Hydrogeological and hydrochemical framework of regional aquifer system in Kali-Ganga sub-basin, India

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Abstract The central Ganga Basin is one of the major groundwater reservoirs in India. The Kali-Ganga sub-basin is a micro watershed of the central Ganga Basin, containing a number of productive aquifers. A detailed hydrogeological investigation was carried out, which reveals the occurrence of a single-tier aquifer system down to 163 m bgl (metres below ground level), but at places it is interleaved with clay layers; thus imparting it a two- to three-tier aquifer system. These aquifers are unconfined to confined in disposition. The transmissivity, storage coefficient and hydraulic conductivity are determined as 2178 m^2/day, 1.12×10^{-5} and 120 m/day, respectively. The groundwater of the basin is fresh, of an alkali-bicarbonate type and is suitable for irrigation and domestic use. However, in certain areas, extensive agricultural activities, and domestic and industrial effluents have caused some deterioration of groundwater quality. This study contains data of where the concentration of Fe, Pb, Cd, Cr and Ni are higher than the permissible limits, which may be hazardous to public health.

Keywords Aquifer parameter · Aquifer system · Kali-Ganga · Water quality

Introduction

India, with its agricultural economy, depends heavily on the availability of water to meet its irrigational demands. Rainfall is characterized by seasonal and annual variations and is not a very reliable source of water supply. Availability of groundwater is therefore a major asset that can greatly influence agriculture.

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However, the evaluation and management of groundwater resources require an understanding of hydrogeological and hydrochemical properties of the aquifer. In Kali-Ganga sub-basin, the aquifers are of major importance because they are the main source of water supply. The development of water resources in the area during the past two decades has produced a mixed result of a declining water table in the top aquifers and waterlogging conditions in the canal command areas. This paper aims to describe the regional aquifers, their hydrological characteristics and give a quality assessment. The paper is based on actual field data collected from 1996–1998 as part of a Doctoral thesis of Asad Umar.

Description of the area

The area under study lies in the sub-tropical climatic zone and falls between latitude 27° 33′–27° 53′N and longitude 78° 48′–79° 11′E in the Etah district of Uttar Pradesh (Fig. 1). Geomorphologically, it occupies the floodplain of the Ganga-Kali interfluves. Physiographically, the area is generally flat with a gentle slope that is due south-east, where the elevation varies between 171 m in the north-west to 152 m in the south-east above mean sea level. The area is bounded in the north-east by the River Ganga and on the south-west by the River Kali. May and early June are the hottest months of the year, which are followed by the onset of the south-west monsoon in mid-June. July and August are the months of heavy rainfall. The average annual rainfall recorded is 715 mm.

Geology

Geologically, the area is underlain by the alluvial deposits of Quaternary age. The subsurface geology, comprises Bundelkhand granite (3000 Ma) as the basement complex, which is unconformably overlain by the rocks of Upper Vindhyan of Upper Proterozoic and is finally overlain by Quaternary alluvium. The Quaternary alluvium consists of alternate beds of sand and clay down to 360 m bgl, and contains several aquifer systems in the basin. Various grades of sand form the granular zones, varying from fine through medium to coarse micaceous sands.

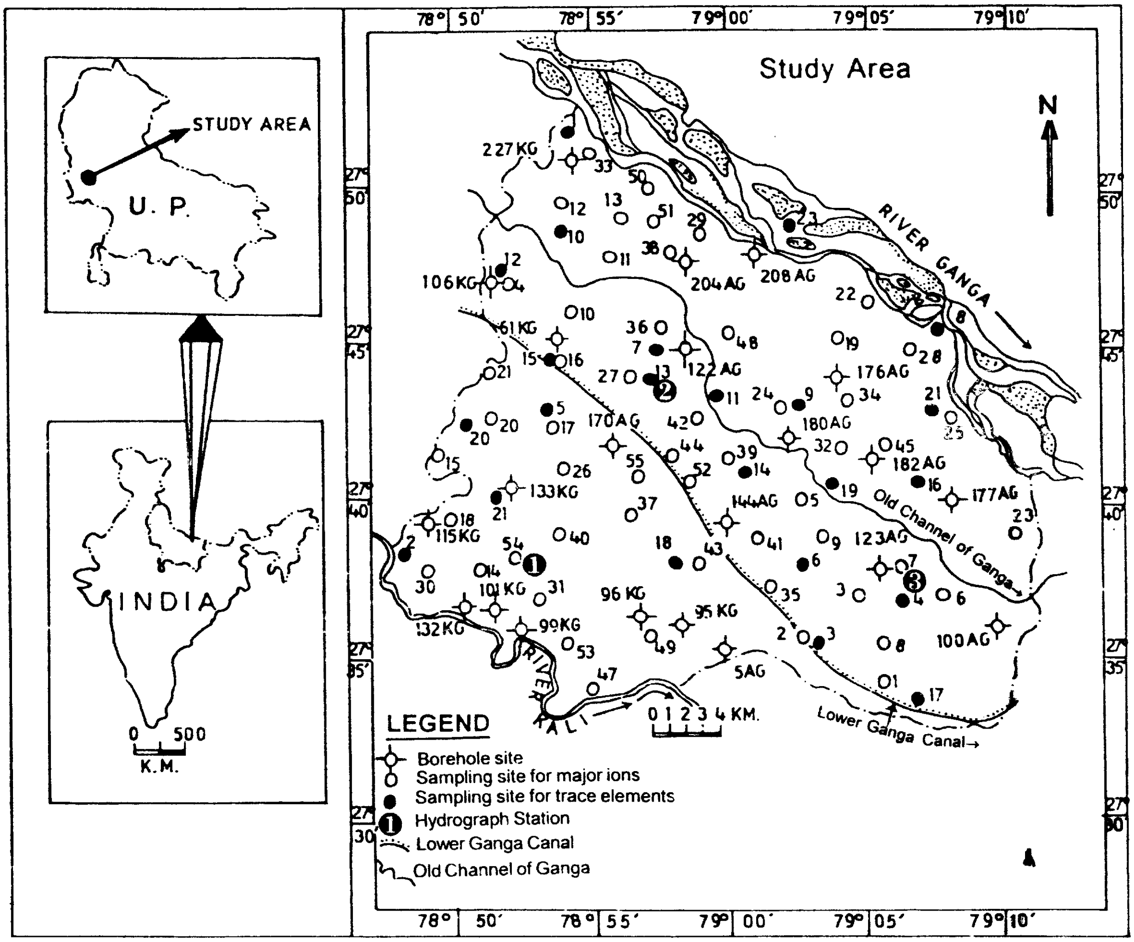

Fig. 1
Location map showing sampling sites, boreholes and hydrograph stations

Hydrogeology

Aquifer system

The nature and the character of alluvium has been studied from the fence diagram (Fig. 2) prepared from the borehole logs, which shows that the alluvial deposits consist of alternate beds of sand and clay where the granular zones form the potential aquifers. There are marked lateral variations in the occurrence of various beds in the alluvium. Figure 2 shows that the aquifers that have intercalations of thin and often thick clay beds, which pinches out laterally, by and large represent a single-tier aquifer system down to 163 m bgl. In general, the granular zone predominates the low permeability horizons. It was also observed at places that the thickness of the clay beds increases to the east. However, all along the right bank of the old channel of the River Ganga, clay beds predominate over the granular zones. The top clay bed appears persistent in the entire study area except at a few places along the Ganga bank.

The pre-monsoon depth water level in the area varies between 10.85 m bgl in the south-eastern part to 1.80 m bgl along the canal command area, whereas in post-monsoon water level variation is between 10.35 to 1.04 m bgl, respectively.

Groundwater flow system

A network of 186 dug wells were monitored for water level in pre- and post-monsoon periods, i.e. June and November, during the years 1996 and 1997. Figure 3 is a water-table map of the study area that is based on the data collected in June 1997. Figure 3 shows that the elevation of water table ranges between 165 m in the north-west to 142 m in the south-east, which indicates a regional groundwater flow direction from north-west to the south-east. Varied local flow directions were also observed. There are eight groundwater mounds of which six are observed along the lower Ganga canal. These mounds were formed by the excessive seepage into the aquifer below the canal bed. The troughs were generated because of excessive water withdrawal in the area away from the canal. The hydraulic gradient was observed to be steeper along the old channel of the Ganga (6.5 m/km) and rather flat in the low valley of the Ganga and in the central plain (0.25 m/km).

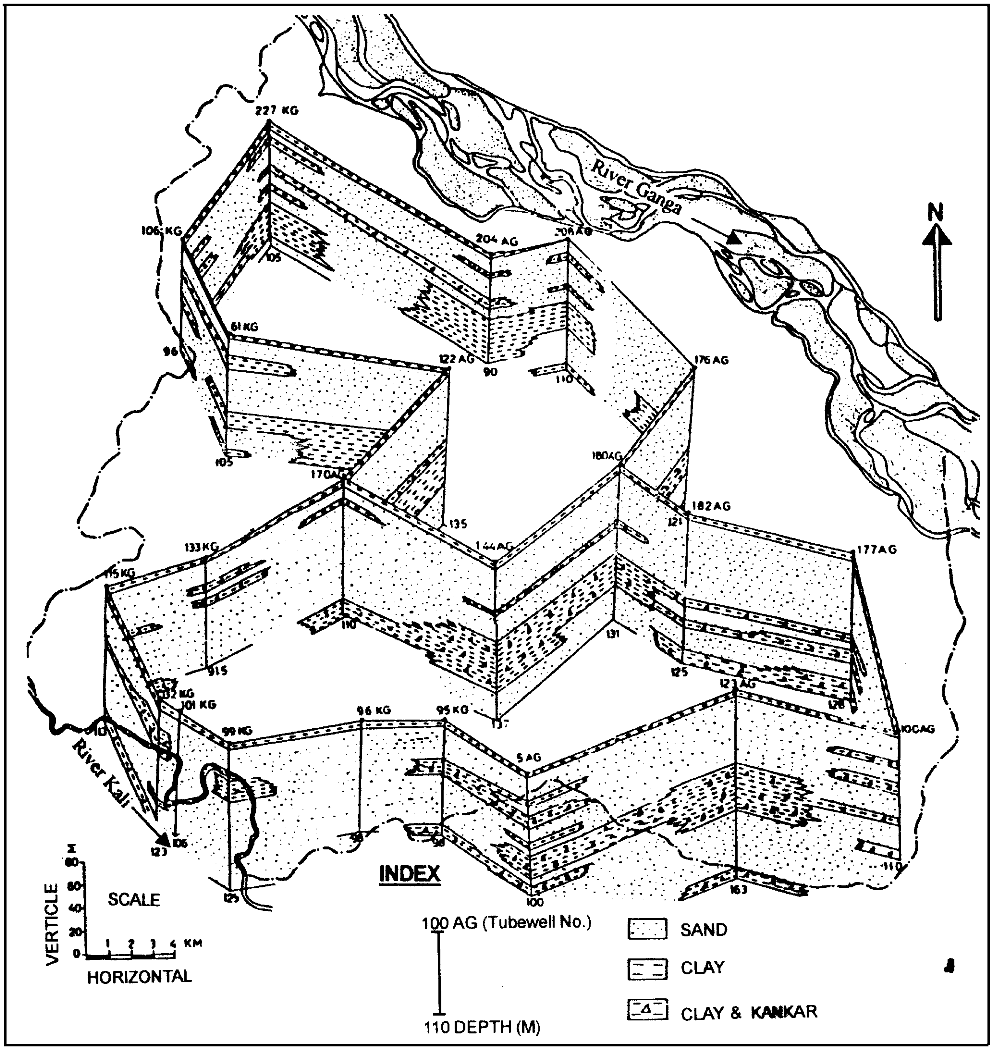

Fig. 2
Fence diagram showing aquifer disposition in the study area

Long-term water level behaviour

The maximum fall in water level (0.20 m/year) is recorded at Sidhpura, and at the Dariyaoganj hydrograph station a declining trend of water level is observed. The Ganjdundwara town well hydrograph shows a rising trend of water level that is attributed to its proximity to the lower Ganga canal (Fig. 4).

Aquifer parameters

In the central Ganga Plain aquifer zones can be characterized as shallow, intermediate and deep aquifers (Dubey and Husain 1991). In general, a shallow aquifer extends all over the basin with an average thickness of 50 m below the ground level. Groundwater occurs under unconfined conditions, whereas in the intermediate and the deep aquifers the groundwater occurs under semi-confined to confined conditions.
Table 1 shows the aquifer parameters of the central Ganga plain. However, the lone pumping test conducted in the area of study gives the values of T, S and K as 2178 m^2/day, 1.12×10^{-5} and 120 m/day, respectively. These values were determined by using the straight line method given by Cooper and Jacob (1946). This reveals that the aquifer parameters in the area are in accordance with the parameters of deep aquifers in the central Ganga Plain.

Hydrochemistry

In order to study the groundwater quality, physico-chemical analyses of groundwater samples were carried out. In all, 55 samples were collected for major ions (Table 2) and 24 samples for trace element (Table 3) studies from evenly spaced wells.

Methodology

Standard sampling techniques were used to collect the water samples. The samples for major ion and trace element studies were collected in cleaned 1-l polythene bottles. Samples for trace element studies were treated with 10 ml of 0.6 M HNO_3. The physico-chemical characteris-

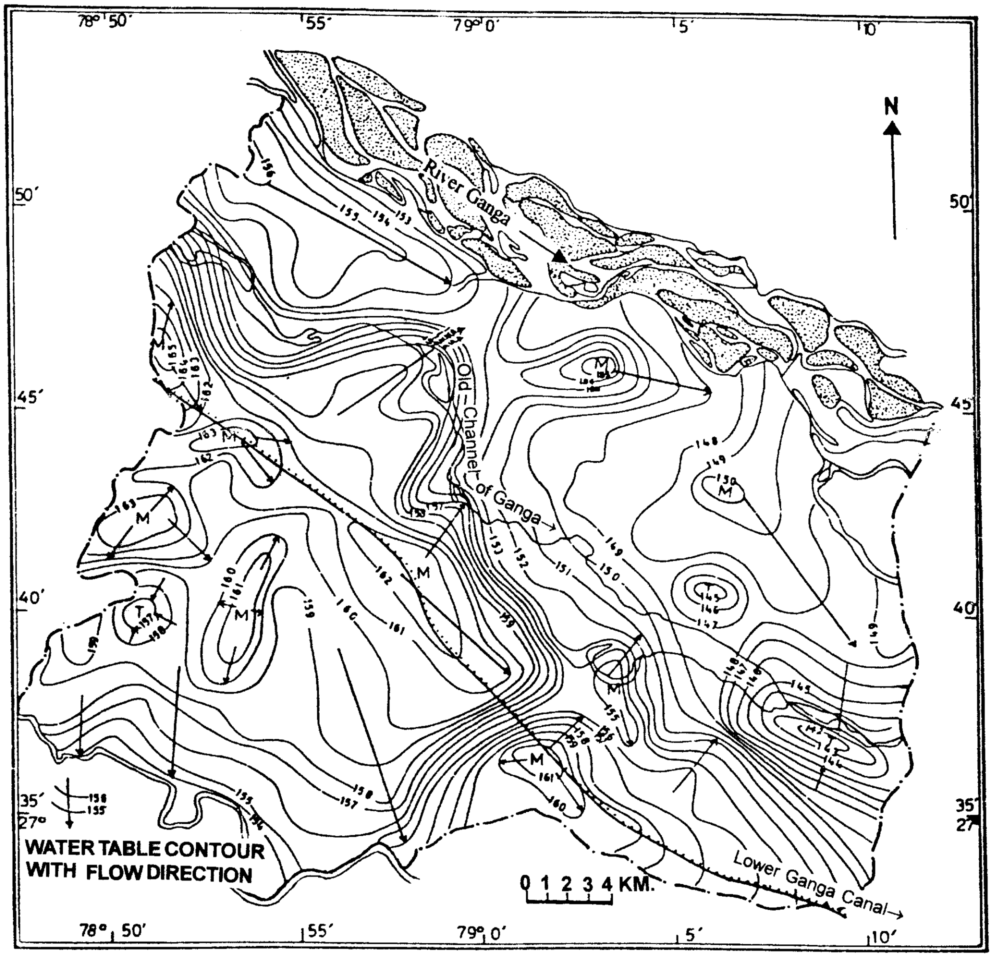

Fig. 3
Water table contour map, June 1997

Table 1
Aquifer parameters in central Ganga Basin (after Dubey and Husain 1991)

Type	Hydraulic conductivity (m/day)	Trans-missivity (m^2/day)	Storativity
Shallow	7.0–3.0	485–789	–
Intermediate	7.0–73.0	485–645	2.05×10^{-3}–6.7×10^{-4}
Deep aquifer	13.0–92.0	950–6660	1.32×10^{-4}–3.31×10^{-5}

tics of water samples were determined according to the standard methods of APHA (1992).

Major ions

The analytical results of major ions are given in Table 2. The value of pH and electrical conductivity ranged between 7.2 to 8.85 and between 200 to 1589 μmhos/cm at 25 °C. Values of carbonate, bicarbonate, chloride, sulphate, sodium, potassium, calcium and magnesium ranged between 0–32, 120–518, 8–224, 29–289, 20–200,1–98, 14–175, 6–67, 124–498 mg/l, respectively. The values of major ions are found well within the permissible limit of WHO (1984) and Indian Standard Institution (ISI 1983).

Groundwater facies

The concept of hydrochemical facies was developed by Back (1966) and Seaber (1962). The term hydrochemical facies is used to describe the bodies of groundwater in an aquifer that differ in their chemical composition. The facies are a function of lithology, solution kinetics and flow pattern of groundwater through the aquifer (Back 1966). The plot of chemical analyses on a trilinear diagram (Fig. 5) shows that a majority of the groundwater samples belong to the bicarbonate type and a few samples fall in the 'no-dominant' class in the anion facies. Among the cation facies, the majority of the water samples fall in the class of 'no-dominant' type and sodium or potassium type and a few samples belong to calcium type. Finally, the trilinear diagram shows that the groundwater in the study area is of alkali-bicarbonate type.

Drinking water standards

Table 4 shows the ISI (1983) and WHO (1984) specification of chemical constituents of water allowed for drinking purposes. Table 2 shows that the concentration of pH, electrical conductivity (EC), total dissolved solids (TDS),

Table 2
Results of partial chemical analysis of water samples collected from shallow aquifers of the study area (results in epm). *EC* Electrical conductivity; *SAR* sodium absorption ratio; *RC* residual carbonate

Site no.	Location	pH	EC	CO_3^-	HCO_3^-	Cl^-	Fl^-	SO_4^-	Total	Na^-	K^+	Ca^{2+}	Mg^{2+}	Total	Na%	SAR	RC
1	Nahin Mushiyar	8.30	653	0.59	6.370	1.282	0.056	2.04	10.340	1.560	2.192	4.052	3.758	11.560	32.44	0.79	0.85
2	Chanhka	8.51	508	0.59	3.850	0.641	0.038	4.15	09.670	1.433	0.153	4.240	3.870	09.696	15.02	0.73	3.27
3	Sri Nagla	8.22	512	0.99	3.840	0.240	0.053	4.08	08.800	0.870	0.280	2.240	3.370	06.761	13.43	0.52	1.18
4	Johari	7.61	671	0.59	4.750	1.723	0.011	3.63	10.940	2.471	1.388	2.440	3.471	09.770	39.50	1.43	0.33
5	Rustampur	8.44	679	0.83	6.490	1.589	0.038	2.36	11.200	3.242	2.506	2.440	2.406	10.550	54.48	2.09	2.41
6	Baraipur	8.61	654	0.73	4.330	1.682	0.038	2.78	09.410	2.828	0.584	3.840	3.088	10.340	32.97	1.52	2.01
7	Sikandrapur M	7.93	647	0.59	6.220	1.122	0.041	5.48	13.190	3.776	0.546	1.759	5.457	11.536	37.46	1.98	0.66
8	Majhola	8.32	549	0.33	3.730	0.561	0.009	2.34	07.010	1.582	0.000	1.929	3.061	06.571	24.07	1.00	0.89
9	Kodar	7.68	482	0.37	5.160	1.122	0.016	3.80	10.100	1.080	0.205	3.840	4.673	09.797	13.10	0.52	3.35
10	Sadikpur	8.05	450	0.00	5.500	0.240	0.034	4.32	10.480	2.470	0.499	1.459	3.753	08.180	36.30	1.53	0.68
11	Khizarpur	8.15	853	0.39	4.420	2.804	0.005	4.84	12.890	8.107	0.694	2.259	2.869	13.929	63.18	5.06	0.12
12	Haibatpur	8.83	865	0.83	6.470	4.967	0.008	4.41	16.180	4.547	1.863	5.171	4.560	16.140	39.72	2.06	2.93
13	Kanchanpur	8.12	671	0.33	5.730	3.125	0.023	4.13	13.420	4.666	0.000	3.200	3.830	11.700	39.88	2.48	0.88
14	Chandpur	8.10	654	0.42	5.160	2.003	0.008	4.14	11.700	2.887	0.380	3.219	4.715	11.200	29.17	1.45	2.33
15	N. Bhimsen	8.85	1589	0.39	8.120	5.608	0.036	4.28	18.780	8.700	0.584	3.092	4.571	16.947	54.78	4.46	1.25
16	Padarathpur	7.20	200	0.79	1.970	0.481	0.032	5.36	07.840	3.640	1.090	1.600	0.882	07.212	65.58	2.94	0.51
17	Sirsaul	7.96	672	0.00	5.900	2.163	0.049	4.30	13.070	3.598	1.351	3.209	4.424	12.583	39.34	1.84	1.07
18	Semra Morcha	8.14	750	0.66	6.470	2.884	0.021	5.17	14.550	4.073	1.169	2.480	5.538	13.260	39.53	2.03	1.54
19	Labher	8.80	1208	0.00	7.530	3.966	0.051	4.47	16.010	8.509	0.036	3.920	4.853	17.318	49.34	4.06	1.24
20	Sarori	7.86	625	0.00	6.720	2.484	0.032	3.39	13.190	2.590	0.492	5.249	4.643	12.974	22.75	1.16	2.60
21	Gopalpur	7.35	510	0.57	5.160	0.401	0.063	3.02	08.640	0.950	0.250	3.279	4.092	08.572	14.00	0.49	2.21
22	Nibia	7.69	556	0.43	5.490	0.801	0.009	3.84	10.570	2.056	0.435	3.360	5.135	10.986	22.67	1.00	2.58
23	Siwara Khas	8.21	846	0.00	5.730	3.365	0.007	5.65	14.750	3.140	1.899	2.880	3.530	11.433	43.93	1.74	0.68
24	Miyaon	7.92	525	0.39	3.110	0.801	0.015	2.43	6.740	0.988	0.803	1.600	1.444	4.836	37.05	0.80	0.27
25	Nakara	8.41	847	0.46	8.450	2.844	0.008	0.599	12.362	3.954	0.950	5.120	2.385	12.408	39.48	2.04	1.44
26	Bahoranpur	8.01	653	0.00	5.570	1.602	0.047	3.58	10.79	2.053	0.548	3.680	1.442	7.727	33.70	1.28	0.45
27	Ganjdundwara	8.72	140	0.76	6.523	2.924	0.008	3.147	13.361	3.598	2.776	1.600	3.310	11.345	56.19	2.29	2.31
28	Pitam Nagar	8.67	653	0.49	4.425	1.282	0.018	3.650	9.865	3.335	0.460	1.714	2.090	7.600	49.93	2.60	1.66
29	Songarhi	7.80	671	0.00	5.240	1.282	0.020	1.470	8.015	3.429	0. 281	3.120	0.540	7.370	50.34	2.54	1.59
30	Sultanpur	8.51	1783	0.39	3.900	6.330	0.000	6.378	16.608	3.286	0.435	8.762	1.336	13.819	26.92	1.46	5.80
31	Pahloi	8.40	575	0.46	4.491	1.122	0.326	2.940	9.045	2.494	0.767	2.690	1.674	7.625	42.77	1.68	0.59
32	Nidhauli	7.85	654	0.00	4.260	0.961	0.013	1.980	7.214	2.973	0.627	2.880	0.800	07.279	49.45	2.19	0.58
33	Ulai	8.40	572	0.53	4.440	1.843	0.00	2.245	9.058	3.204	0.690	1.689	1.957	7.540	51.65	2.37	1.33
34	Bahora	8.62	848	0.00	4.720	1.282	0.015	1.777	7.793	3.010	0.422	1.600	1.846	6.967	52.58	2.36	1.27
35	N. Jali	8.04	653	0.59	5.040	1.442	0.046	2.199	9.317	2.719	1.227	2.650	1.875	8.470	46.59	1.81	1.11
36	Shamspur	8.58	1075	0.46	4.820	3.205	0.038	3.050	11.573	3.176	0.358	2.710	3.480	9.733	36.30	1.81	0.91
37	N. Karan	7.91	627	0.00	4.240	2.083	0.034	3.221	9.579	3.661	0.460	2.109	2.699	8.329	46.16	2.36	0.57
38	Ganeshpur	8.50	574	0.00	5.080	1.362	0.00	1.889	8.332	3.915	0.499	1.739	1.866	8.019	55.04	2.91	1.46
39	Patiyali	8.20	669	0.69	5.70	1.282	0.023	2.740	1.436	2.516	0.486	1.809	3.241	8.052	37.23	1.58	1.31
40	Wajidpur	8.72	705	0.33	5.650	1.522	0.011	2.844	10.357	2.719	0.767	3.440	2.409	9.334	37.34	1.58	0.13
41	Kutubsarai	8.41	745	0.26	4.723	1.023	0.067	4.895	11.143	3.226	0.537	3.126	3.243	10.132	37.14	1.18	1.39
42	Mastipur	7.92	637	0.00	4.990	1.843	0.009	1.765	8.607	2.567	0.265	2.040	2.367	7.407	38.07	1.69	0.39
43	Karanpur	8.36	651	0.00	4.830	1.923	0.036	1.036	7.824	3.987	1.406	1.459	1.665	8.510	63.37	3.19	1.70
44	Alipur Dadar	8.17	546	0.69	4.110	0.641	0.021	1.807	7.269	2.363	0.345	1.705	1.981	6.394	42.36	1.74	1.11
45	Narethi	8.78	815	0.39	4.884	2.247	0.013	2.296	9.830	4.894	2.352	1.999	2.085	11.331	63.94	3.42	1.11
46	Daryavganj	8.64	676	0.53	2.980	1.682	0.000	6.012	11.204	3.040	0.533	2.258	2.228	8.058	44.33	2.03	1.13
47	Dharmpura	8.31	671	0.00	5.081	1.122	0.038	3.378	9.619	1.763	0.259	2.586	3.624	8.232	24.56	1.00	1.13
48	Mahmoodpur	7.66	819	0.00	3.900	2.083	0.020	1.718	7.721	4.698	0.562	1.398	1.446	8.104	63.91	3.93	1.06
49	Karanpur	8.67	490	0.33	4.390	0.721	0.26	3.622	8.089	2.635	0.358	2.359	1.343	6.696	44.70	1.93	1.02
50	Kiloni	8.16	513	0.39	4.580	0.961	0.018	2.570	8.520	2.820	1.023	1.458	1.947	7.288	52.73	2.15	1.53
51	Sikandarpur	8.70	510	0.63	4.475	1.442	0.008	1.011	7.767	2.617	0.946	1.114	2.068	6.745	52.83	2.08	1.92
52	Rampura	7.90	557	0.26	4.390	1.760	0.004	1.714	8.132	2.160	0.380	1.720	2.688	6.956	36.59	1.45	0.25
53	Sarawal	8.83	612	0.39	3.140	2.592	0.009	2.073	8.210	3.480	0.460	0.960	2.650	7.550	52.18	2.59	0.08
54	Sidhpura	8.59	580	0.33	4.500	1.282	2.023	2.604	8.739	4.690	0.358	0.944	2.220	8.220	61.50	3.73	1.67
55	Gudiyai	8.12	708	0.23	3.030	1.840	0.038	4.630	9.770	4.240	0.360	1.260	3.310	9.170	50.16	2.80	1.31

Table 3
Trace elements data of the water samples collected from shallow aquifer (mg/l)

Site no.	Location	Fe	Pb	Zn	Cu	Cd	Cr	Ni
1	Shahbazpur	0.813	0.20	0.20	0.152	0.006	0.000	0.062
2	Magthara	1.135	0.418	0.282	0.140	0.012	0.032	0.064
3	Chanhka	1.072	0.518	0.540	0.150	0.016	0.060	0.080
4	Aurangabad	1.432	0.486	0.118	0.164	0.014	0.064	0.080
5	Sirsaul	0.632	0.298	0.120	0.140	0.010	0.000	0.064
6	Daryavganj	0.741	0.360	0.080	0.144	0.010	0.028	0.056
7	Shamspur	0.932	0.238	0.078	0.106	0.008	0.000	0.048
8	Nardaulic	0.303	0.394	0.118	0.276	0.012	0.048	0.064
9	Miaon	0.447	0.482	0.154	0.096	0.016	0.000	0.042
10	Bhikampur	0.508	0.190	0.046	0.146	0.006	0.000	0.042
11	Burhi Ganga	0.640	0.024	0.186	0.012	0.000	0.000	0.042
12	Johari	0.348	0.146	0.000	0.056	0.004	0.000	0.038
13	Ganjdundwara	0.903	0.338	0.426	0.064	0.008	0.40	0.040
14	Patiyali	1.053	0.366	0.084	0.164	0.010	0.057	0.057
15	Padaratpur	0.109	0.354	0.082	0.138	0.010	0.032	0.048
16	Badiaila	0.857	0.516	0.454	0.170	0.018	0.056	0.070
17	Nohin Mushiyar	0.251	0.508	0.118	0.272	0.012	0.042	0.070
18	Majhola	0.786	0.390	0.082	0.196	0.010	0.042	0.070
19	Rustampur	0.601	0.436	0.124	0.200	0.012	0.028	0.056
20	Sidhpura	0.973	0.340	0.034	0.556	0.128	0.016	0.049
21	Mohanpur	0.349	0.290	0.116	0.132	0.010	0.016	0.049
22	Pilkhuni	0.735	0.206	0.000	0.116	0.006	0.014	0.028
23	Ganga	0.832	0.438	0.148	0.100	0.014	0.000	0.016
24	Sanodhi	0.106	0.342	0.000	0.136	0.008	0.018	0.000

Table 4
Drinking water specification given by WHO (1984) and ISI (1983)

Constituents	Indian Standard Institution (1983)		World Health Organisation (1984)	
	Highest desired limit (mg/l)	Maximum permissible limit (mg/l)	Highest desired limit (mg/l)	Maximum permissible limit (mg/l)
pH	6.5–8.5	6.5–9.5	7–8.5	6.5–9.2
Total Hardness	300	600	100	500
Calcium	75	200	75	200
Magnesium	30	100	–	150
Chloride	250	1000	200	600
Fluoride	–	1.5	–	1.5
Copper	0.05	1.5	0.05	1.0
Iron	0.3	1.0	0.1	1
Lead	0.1	No relaxation	–	0.1
Zinc	5	15	–	15
Cadmium	0.01	No relaxation	–	0.01
Chromium	–	–	0.5	No relaxation

Ca, Mg, Cl, Na and K are within the permissible limits of WHO (1984, 1993). However, the trace elements Fe, Pb, Cd, Cr^{6+} and Ni have been found at higher levels than their permissible limits. These elements are probably most harmful because of their biologically non-biodegradable nature and their potential to cause adverse effect in human beings at certain levels of exposure and sorption.
The most significant and natural sources of heavy metals is weathering of rocks, from which the released metals find their way into the water bodies. Domestic, industrial and agricultural activities are also responsible for the higher concentration of heavy metals in the groundwater.

Iron

Iron is essential in human nutrition, but it becomes highly toxic when administered parentally (Fairbanks and others 1971). In a majority of the samples collected from the shallow aquifers the concentration of Fe exceeds the permissible limits of WHO (1984). Iron in the normal

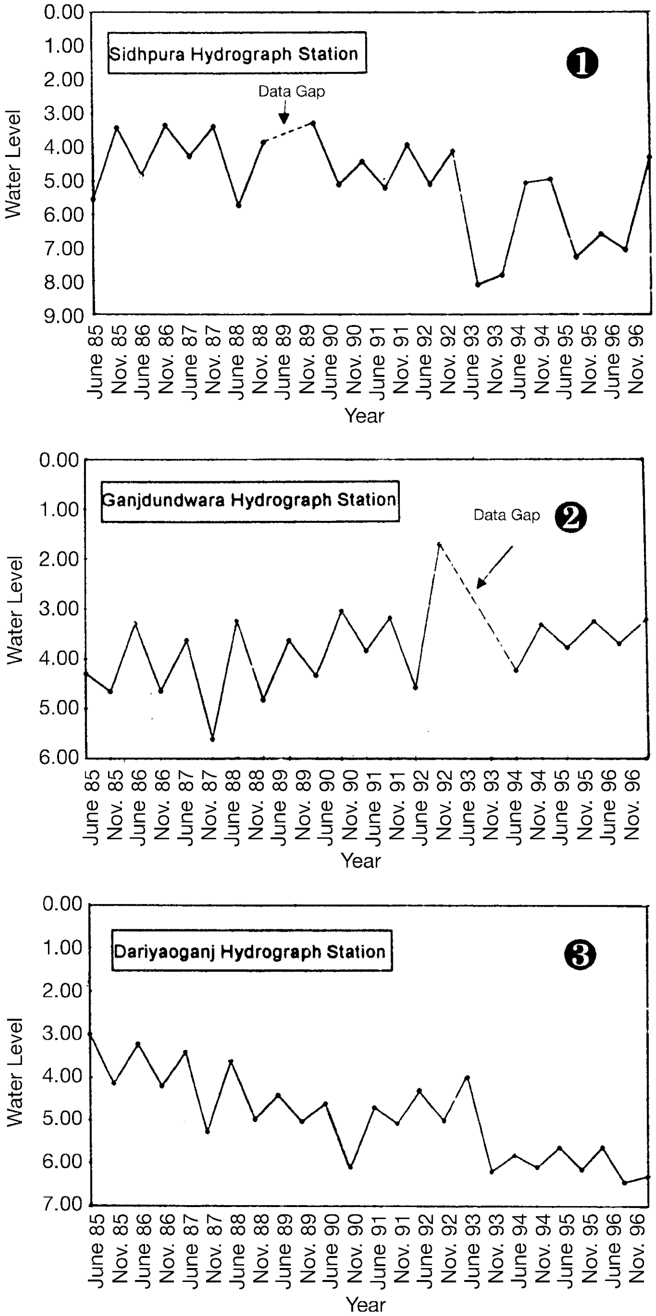

Fig. 4
Selected well hydrographs

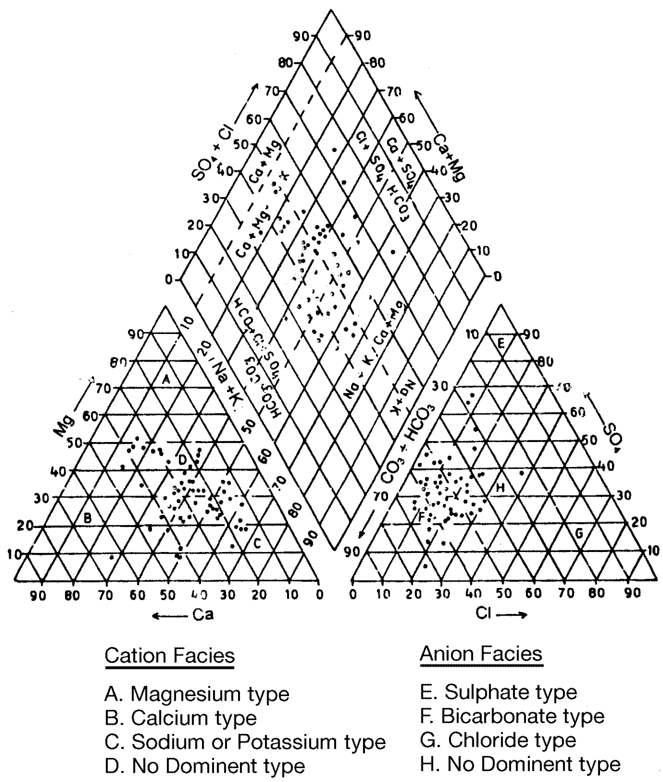

Fig. 5
Trilinear plots for groundwater samples of the study area

groundwater is in the form of inorganic complexes derived from laterite and other types of soil (Mohan and others 2000).

Lead

The concentration of lead in natural water increases mainly through anthropogenic activities (Goel 1997). Lead is extensively used in some pesticides such as lead arsenate. Pregnant women exposed to lead were found to have high rates of still births and miscarriages (WHO 1973). Lead has caused mental retardation among children. Hypertension caused by Pb exposure has also been reported (Beevers and others 1976). Lead poisoning is accompanied by symptoms of intestinal cramps, peripheral nerve paralysis, anaemia and fatigue.
The Pb concentration in the water samples of the study area varies between 0.518–0.024 mg/l. A perusal of the Table 3 shows that the concentration of lead in the shallow aquifers is higher than the permissible limit.

Cadmium

Cadmium is highly toxic to man and animals (Friberg and others 1974). Of all the highly toxic metals, cadmium exceeds the permissible limits in 10 samples out of 24 analysed from the shallow aquifers. The cadmium concentration ranges between 0.00 to 0.128 mg/l. One of the major sources of Cd in soil is phosphatic fertilizers (Alan 1996). The pathways and migration of Cd could because of industries dumping untreated effluents into the natural hydrological system.

Chromium

Hexavalent chromium (Cr^{6+}) is highly toxic and in higher concentrations is found to be carcinogenic (Swayer and MacCarty 1978). The concentration of Cr^{6+} ranges between 0 and 0.064. Out of 24 samples analysed, 7 showed chromium concentrations below the detection limits, 4 samples were found to be above the recommended limit, and concentrations of chromium in the remainder of the samples were within the permissible lim-

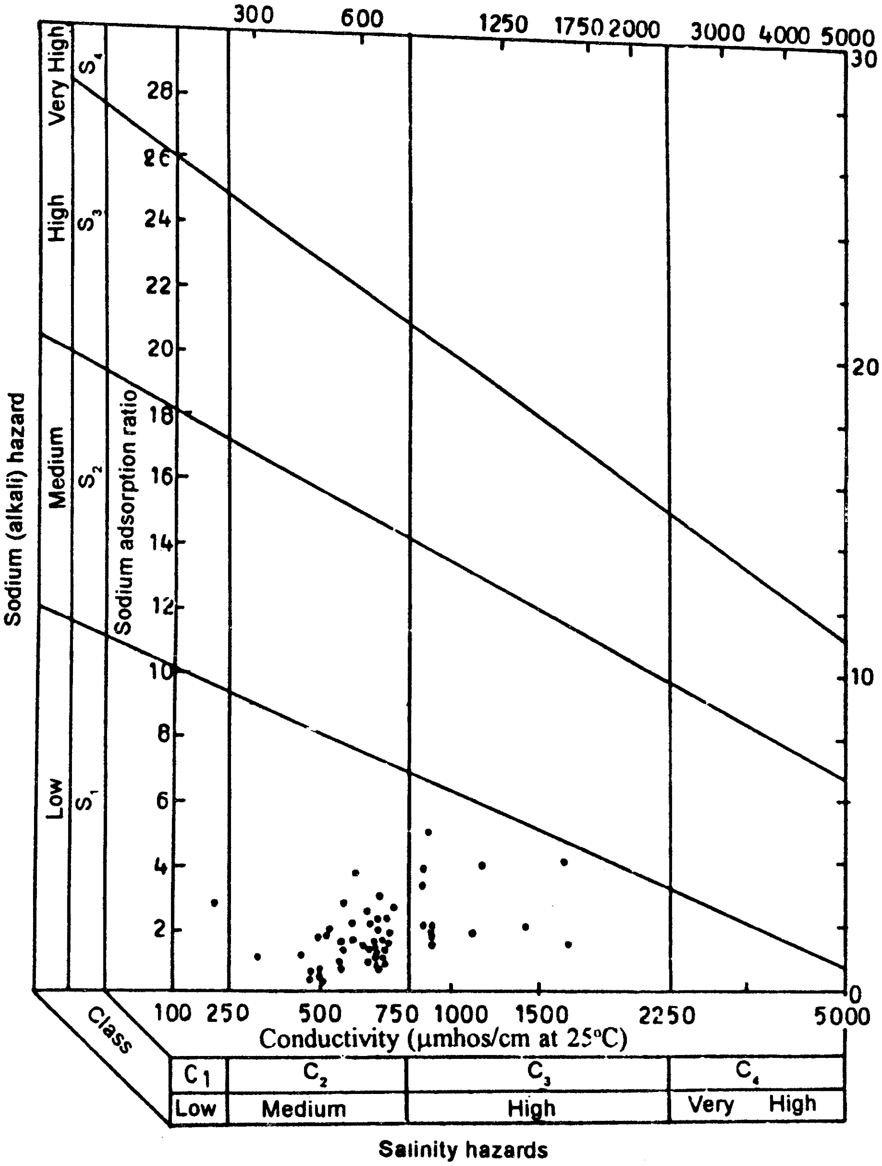

Fig. 6
Sodium adsorption ratio (SAR) and salinity hazard plot

its of ISI (1983). This shows that, except in a few samples, the concentrations of chromium were generally within recommended limits.

Nickel

The concentration of nickel in drinking water is normally less than 0.02 mg/l (WHO 1993). High concentrations of nickel as both soluble and sparingly soluble compounds, are now considered to be a human carcinogen when related to pulmonary exposure (WHO 1993). The concentration of nickel ranges from below detection level to as high as 0.08 mg/l. Generally, higher concentration of nickel are observed in the study area.

Copper and zinc

Although average concentration of Cu in the groundwater range from 0.064 to 0.554 mg/l, that of Zn varies from below the detection level to 0.54 mg/l. These values are within the permissible limits of ISI (1983) and WHO (1984). Because both elements are essential for plant and animal metabolism, their limited occurrence in groundwater is useful from the point of view of water quality. Thus, it is evident from the groundwater chemistry that if the concentration of heavy metals exceeds the permissible levels recommended by ISI (1983) and WHO (1984), they may entail various health hazards.

Irrigation water standards

Parameters such as sodium absorption ratio (SAR), percent sodium (%Na) and residual sodium carbonate (RSC) were estimated to assess the suitability of water for irrigation purposes. The total dissolved content measured in terms of specific electrical conductance, gives the salinity hazard of irrigation water. The salt present in the water, besides affecting the growth of plants directly also affects soil structure permeability and aeration, which indirectly

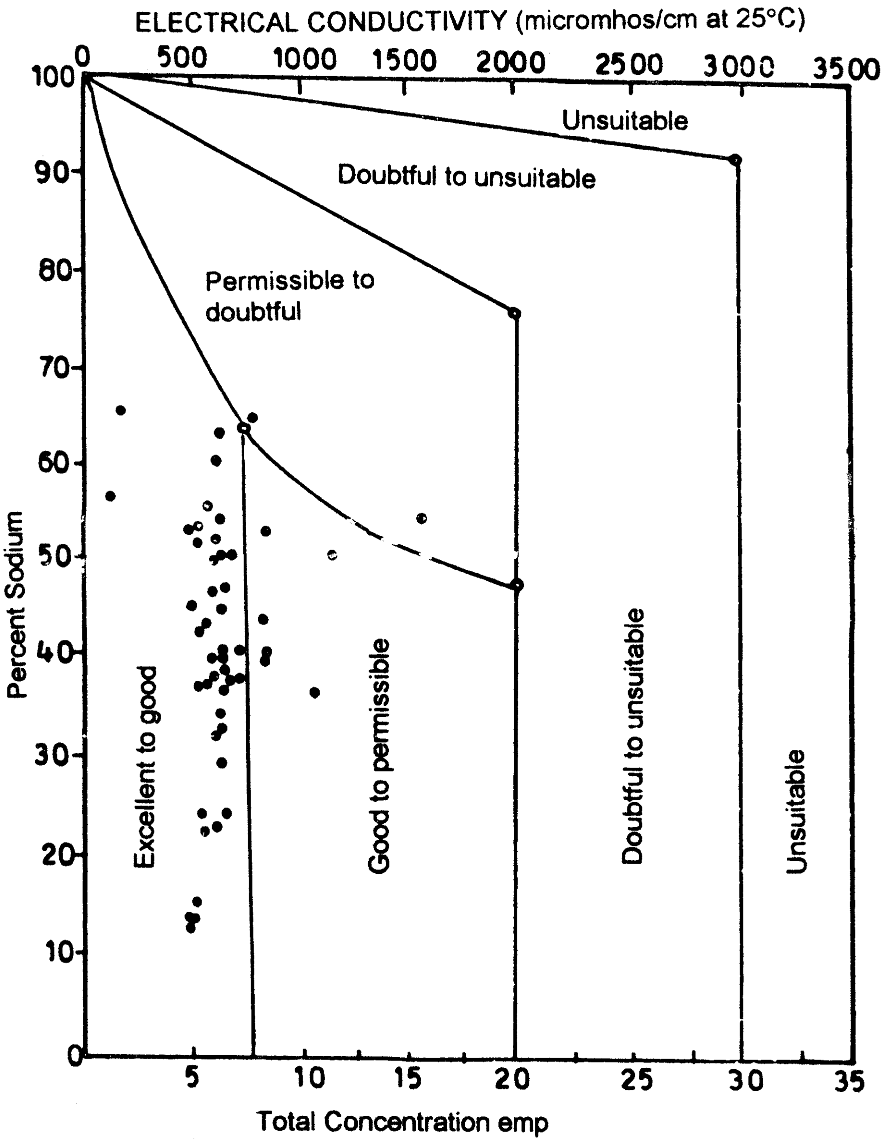

Fig. 7
Sodium percentage and EC value plot

affects plant growth (Mohan and others 2000). A high value of sodium may also damage sensitive crops because of sodium phytotoxicity (Goel 1997). Based on SAR and EC, USSL (1954) has given a graphic classification which is given in Table 5. Here, the SAR is expressed as

$$SAR = \frac{Na}{\sqrt{Ca + Mg/2}} \quad (1)$$

The chemical quality plot in Fig. 6 shows that, except for the lone water sample collected from Padarathpur village, which falls under C_1–S_1 class, the majority of samples are confined to the C_2–S_1 and C_3–S_1 class.

RSC has been calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purpose (Eaton 1950) and has been determined by the formula

$$RSC = (CO_3^- + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \quad (2)$$

Table 5
Water quality classification (after USSL 1954)

Quality of water	EC (μmhos/cm)	SAR (epm)
Excellent	250	up to 10
Good	250–750	10–18
Fair	750–2250	18–26
Poor	72250	>26

The concentration of cations and anions are expressed in epm (Table 6).

The value of RSC has been calculated and compared with the classification in Table 6, which reveals that most of the values are within the limit of suitability except the few values that are found above the limits.

Table 6
Water quality classification on the basis of residual sodium carbonate (RSC)

Quality	RSC
Excellent	≪1.25
Good	<1.25
Fair	1.25–2.5
Poor	>2.5

A perusal of Wilcox's (1955) diagram (Fig. 7) shows that 20% of the samples fall within the permissible quality, whereas the remainder fall under excellent to good quality, with a few exceptions that lie in the permissible to doubtful category. The above discussions show that the groundwater quality of the study area is suitable for irrigation.

Conclusion

The data collected from open wells, and shallow and deep tube wells in Kali-Ganga sub-basin were analysed to gain an insight into the hydrogeology and water quality of the basin. The study reveals that, in general, there occur two to three-tier aquifer systems, which finally merge with each other and behave as a single-bodied aquifer system. The aquifers are unconfined to confined in nature. The transmissivity storage coefficient and hydraulic conductivity is computed as 2178 m^2/day, 1.12×10^{-5} and 120 m/day, respectively.
The groundwater of the basin is alkali-bicarbonate type and is suitable for domestic and irrigation use. In certain areas, higher concentrations of heavy toxic trace metals are observed, which may entail various health hazards. It is recommended that the use of such wells be avoided.

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