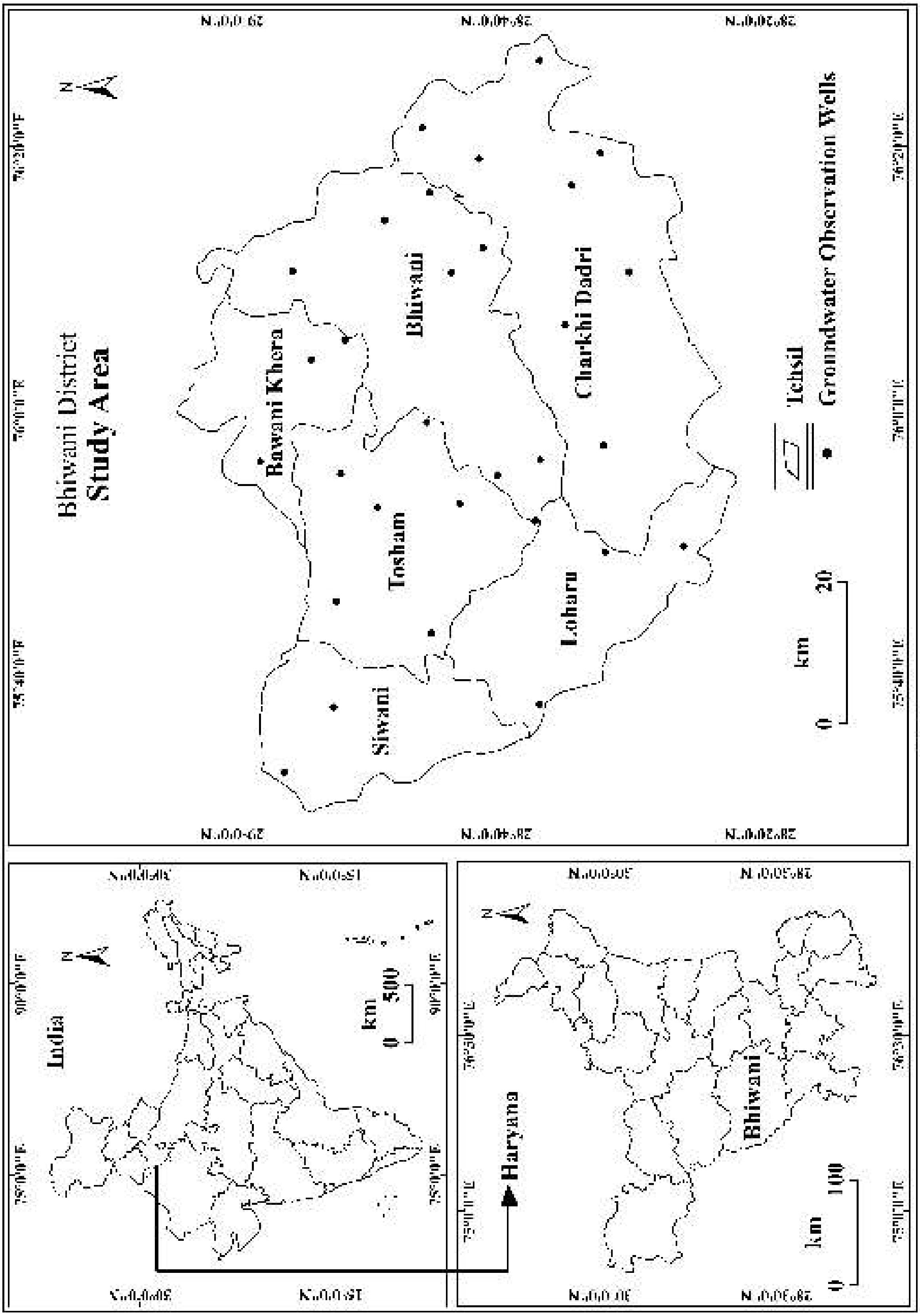
Bhiwani District
Study Area
Bawani Khera
Bhiwani
Charkhi Dadri
Tosham
Loharu
Siwani
Tehsil
Groundwater Observation Wells
km
India
Haryana
Bhiwani

Fig. 1

precipitation, and inland surface water and sub-surface geochemical processes.

Likewise, groundwater depletion and deterioration of its quality are major environmental issues where tube-wells have emerged as dominant source of irrigation. In some of these areas drinking water quality has worsened to the extent of affecting public health. Drinking water quality has posed a major health hazard on account of deterioration in quality of groundwater in various parts of Haryana (Mor. et al., 2003; Kaushik et al., 2004; Meenakshi et al., 2004; Khaiwal and Garg, 2006). Therefore, an attempt has been made in this study to assess the quality of groundwater of Bhiwani district which is largely a semi-arid tract and where over dependence on groundwater has resulted in excessive exploitation of groundwater.

Objectives of study

The present study aims at achieving the following objectives:

- To analyze the spatio-temporal dimensions of hydro-geochemistry of groundwater in order to assess its suitability for drinking purpose.
- To evaluate main factors affecting the quality of groundwater in the study area.

Study Area

Bhiwani district located between 28°10' to 29° 05' North latitudes and 75° 28' to 76° 28' East longitudes lies in south-western part of Haryana covering an area of about 5,140 km² (Fig. 1). The geological formations underlain in the district are ferrugineous chiastolite schist and associated argillaceous rocks of Aravalli group, Alwar quartzite of Delhi system, Malani suite of volcanic of lower Vindhyan age, older alluvium deposit of Quateranary age and aeolian sand of recent age. Groundwater mostly occurs in the strata comprising alluvium and aeolian sands. Located along the eastern expanses of Thar Desert, the study area has typical semi-arid climatic conditions and topographical features. The physiography of study area consists of flat and undulating sandy plains often interrupted from place to place by clusters of sand dunes, isolated Aravalli hillocks and rocky ridges. The main slope in the area is from south-west to north-east. There is concentration of sand dunes in south and south-western parts of the district. Soils in the study area are mostly sandy-loam to sandy containing high percentage of fine to very fine sand which makes them quite permeable. The district receives most of rainfall during June to October from the south-west monsoon. The annual rainfall varies from 30 to 40 cm. According to Census of India, 2011 the total population of the district is 16, 34,445 and ranks 3rd in the state. Due to low rainfall, and limited availability of surface water through canal network, people have to largely depend on groundwater to meet their water requirements.

Database and Methodology

The present study is based on different secondary sources of data collected for the years 1992, 2000 and 2010. The data about depth to groundwater, salts and chemicals dissolved in groundwater have been collected from the Annual Reports of Central Ground Water Board, North-western Region, Chandigarh. Source-wise, irrigated area for the years 1992-93, 2000-01 and 2009-10 has been collected from District Statistical Abstract of Bhiwani district. Drinking water standards have been derived from Bureau of Indian Standards (BIS, 1991) and World Health Organization (WHO, 2011) listed in Table 1.

Maps showing spatial concentration pattern of different physico-chemical parameters of groundwater in the district have been prepared with the help of Arc GIS 10.2.

Table 1
BIS and WHO: Drinking Water Quality Standards

Water Quality Parameters	BIS Standards		WHO Standards
	Desirable Limits	Permissible Limits (In the absence of alternate source)	
pH	6.5 to 8.5	No relaxation	6.5 to 9.2
Electrical Conductivity EC(µs/cm)	500	1500	500
TDS	500	1500	500
TH mg/l	300	600	200
Calcium as Ca^{2+} mg/l	75	200	100
Magnesium as Mg^{2+} mg/l	30	100	150
Sodium as Na^{+} mg/l	200	-	200
Potassium as K^{2+}(mg/l)	-	12	12
Bicarbonate as HCO_3^-	300	No relaxation	300
Nitrate as NO_3^- mg/l	45	No relaxation	50
Chloride as Cl^- mg/l	250	1000	250
Sulphate as SO_4^{2-} mg/l	200	400	200

Source: WHO, 2011; BIS, 1991

Piper Diagram has been constructed to plot the parameters of physico chemical data of groundwater and for depicting different hydro geochemical facies. Quality of water has been classified into different categories on the basis of classification scheme given by (Back, 1961; Hanshow, 1965). Gibbs Diagram has been prepared to depict controlling mechanism of groundwater chemistry.

Computation of Groundwater Quality Index (GWQI)

The Water Quality Index (WQI) has been computed by evaluating influence of natural and anthropogenic activities based on several key parameters (eg. pH, EC, Ca^{2+} and Mg^{2+} etc.) of groundwater chemistry. Following the methods used by Vasanthavigar et al. (2010), WQI has been calculated by assigning different weights to physico-chemical parameters according to their relative importance to determine the quality of drinking water. The assigned weights range from 1 to 5. The maximum weight, 5 has been assigned to NO_3 and TDS; 4 to pH, EC, SO_4; 3 to HCO_3, Cl^-; 2 to Ca^{2+}, Na^+ and K^{2+} and 1 is assigned to Mg^{2+}. The relative weight has been computed based on following equation:

$$Wi = \sum_{\frac{wi}{i}=1}^{n} wi$$

(where, Wi is the relative weight; wi is the weight of each parameter; n is the number of parameters)

The quality rating scale for each parameter is calculated by dividing its concentration in each water observation well by its respective standards (WHO, 2011) and multiplied by 100 (Table 2).

$$qi= (ci/si)*100$$

where, qi is the quality rating; ci is the concentration of each chemical parameter in each water observation well in milligrams per liter; si is the WHO standard for each chemical parameter in milligrams per litre for computing the final stage of WQI, the Sli is first determined for each parameter. The sum of Sli values gives the WQI for each water observation well.

$$Sli= wi \times qi$$

$$WQI = \sum Sli$$

Table 2
Water Quality: Relative Weight of Physico-Chemical Parameters

Water Quality Parameters	WHO Standards (2011)	Weight (wi)	Relative Weight $Wi = \sum_{\frac{wi}{i}=1}^{n} wi$
pH(on scale)	6.5-8.5	4	0.114
EC (µS/cm)	1500	4	0.114
TDS (mg/l)	500	5	0.142
Ca^{2+} (mg/l)	75	2	0.057
Mg^{2+} (mg/l)	50	1	0.029
Na^{+} (mg/l)	200	2	0.057
K^{2+} (mg/l)	12	2	0.057
HCO_3^- (mg/l)	500	3	0.086
NO_3^- (mg/l)	45	5	0.142
Cl^- (mg/l)	250	3	0.086
SO_4^{2-} (mg/l)	250	4	0.114

Source: Vasanthavigar et al. (2010)

(where, Sli is the sub-index of ith parameter; Qi is the rating based on concentration of ith parameter; n is the number of parameters).Water quality types, have been determined on the basis of WQI.

Results and Discussions

Parameters of Groundwater Quality

(i) pH

pH is a measure to exhibit balance between the concentration of hydrogen ions and hydroxyl ions in water. It is controlled by carbon dioxide, carbonate and bi-carbonate equilibrium (Hem, 1985). The combination of CO_2 and water form carbonic acid, which affects pH. It has been found that pH is within desirable limit in most parts of Bhiwani district during 1992 and 2010. However, during the year 2000 in about one-fifth area in Siwani and Loharu tehsils (western parts of the district) pH value has been found beyond desirable limit (Fig. 2a).

(ii) Electrical Conductivity (EC)

Electrical conductivity is a measure of capacity of water to pass electric current. Higher EC value indicates the enrichment of groundwater with salt contents. It also represents the total dissolved substance in water. It is apparent from Fig. 2b that EC value of groundwater in whole study area exceeded desirable limit in 1992 and 2010. But in 2000, about 32 per cent area of Bhiwani district, lying mostly in Bhiwani tehsil did have EC level within desirable limit (Table 3). It may be attributed to dilution of groundwater due to canal irrigation and higher rainfall during the year.

(iii) Total Hardness (TH)

Hardness is very important property of water in concern of drinking purposes. The hardness of water depends upon calcium and magnesium contents. Hard water is unsuitable for domestic use. The analysis revealed that groundwater in the study area is generally hard in nature. However, Table 3 revealed that total hardness has decreased over the period of study. Groundwater hardness is beyond desirable limit in all parts of Bhiwani district in 1992 and 2010. But in 2000, 58.48 per cent area is within desirable limit (Fig. 2c and Table 3).

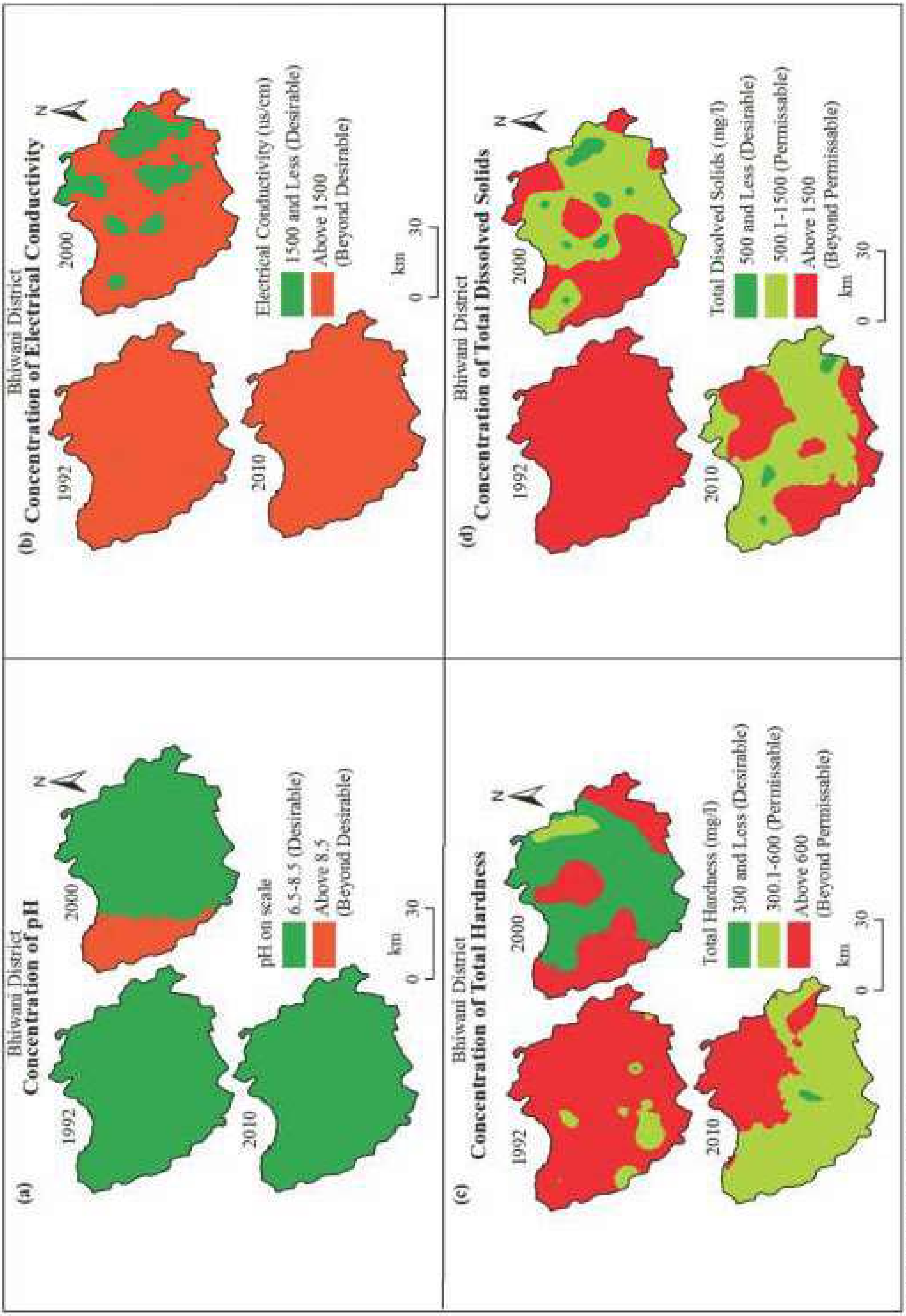

Fig. 2

Source: Computed by Authors

Table 3
Bhiwani District: Percentage of Area under Different Categories of Groundwater Quality

Water Quality Parameters	Area in Percentage under Different Limits of Ground Water Quality											
	Desirable Limit			Beyond Desirable Limit			Permissible Limit			Beyond Permissible Limit		
	1992	2000	2010	1992	2000	2010	1992	2000	2010	1992	2000	2010
pH	100	80.38	100	0.00	19.62	0.00	00.00	0.00	0.00	00.00	0.00	0.00
EC	0.00	32.00	0.00	100	68.00	100	00.00	0.00	0.00	00.00	0.00	0.00
TDS	0.00	5.05	3.13	100	0.00	0.00	00.00	50.22	55.68	00.00	44.73	41.19
TH	0.00	58.48	5.88	0.00	0.00	0.00	11.00	5.66	55.14	89.00	35.86	38.98
Ca^{2+}	0.00	44.04	59.43	0.00	0.00	0.00	29.00	45.42	40.57	71.00	10.54	0.00
Mg^{2+}	0.00	04.04	0.00	0.00	0.00	0.00	35.62	64.05	65.54	64.38	31.91	34.46
Na^{+}	0.00	42.55	15.55	100	57.45	84.45	00.00	0.00	0.00	00.00	0.00	0.00
K^{2+}	2.05	0.00	35.78	97.95	100	64.22	00.00	0.00	0.00	00.00	0.00	0.00
HCO_3^-	22.65	54.63	0.00	77.35	45.37	100	00.00	0.00	0.00	00.00	0.00	0.00
NO_3^-	12.55	100	0.00	87.45	0.00	0.00	00.00	0.00	0.00	00.00	0.00	100
Cl^-	00.00	39.67	14.83	0.00	0.00	0.00	47.34	55.67	80.58	52.66	4.66	4.59
SO_4^{2-}	00.00	00.00	0.00	0.00	0.00	0.00	68.54	39.67	78.72	31.46	60.33	21.28

Source: Computed from Annual Reports of Central Ground Water Board

(iv) Total Dissolved Solids (TDS)

TDS encompasses salt, metal, mineral, and cation and anion dissolved in water. Total dissolved solids in the groundwater crossed the limit for drinking in 1992 as prescribed by WHO (Fig. 2d). In 2000 and 2010, large area of Bhiwani district falls in permissible limit for drinking purpose. But it crosses the desirable limit in north-east and south-west part of study area in 2000 and 2010 (Fig. 2d). It may be attributed to over-exploitation of groundwater in south-western parts and waterlogging in north-eastern parts of the Bhiwani district. The high TDS may also be attributed to mixing of residues of chemical fertilizer in water due to shallow water table in north-eastern parts of the study area.

Cation Chemistry

(i) Calcium and Magnesium (Ca^{2+} and Mg^{2+})

The quantity of calcium and magnesium in groundwater generally determines its suitability for drinking. These ions are mostly found in surface and sub-surface water, existing mainly as bicarbonate and to a lesser degree in form of sulphate and chloride. A high concentration of calcium in large part of the study area has been observed during the year 1992 but it has been found within permissible and desirable limits in 2000 and 2010 (Fig. 3a). Also, high concentration of magnesium has been witnessed in 1992 in comparison to 2000 and 2010. In north-eastern part of the study area, majority of water observation wells have recorded the quality of water beyond permissible limit during 1992 and 2010 (Fig. 3b). The hardness of groundwater in the study area is mainly attributed to concentration of calcium and magnesium ions.

(ii) Sodium and Potassium (Na^{+} and K^{2+})

In general, Na is the dominant ion among the cations and found in most of the natural water. The study reveals that there is high concentration of these cations in groundwater. Sodium crossed the desirable limit in 1992 and 2010 in most parts of the district. But in 2000, in north-eastern parts a few water observation wells have fallen in category of desirable limit (Fig. 3c). Fig. 3d and Table 3 show that potassium crossed the desirable limit in 1992 and 2000 but a few water observation wells have been found in category of desirable limit in 2010. Low concentration of sodium in groundwater in 2000 may be attributed to expansion of canal irrigation. The

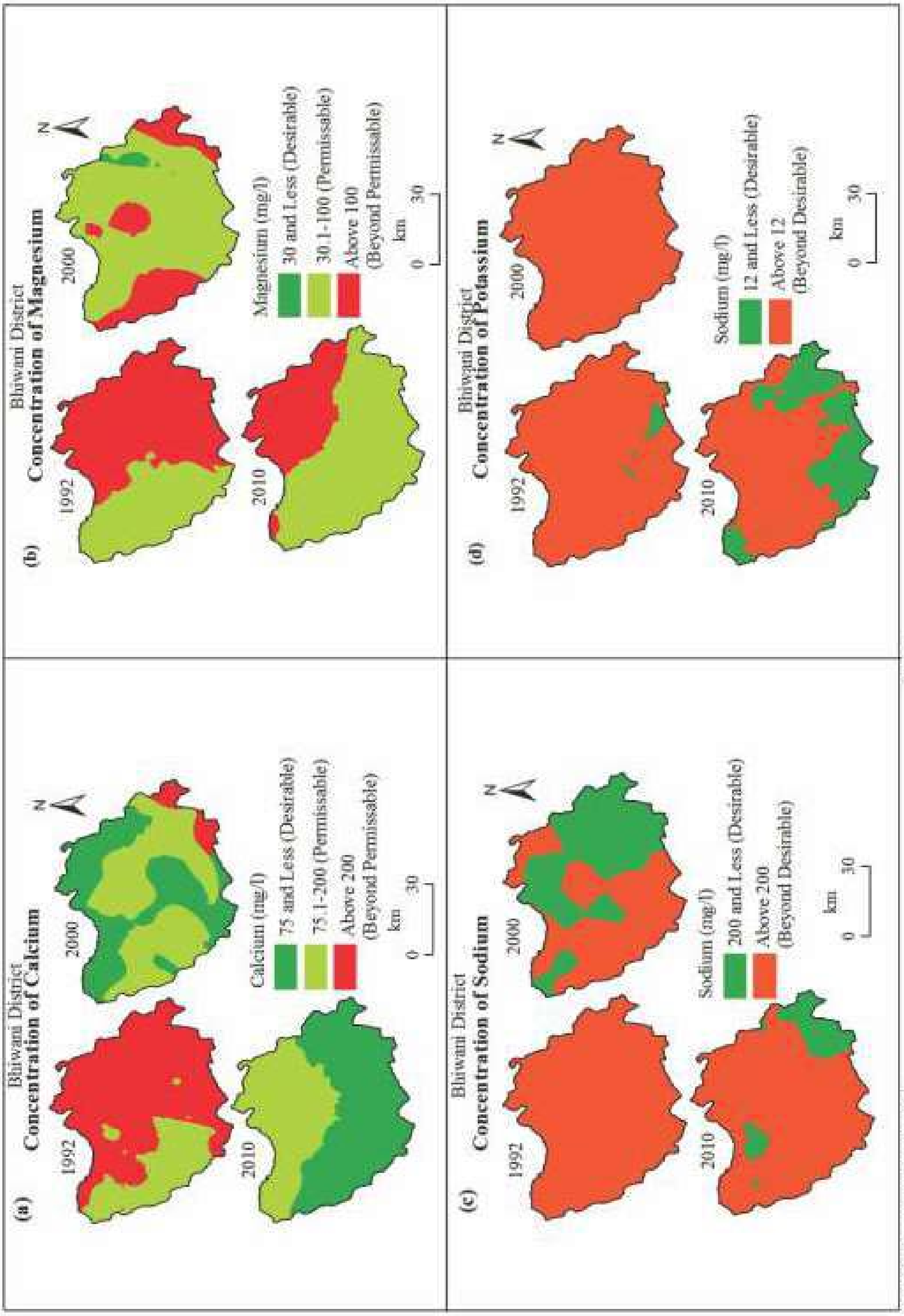

Fig. 3

Source: Computed by Authors

seepage from the canal irrigated area may have diluted the content of Na in groundwater.

Anion Chemistry

(i) Bicarbonate (HCO_3)

The concentration of carbonate in natural water is a function of dissolved CO_2, temperature, pH, cation and other dissolved salts. Majority of water observation wells crossed the desirable limit for drinking in case of HCO_3 in 1992 and 2010. But in 2000 about half of the district, particularly north-eastern and central parts had optimum concentration of bicarbonate (Fig. 4a and Table 3).

(ii) Nitrate (NO^{3-})

High concentration of nitrate directly affects the water quality as well as human health. Nitrogen compounds originated from point and non-point agriculture sources are mainly found in sub-surface environment (Pang et al. 2013). Increasing nitrogen compound concentration in water is seriously dangerous for human body. The analysis reveals that concentration of nitrate was beyond desirable limit in most parts of the study area in 1992 and 2010 (Fig. 4b). But the concentration of nitrate has been observed in desirable limit during the year 2000 in Bhiwani district. This may also be attributed to dilution of nitrates in groundwater due to increased seepage of canal water.

(iii) Chloride (Cl^-)

Chloride is important in detecting the contamination of groundwater by waste water. It is extremely stable and most predominant element of water. The chloride in groundwater may enter from diverse sources such as weathering, leaching of sedimentary rock, soil and domestic and municipal effluents (Sarath et al., 2012). The study reveals that groundwater in half of the area during 1992, comprising parts of Loharu, Siwani and Bhiwani tehsils, have been observed within permissible limit, however, during the year 2000 and 2010 most parts of Bhiwani district have been found well within the permissible limits (Fig. 4c).

(iv) Sulphate (SO_4^{2-})

The concentration of sulphate is harmful for human body if it exceeds the maximum allowable limit of 400 mg/l and causes laxative effect on human body (Kumar et al., 2014). The study reveals that sulphate concentration increased in the year 2000 in the south-western parts of the district but again it has been found in permissible limits during 2010 (Fig. 4d).

Hydro-chemical Facies and Water Classification

Piper diagram is a tool for analyzing the chemistry of groundwater. It comprises of three parts, a ternary diagram in the lower left representing the cations, a ternary diagram in the lower right representing the anions and the diamond plot in the middle representing a combination of the two (Fig. 5). Chemical parameters of groundwater plotted on Piper Tri-linear diagram infer the dissimilarities and different type of water in the study area, which have been listed in Table 4. It is evident from Fig. 5 that during the year 1992 and 2010 alkaline earth (Ca^{2+}+Mg^{2+}) and alkalies (Na^++K^{2+}) have been found almost in equal proportion. However, during the year 2000 there has been a dominance of alkaline earth in 70 per cent water observation wells. Similarly, strong acid exceeds weak acid during the three time periods in Bhiwani district. Maximum number of water observation wells has been found to have sodium chloride type category during 1992 and 2010, which dominantly affects the water quality negatively (Table 4).

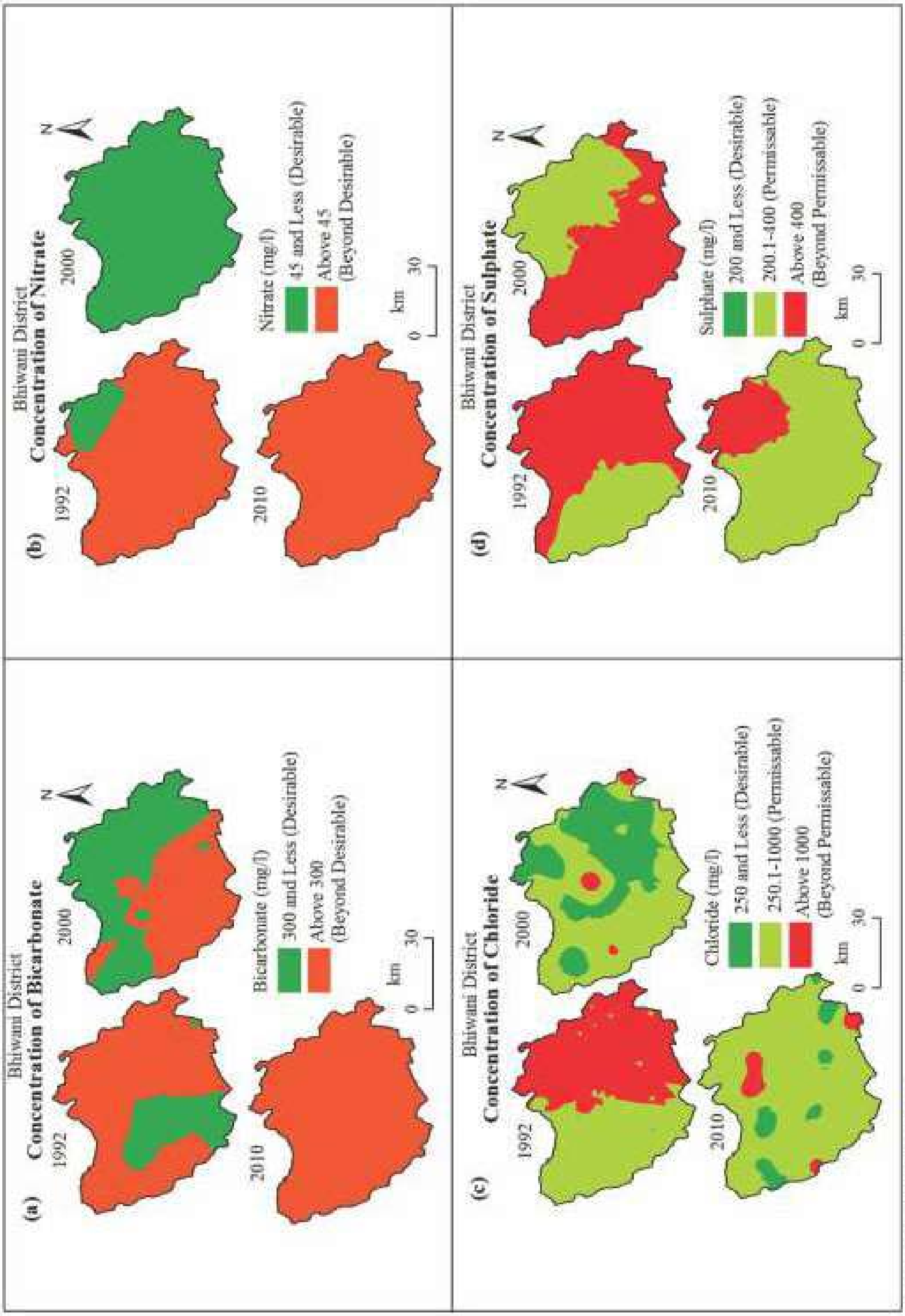

Fig. 4

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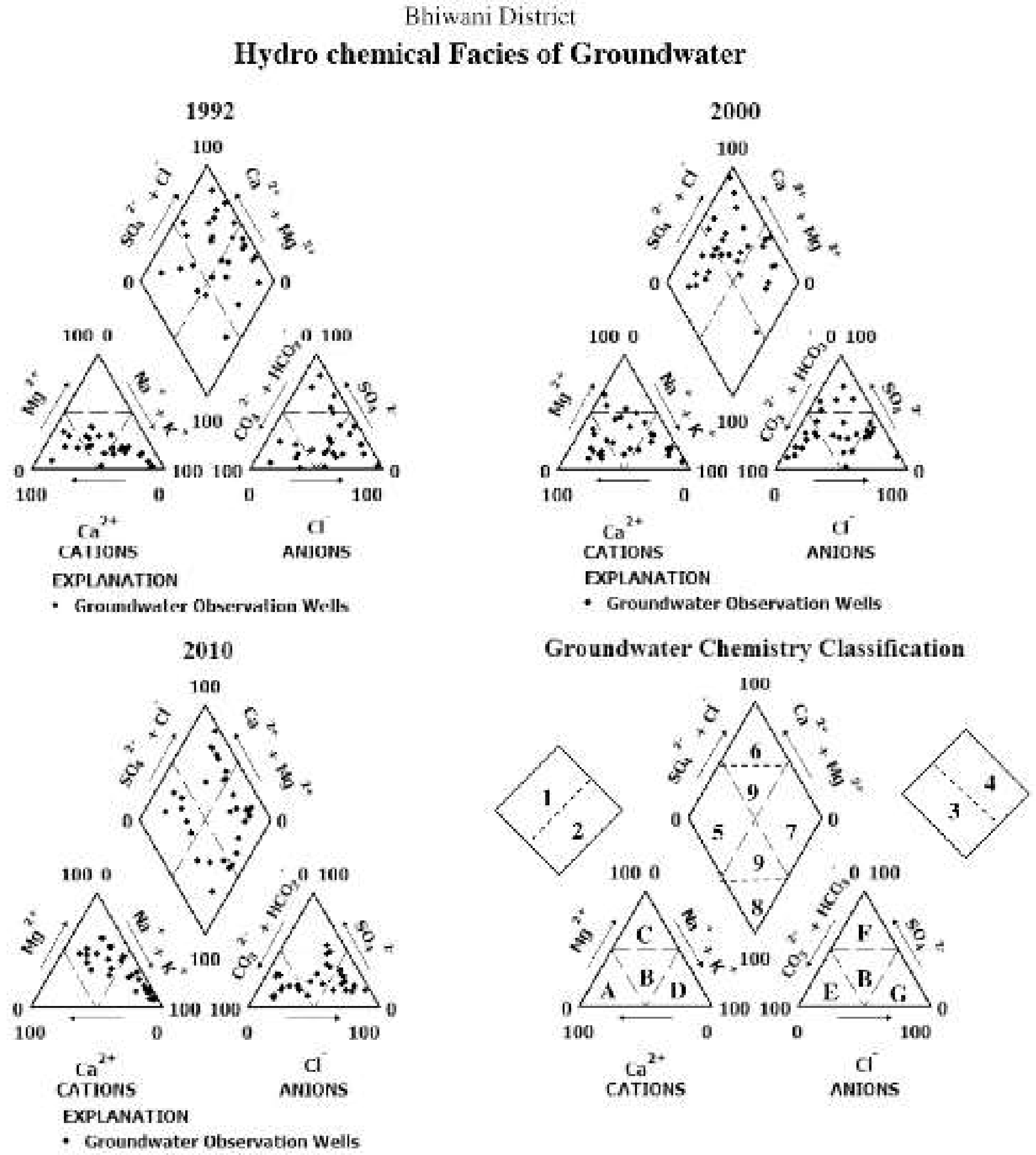


Groundwater Chemistry Classification

A- Calcium type
B- No Dominant type
C Magnesium type
D- Sodium and potassium type
E- Bicarbonate type
F- Sulphate type
G- Chloride type

1. Alkaline earth (Ca+Mg) exceeds alkalies (Na+K)
2. Alkalies exceeds alkaline earth
3. Weak acid (CO_3+HCO_3) exceeds strong acids(SO_4+Cl)
4. Strong acids exceeds weak acid
5. Magnesium Bicarbonate type
6. Calcium-chloride type
7. Sodium-chloride type
8. Sodium Bicarbonate Type
9. Mixed type

Source: Computed by Authors

Fig. 5

Table 4
Bhiwani District: Characterization of Groundwater based on Piper Tri-Linear Diagram

Sub-division of the Diamond	Characteristics of Corresponding Sub-division of Diamond Shaped Fields	Number of Wells		
		1992	2000	2010
1	Alkaline earth (Ca^{2+} +Mg^{2+}) exceeds alkalies (Na^{+}+K^{2+})	15 (50.00)	21 (70.00)	15 (50.00)
2	Alkalies exceeds alkaline earth	15 (50.00)	9 (30.00)	15 (50.00)
3	Weak acid (CO_3^{2}+ HCO_3-) exceeds strong acids(SO_4^{2-}+ Cl^{-})	6 (20.00)	8 (26.67)	11 (36.66)
4	Strong acids exceeds weak acid	24 (80.00)	22 (73.33)	19 (63.34)
5	Magnesium bicarbonate type	4 (13.33)	7 (23.33)	6 (20.00)
6	Calcium-chloride type	7 (23.33)	4 (13.33)	5 (16.68)
7	Sodium-chloride type	14 (46.66)	8 (26.68)	10 (33.33)
8	Sodium bicarbonate type	1 (3.33)	0 (0.00)	1 (3.33)
9	Mixed type (No Cation, Anion)	4 (13.35)	11 (36.66)	8 (26.66)

(Figures in parentheses are percentage of wells in total observation wells.)
Source: Computed from Annual Reports of Central Ground Water Board

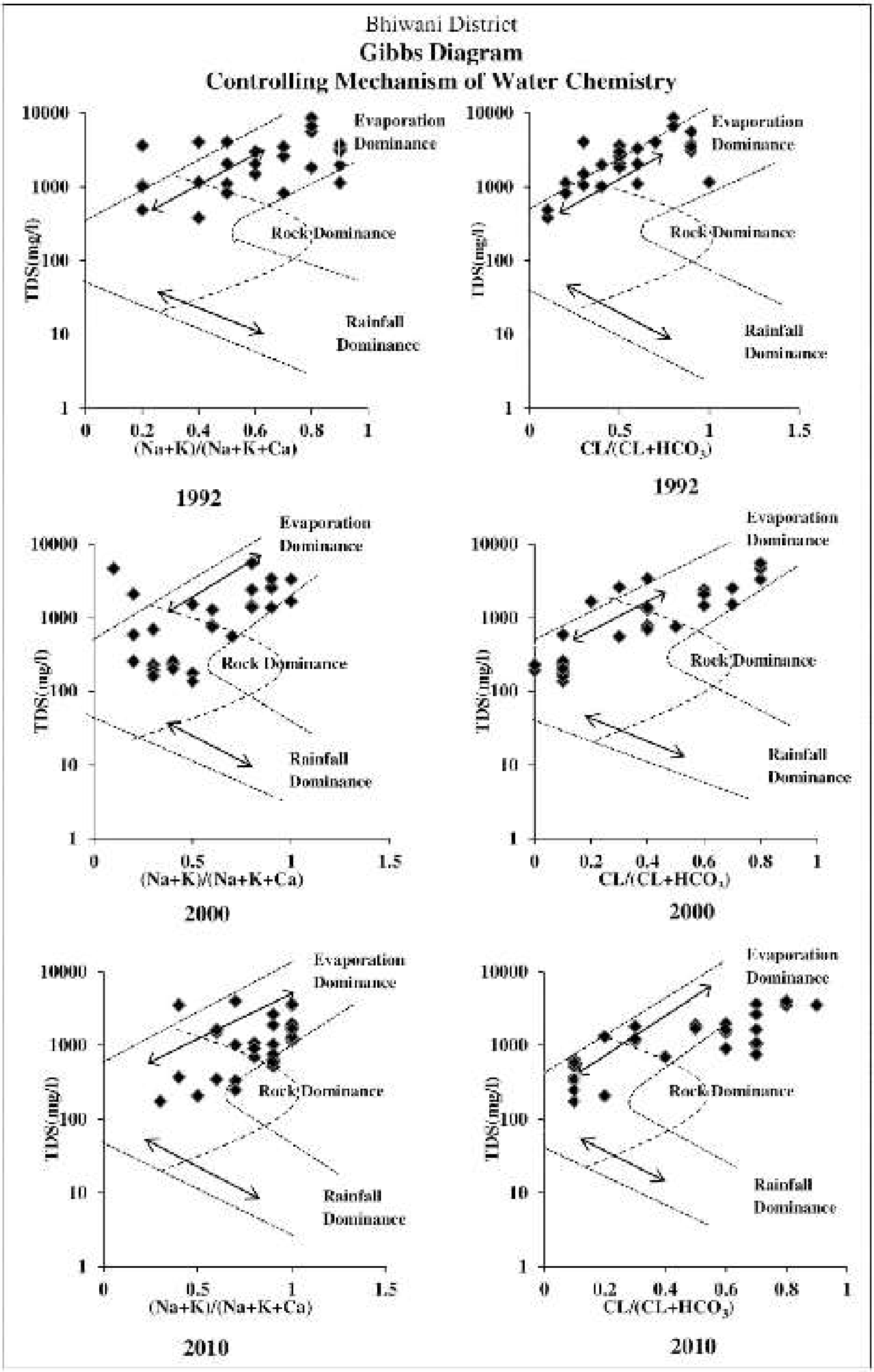
Controlling Mechanism of Water Chemistry

Gibbs diagram represents the ratio of Na+K+/Na+K+Ca and Cl/(Cl+HCO_3) as a function of TDS which is widely used to assess the functional sources of dissolved chemical constituents such as precipitation, rock and evaporation dominance (Gibbs, 1970).The chemical data of the groundwater water observation wells from the study area have revealed a dominance of evaporation during the year 1992 and 2010 due to which concentration of Na^{+}+, K^{2+} and Cl^{-} led to increase in salinity in groundwater and decline in quality of groundwater (Fig. 6). However, rock water dominance prevailed in the district during the year 2000 on account of improvement in groundwater quality and that can be attributed due to the expansion of canal irrigation in the district during the year 2000.

Spatial Pattern of Groundwater Quality

Water Quality Index (WQI) is an important indicator for suggesting the quality of water and its suitability for drinking purpose. It is composite index of the sum-total of all the parameters of groundwater quality. Overall, the quality of groundwater has been observed to be poor to very poor and not suitable for drinking purpose in entire Bhiwani district during the year 1992 (Table 5). This is attributed to the fact that almost all the observation wells in Bhiwani, Siwani, Loharu and Bawani Khera tehsils have recorded the quality of water from poor to not suitable for drinking purpose category. Only two observation wells at Lanchamnpura and Sanwar villages had excellent and good quality of groundwater (Table 6). The poor groundwater quality in the district during the year 1992 may be attributed to overall deep groundwater level dominated by saline water regime (Fig. 7 and 8).

There was a significant improvement in groundwater quality during the year 2000 in comparison to 1992 in most parts of the district (Fig. 7). About 32 per cent area and 57 per cent observation wells covering north, north-east and north-west parts comprising Bhiwani, Charkhi Dadri, Siwani and parts of Bawani Khera tehsils have witnessed good to excellent



Source: Computed by Authors

Fig. 6

Table 5

Bhiwani District: Tehsil-wise Distribution of Percentage of Observation Wells according to Quality of Groundwater

Tehsil	Percentage of Observation wells under Different Categories of Ground Water Quality														
	Excellent			Good			Poor			Very Poor			Unsuitable for Drinking		
	1992	2000	2010	1992	2000	2010	1992	2000	2010	1992	2000	2010	1992	2000	2010
Bhiwani	0.0	37.50	0.0	0.0	12.50	12.50	25.00	12.50	62.50	12.50	12.50	0.0	62.50	25.00	25.00
Bawani Khera	0.0	33.33	0.0	0.0	0.0	33.33	0.0	33.33	33.33	33.34	0.0	0.0	66.66	33.34	33.34
Loharu	0.0	0.0	0.0	0.0	33.33	0.0	66.66	0.0	66.66	0.0	33.33	0.0	33.34	33.34	33.34
Tosham	0.0	33.33	16.70	33.30	16.66	16.66	33.33	16.66	16.66	0.0	16.66	33.33	33.34	16.69	16.65
Charkhi Dadri	12.50	25.00	25.00	0.0	37.50	25.00	25.00	12.50	37.50	25.00	12.50	0.0	37.50	12.50	12.50
Siwani	0.0	50.00	50.00	0.0	50.00	0.0	100	0.0	50.00	0.0	0.0	0.0	0.0	0.0	0.0
Bhiwani District	**0.0**	**30.00**	**13.5**	**0.0**	**27.00**	**20.00**	**40.00**	**16.40**	**46.7**	**13.34**	**13.30**	**6.70**	**46.66**	**13.30**	**13.10**

Source: Computed by Authors from Annual Reports of Central Ground Water Board

Table 6
Bhiwani District: Observation Well-wise and Year-wise Groundwater Quality Index

Observation Wells	1992	2000	2010
Gurera	148	84	112
Mohila	152	30	34
Miran	138	135	49
Loharu	363	340	125
Jhumpa	375	323	85
Isharwal	499	229	660
Tosham	87	77	215
Bajina	198	472	187
Bahal	112	138	175
Sungurpur	417	36	275
Lachamanpur	54	45	55
Juikalan	268	244	168
Chirya	372	218	373
Singhani	119	92	116
Atela	151	34	82
Charkhi Dadri	817	69	27
Sanwar	44	77	42
Bambla	369	29	172
Sui	216	117	350
Dhanana	347	485	182
Bawanikhera	530	26	98
Imlota	220	420	79
Sodiwas	182	227	455
Hetampura	474	33	192
Gopi	409	154	166
BijaLanwas	144	148	63
Lohani	480	24	310
Mainharu	544	81	130
Meharana	174	35	108
Baund kalan	224	67	158

Source: Computed by Authors from Annual Reports of Central Ground Water Board

groundwater quality (Table 5 and 7). However, poor to very poor quality of groundwater has been observed in western and south-western parts of the district in the year 2000. Overall improvement in the groundwater quality during the year 2000 in the district may be attributed to expansion of canal irrigation and rise in the depth of groundwater level (Table 8 and 9). With the increase in the seepage from the canal irrigated areas, shallow fresh water aquifers develop and overlay the saline water aquifers. However, poor to very poor quality groundwater regime have been observed throughout the district during the year 2010 except in some parts of Charkhi Dadri tehsil. Deterioration in the quality of groundwater during this period may be attributed to rapid expansion of tube-well irrigation leading to over exploitation of freshwater resources (Table 8 and 9). Consequently, with the lowering of water table the saline aquifer got exposed and quality of water got deteriorated.

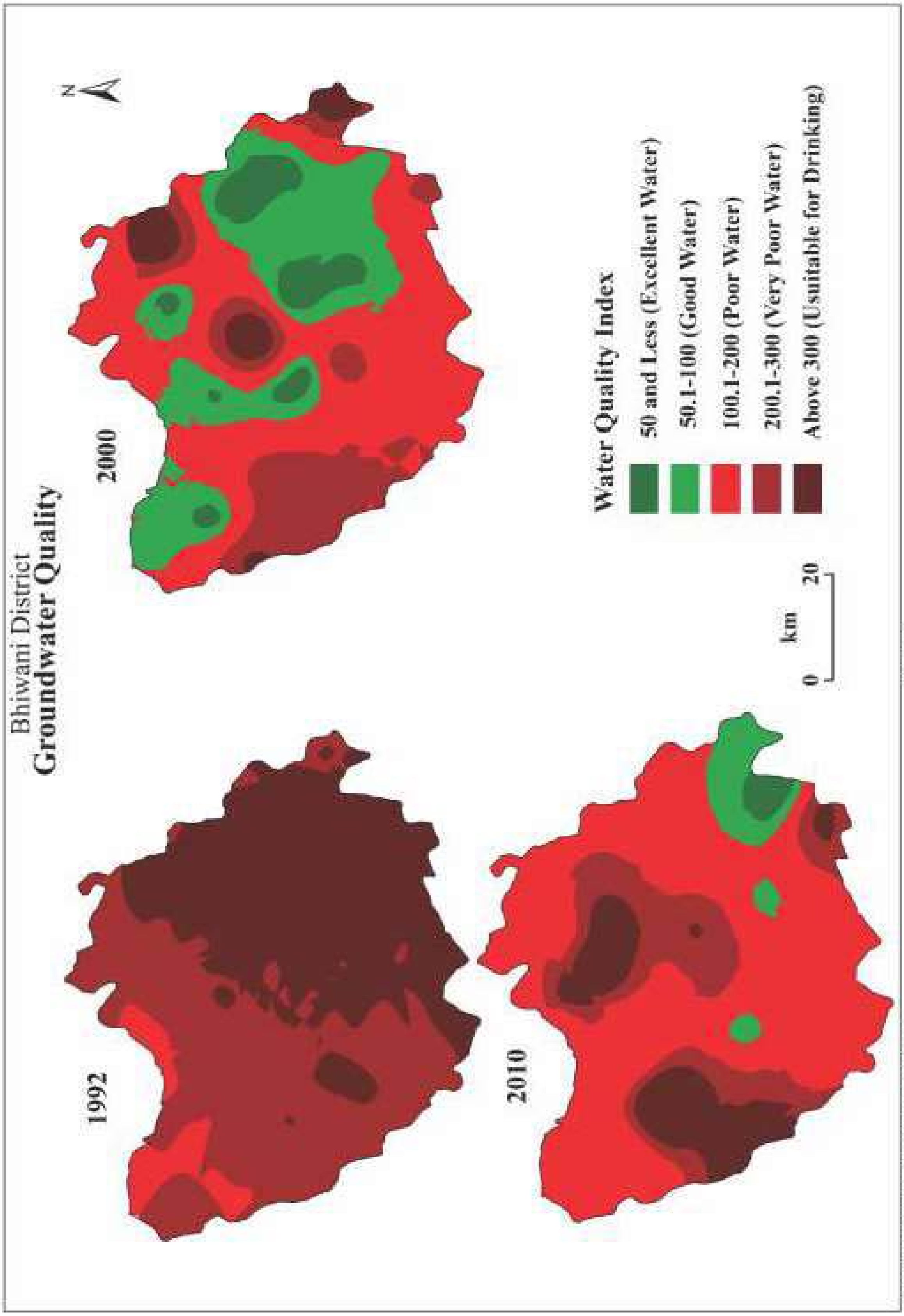
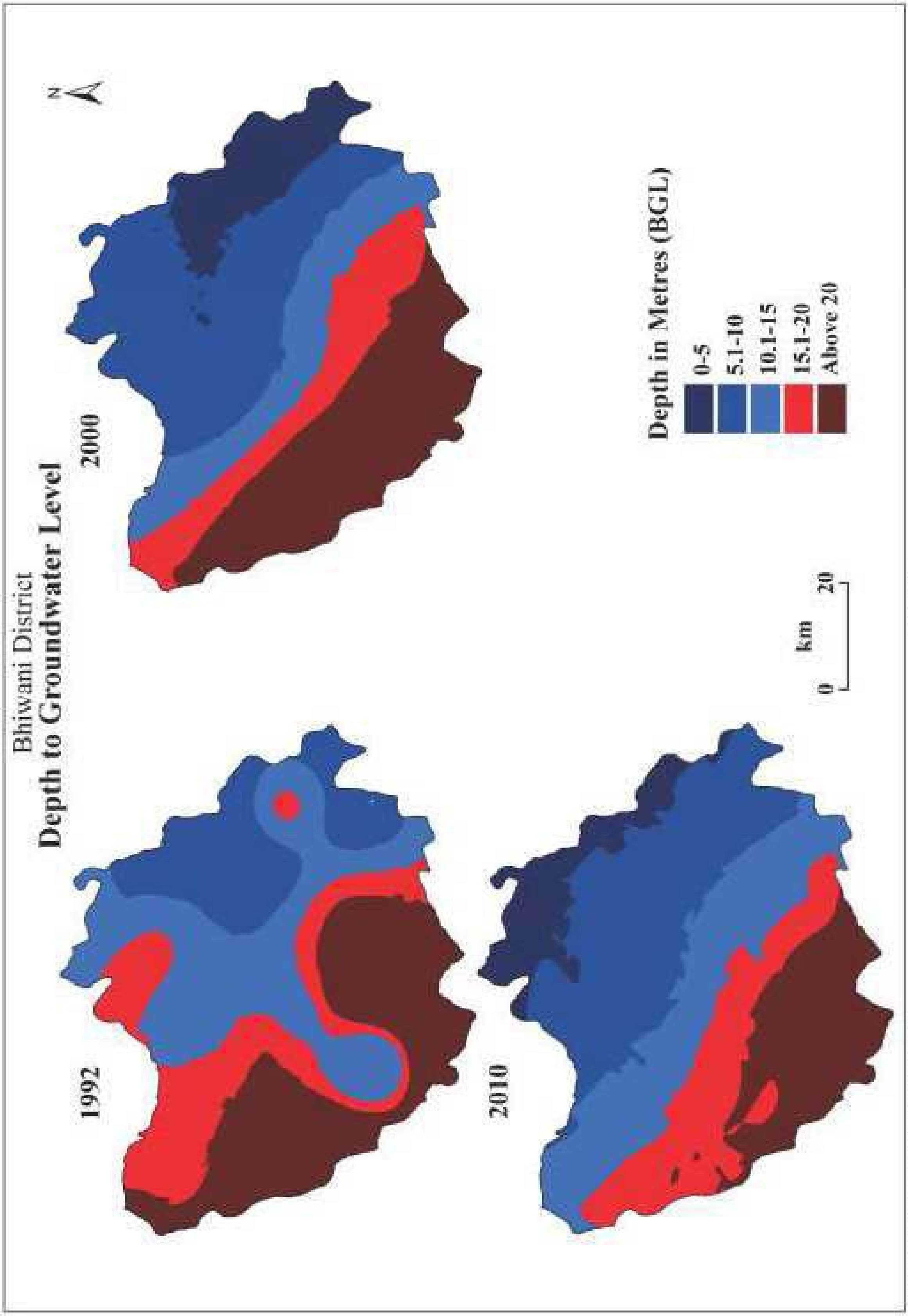


Fig. 7

Source: Computed by Authors



Source: Computed by Authors

Fig. 8

Table 7
Bhiwani District: Year-wise, Percentage of Area under Different Categories of Groundwater Quality

GWQI	Water Quality	Percentage of Area		
		1992	2000	2010
50 and Less	Excellent	0.00	7.55	2.56
51.1-100	Good	0.00	24.76	7.15
100.1-200	Poor	7.04	43.24	57.83
200.1-300	Very Poor	46.22	16.35	17.21
Above 300	Unsuitable for Drinking	46.74	8.10	15.25

Source: Computed by Authors from Annual Reports of Central Ground Water Board

Table 8
Bhiwani District: Tehsil-wise and Year-wise, Percentage Net Area Irrigated by Canals and Tube-wells

Tehsil	1992-93		2000-01		2010-11	
	Canals	Tube-wells	Canals	Tube-wells	Canals	Tube-wells
Loharu	11.12	88.88	21.04	78.96	21.79	78.21
Bhiwani	88.38	11.62	90.72	9.28	77.32	22.68
Tosham	DNA	DNA	79.02	20.98	57.23	42.77
Charkhi Dadri	23.19	76.81	29.98	70.02	17.86	82.14
Bhiwani Khera	98.64	1.36	97.53	2.47	83.63	16.37
Siwani	90.91	9.09	99.59	0.41	60.82	39.18
Bhiwani District	**57.62**	**42.38**	**61.37**	**38.63**	**41.79**	**58.21**

Source: Bhiwani, District Statistical Abstract (1992-93, 2000-01, 2010-11)

Table 9
Bhiwani District: Year-wise, Percentage of Area under Categories of Depth to Groundwater Level

Depth to Water Table (Meter)	Percentage of Area		
	1992	2000	2010
5 and Less	0.00	11.27	10.39
5.1-10	16.51	31.30	29.37
10.1-15	29.14	15.10	22.72
15.1-20	22.88	14.04	17.39
Above 20	31.47	28.29	20.13

Source: Computed by Authors from Annual Reports of Central Ground Water Board

Conclusions

Based on various physico-chemical parameters, the present study highlights the spatio-temporal scenario of groundwater quality in Bhiwani district. Groundwater quality for drinking purpose has been found better in vast areas of Bhiwani district during the year 2000 in comparison to 1992 and 2010. The analysis of Gibbs diagram has revealed that the quality of groundwater is dominated by evaporation except the year 2000 when a sizeable area has been observed under rock water dominance. Improvement in groundwater quality in the district is largely synchronized with rise in the groundwater level. The overall improvement in quality of groundwater during the year 2000 may be attributed to development of shallow fresh aquifer, resulting dilution of saline groundwater aquifer. The increased seepage of water into the ground on account of expansion of canal irrigated area and occurrence of above normal rainfall during that period may be linked to the growth of shallow aquifer. Piper diagram indicates that groundwater chemistry in the district is dominated by alkalinity and strong acid base, which is directly influenced by the geo-genic characteristics, particularly the concentration of soluble salts in soil horizons. Overall quality of groundwater is better in canal irrigated areas, such as in north-east and eastern parts, whereas poor quality saline groundwater with high concentration of sodium chloride dominates the western and southern parts of the district.

It is evident that the groundwater quality in Bhiwani district is largely linked to the intensity and expansion of tube-well and canal irrigation. Hence, there is a need to reduce the intensity of groundwater irrigation by growing low soil moisture consuming crops. Expansion of the canal irrigation on the other hand is likely to improve the ground water quality.

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