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ORIGINAL ARTICLE

Impact of land-use on groundwater quality: GIS-based study from an alluvial aquifer in the western Ganges basin

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Abstract In this study, groundwater quality of an alluvial aquifer in the western Ganges basin is assessed using a GIS-based groundwater quality index (GQI) concept that uses groundwater quality data from field survey and laboratory analysis. Groundwater samples were collected from 42 wells during pre-monsoon and post-monsoon periods of 2012 and analysed for pH, EC, TDS, Anions (Cl, SO_4, NO_3), and Cations (Ca, Mg, Na). To generate the index, several parameters were selected based on WHO recommendations. The spatially variable grids of each parameter were modified by normalizing with the WHO standards and finally integrated into a GQI grid. The mean GQI values for both the season suggest good groundwater quality. However, spatial variations exist and are represented by GQI map of both seasons. This spatial variability was compared with the existing land-use, prepared using high-resolution satellite imagery available in Google earth. The GQI grids were compared to the land-use map using an innovative GIS-based method. Results indicate that the spatial variability of groundwater quality in the region is not fully controlled by the land-use pattern. This probably reflects the diffuse nature of land-use classes, especially settlements and plantations.

Keywords Groundwater quality index · Geographic information system · Land-use · Kali watershed

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Introduction

Groundwater resources are dynamic in nature and are influenced by transitions in irrigation, industrialization, and urbanisation. Hence, monitoring and conserving this important resource is essential (Selvam et al. 2013). Groundwater quality in an area is largely determined by the natural processes such as lithology, groundwater velocity, and quality of recharge waters, rock–water interaction, and interaction with other types of aquifers (Helena et al. 2000; Khan et al. 2015). Water quality if not adequately managed can serve as a serious limiting factor to the future economic development and to the public health and environment which will result in enormous long-term costs to society (Pius et al. 2012). Water quality assessment involves evaluation of the physical, chemical, and biological nature of water in relation to natural quality, human effects, and intended uses (UNESCO/WHO/UNEP 1996). Such hydrochemical analysis helps in identifying potential zones of contamination and suitability of groundwater for drinking, irrigation, and other purposes.

The use of GIS technology has greatly simplified the assessment of natural resources and environmental concerns, including groundwater (Khan et al. 2011). GIS can be a very strong tool for generating solutions for water quality assessment, problems of water resources, and determination of water availability and management of water resources on a local or regional scale (Ketata et al. 2011; Shabbir and Ahmad 2015). Coupled with GIS, the groundwater quality assessment helps in demarcating the areas affected by groundwater pollution. GIS can be used to obtain reliable information about the existing groundwater quality scenario that may be essential for the groundwater planning and management strategies (Adhikary et al. 2012).

Water quality index (WQI) can be defined as a parameter which reflects the overall water quality at a particular location, i.e., cumulative effect of different water quality parameters (Singh et al. 2011). GIS-based groundwater quality index assessment has been carried out by many researchers, e.g., Noori et al. (2014), Tiwari et al. (2014), Selvam et al. (2013), Magesh and Chandrasekar (2013), Ishaku et al. (2012), Magesh et al. (2012), Yue et al. (2010), Reza and Singh (2010), etc. Babiker and Mohamed (2014) carried out GIS-based groundwater quality index assessment in Omdurman area of Central Sudan. Kumar et al. (2014) evaluated the groundwater quality using water quality index and fuzzy logic in the urban coastal aquifer of south Chennai. Singh et al. (2011) studied the effect of land-use change on groundwater quality using remote sensing and GIS-based approach in lower Shiwaliks of Punjab. Ketata et al. (2011) used GIS and WQI to assess groundwater quality in El Khairat deep aquifer, Central east Tunisia and revealed that the groundwater from south east of the aquifer is unsuitable for drinking purpose. Ramakrishnaia et al. (2009) used water quality index to assess the groundwater quality of Tumkur taluk, Karnataka, and the analysis reveals that the groundwater of the area needs some degree of treatment before consumption.

This study aims at evaluating the significance and applicability of a GQI generated using GIS approach for the assessment of groundwater quality in parts of an alluvial aquifer in Ganges Plains. The study also aims to analyse the influence of land-use activities in the study area on the underlying groundwater quality. The study is particularly innovative considering the methodology used to extract the water quality status for each land-use class using GIS routines.

Study area

The study area (Fig. 1) lies in the western Ganges plains. It is a part of the Kali watershed in Aligarh and Bulandshahr district, with a spatial coverage of 665 km^2 extending from 28° N to 28°15′ N and 77° E to 77°15′ E. This falls in the Survey of India toposheet no 53 L/4 on a scale of 1:50,000. The area experiences tropical monsoon type of climate with hot summers and mild winters, and a distinct rainy season known as the monsoon season. The monsoon rains are received from July to September. Average annual rainfall in the area is 856 mm. The topography is relatively flat with elevation ranging from 176 m to 208 m above mean sea level. The general slope direction is from NW to SE. River Kali, a small tributary of River Ganges, flows through the area from NW to SE. River Kali is a perennial river fed by baseflow all along its length within the study area and beyond. Another small stream Choiyya Nadi, which is a tributary of the River Kali, flows along the NE corner of the study area from NW towards SE direction. This is a seasonal river that flows during the monsoons. The area is also traversed by the Upper Ganga Canal

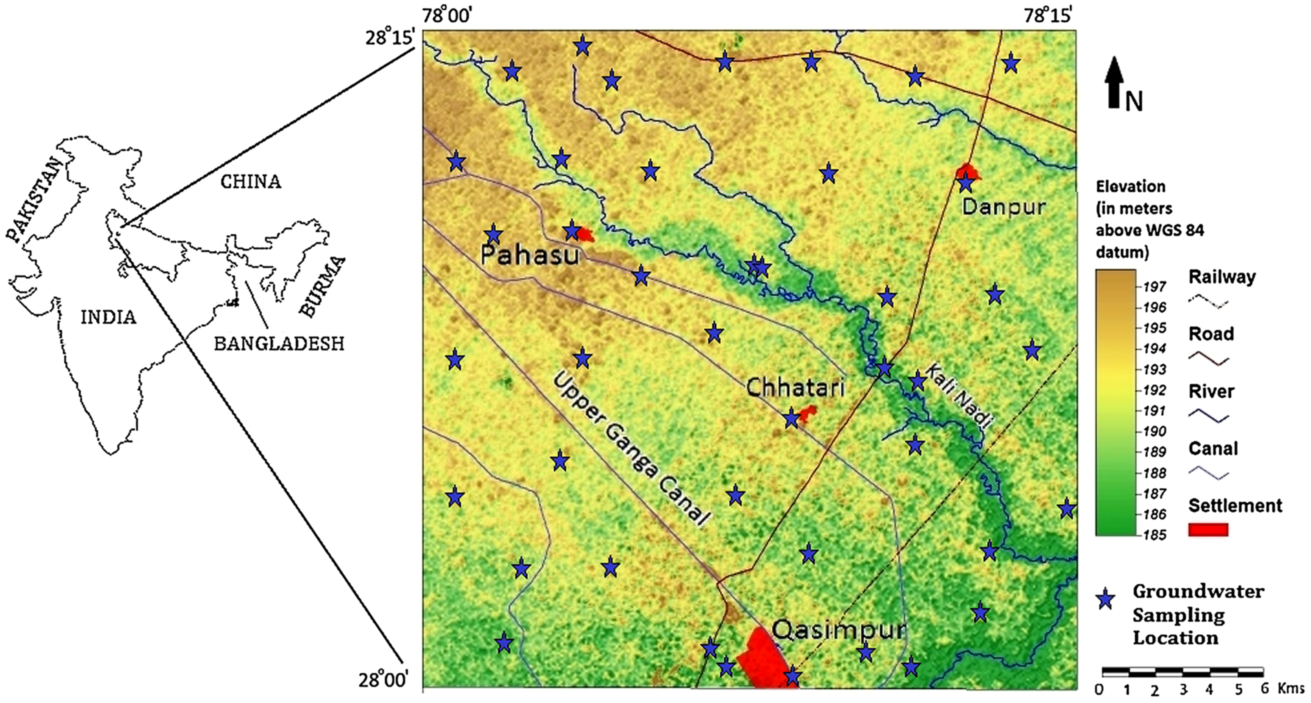

Fig. 1 Location of the study area

flowing towards the south east. Upper Ganga Canal branches into several distributaries like Palra, Pahasu, Kol, etc., and forms a fairly dense network of canals in the study area. The region is dominantly agricultural with some industrial activity.

Geology and hydrogeology

Quaternary sediments comprising of various grades of sand, calcareous concretions, and clay overlie the area. The alluvial sediments of the area overlie the Vindhyan rocks in an unconformable way. The thickness of the alluvial deposit varies from 287 to 380 metres in Aligarh district (Kumar and Bhargawa 2002) and from 400 to 600 m in Bulandshahr district (Bhartariya 2009). The surface alluvium in the area consists of clay, silt, and fine sand. There is alternation of granular or sandy zone and clay beds associated with calcareous concretions known as 'Kankar'. The extensive granular zones which comprise medium-to-fine grey sand occasionally mixed with coarse sand and gravel is sub-divided into two or three sub groups by intervening clay beds. Figure 2 shows hydrogeological section of the aquifer along four section lines. The sandy horizons form the aquifer in the area. Groundwater occurs under unconfined conditions and depth to water varies between 2.23 and 12.4 m bgl. The hydraulic conductivity of the area varies from 8.13 to 51.25 m/day. Figure 3 shows the elevation of water table and the general groundwater flow direction which is from North–West to South–East.

Methodology

Groundwater sampling and GIS database

The study area, a segment of Kali watershed is, contained in the Survey of India Toposheet number 53L/4 at a scale of

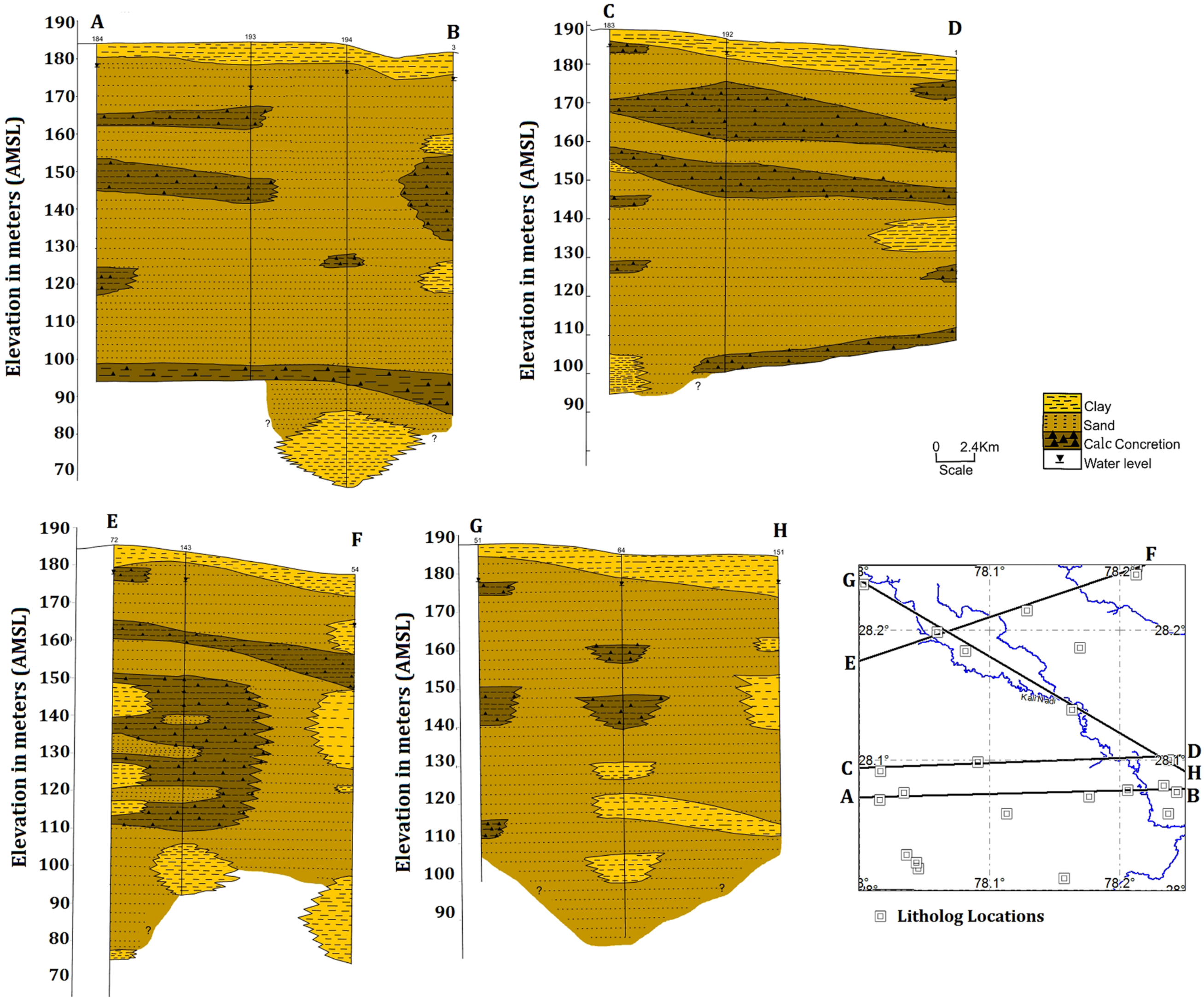

Fig. 2 Hydrogeological section of the aquifer (based on litholog data)

1:50,000. The toposheet was used as a base for preparing the spatial GIS database for the study area. Open source GIS package SAGA 4.1.0 was employed for all the GIS tasks. The toposheet was scanned and georeferenced. Onscreen digitization was undertaken for the generation of spatial database. Attribute data collected from the field work were linked to the topological data generated by digitization. Water samples were collected from 42 groundwater bore-wells (Fig. 1) uniformly spread in the study area. Sampling was conducted during pre- and post-monsoon season of 2012. The geographical coordinates of the wells were captured using a handheld Garmin GPS receiver. Ground surface elevation at well location was obtained from SRTM 30 m DEM, since elevation information in the toposheet was limited due to the relative flatness of the terrain. Depth to water table was recorded at each well using Water Level Indicator. Well locations were downloaded from GPS and converted to a point shapefile in SAGA GIS. The hydrochemical data obtained from laboratory analysis of the water samples were linked to the spatial database of the well locations. These shape files were overlaid on the land-use map to assess the position of the sampling locations with respect to potential sources of groundwater contamination. Later, these point shapefiles were used for the preparation of concentration maps using Kriging Interpolation. Concentration maps are representations of the spatial variability of a particular water quality parameter and are prepared by spatial interpolation of the originally scattered concentration measurements (point data).

Groundwater quality analysis

Groundwater samples were collected from 42 bore-wells in the study area (Fig. 1) during May and November 2012 for physico-chemical analysis. The sampling wells were carefully selected to spread the sampling points over the study area evenly. The sampling location of each bore-well was recorded using a handheld Garmin GPS receiver. Prior to sample collection, the wells were pumped for about 3–5 min to remove the stagnant water in the wells. Polyethylene bottles of 1 litre capacity were used to store sampled water. All sample bottles were stored in ice-packed coolers immediately after collection. The temperature of all stored samples was maintained at 0–4 °C until immediately before analysis. The samples were analysed as per the standard methods of APHA (1992) in the geochemical laboratory of the Department of Geology, Aligarh Muslim University. EC, pH, and TDS were measured by a portable digital water analysis kit. Ca^{2+} was analysed by EDTA titrimetric method. Mg^{2+} was determined by the difference of hardness and calcium. Cl^- was determined by titration. SO_4^- values were determined by gravimetric method, Na and K by flame emission photometry, and NO_3^- by colorimetric method.

Groundwater quality index generation

GQI proposed by Babiker et al. (2007) was used for water quality assessment. To generate the index, seven parameters listed in World Health Organization guidelines (WHO 2004) for drinking water quality were selected from the main data set. These are Cl^-, Na^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, and TDS and NO_3^-. After selecting the parameters, the concentration of each parameter in all the wells was interpolated using the Ordinary Kriging module in SAGA. Thus, seven concentration maps, one for each parameter, were obtained. The concentration maps were standardised (transforming the parameters to a common scale) for easy

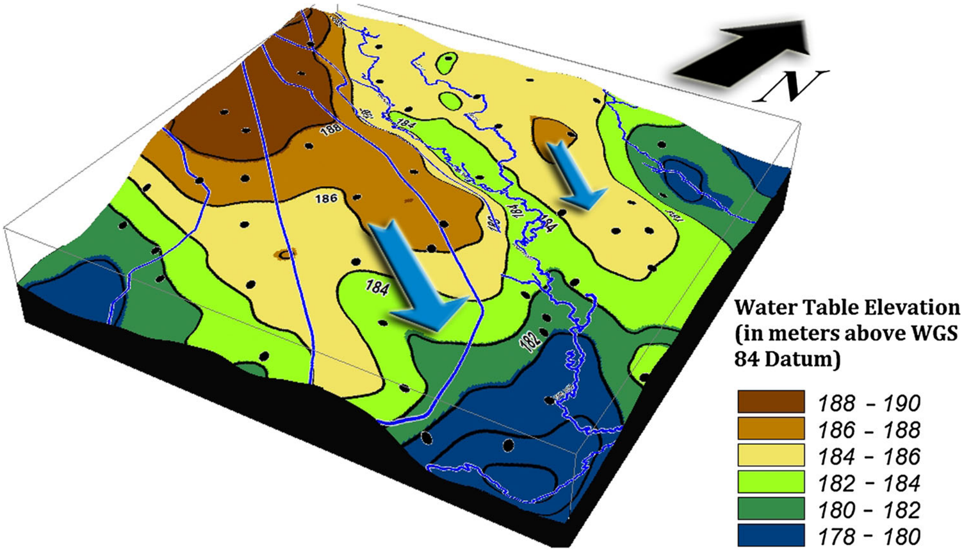

Fig. 3 Water table elevation map of the study area showing the regional groundwater flow direction in *bold blue arrows* (relief is vertically exaggerated to highlight groundwater flow)

integration in GIS. For standardisation, each grid cell value in the primary concentration map was transformed using a normalized difference index:

$$C = (X' - X)/(X' + X) \tag{1}$$

where X' is the observed concentration and X is the WHO maximum desirable concentration

The contamination index values in the resultant normalized difference map range between -1 and 1. The normalized difference map was further transformed into a rank map (sub-index), to remove the negative values, using the following polynomial function:

$$r = \left(0.5 * C^2\right) + (4.5 * C) + 5 \tag{2}$$

where C stands for the contamination index value for each grid cell in the normalized difference map and r stands for the corresponding rank value. The rank map rates the contamination index values from 1 to 10. Rank 1 indicates minimum impact on groundwater quality, while the rank 10 indicates maximum impact. Assignment of weights to the rank maps of each parameter was achieved by the spatial average rank value of each parameter's rank map. The weights assigned to each parameter indicate its relative importance to groundwater quality. Parameters with high mean rate inflict higher impact over groundwater quality and are assumed to be more important in evaluating the overall groundwater quality (Babiker et al. 2007). For the six parameters categorized as chemically derived contaminants (Cl^-, Na^+, Ca^{2+}, Mg^{2+}, $SO_4{}^{2-}$, and TDS), the average rank value was used as weight, while for $NO_3{}^-$, a value two (2) was added to the mean rank value due to potential health risk posed by $NO_3{}^-$:

$$w = \text{mean } r \quad \left(\text{for } Cl^-, Na^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, \text{ and TDS}\right)$$

$$w = (\text{mean } r) + 2 \quad \left(\text{for } NO_3^-\right)$$

where w is weight and r is rank value.

Finally, the seven sub-indices (rank maps) were aggregated to yield an index map using the "grid calculus" module in SAGA GIS. Here, a weighted sum index has been used. This GQI represents a weighted averaged linear combination of factors as shown below:

$$\text{GQI} = 100 - ((r_1 w_1 + r_2 w_2 + \cdots + r_n w_n)/N), \tag{3}$$

where 'r' stands for the rate of the rank map (1–10), 'w' stands for the relative weight of the parameter, and 'N' is the total number of parameters used in the suitability analyses.

Dividing by the total number of parameters involved in the computation of the GQI averages the data and limits the index values between 1 and 100. In this way, the impact of individual parameters is greatly reduced and the index computation is never limited to a certain number of chemical parameters. The "100" in the first part of the formula directly projected the GQI value, such that high index values close to 100 reflect high water quality and index values far below100 (close to 1) indicate low water quality.

Land-use mapping The very high-resolution satellite imagery available in Google earth offers a unique and readily accessible source for the preparation of land-use and land cover maps of a region. Land-use map for the study area was prepared using Google earth imagery of year 2012. Google earth also offers tools for digitisation of points, lines, and polygons. Polygons were generated for plantations, wasteland, ponds, and settlements; lines were digitised for rivers, canals, railway lines, and roads. Brick kilns were represented as points. The polygons, lines, and points were separately saved as.kml files which were imported into SAGA GIS. The different polygons were intersected with the outline vector file of the study area and the area excluding the digitised polygons was assigned as cropland. Final land-use map was employed for the impact assessment of land-use on groundwater quality.

Results and discussion

The groundwater quality data for the seven selected parameters for the 42 bore-wells are given in Table 1. Table 2 represents the basic statistics for the seven groundwater quality parameters selected for the preparation of GQI maps. It is observed that the mean values of all the parameters for both the seasons do not exceed the WHO threshold values. However, the maximum concentration of TDS, Na^+, SO_4, and NO_3 exceeds the WHO threshold concentration in few wells during pre-monsoon as well as post-monsoon season.

Figures 4 and 5 show the groundwater quality index maps for pre-monsoon and post-monsoon season 2012, respectively. Dark green shade represents high GQI and good groundwater quality. The GQI values in pre-monsoon season range from 86.66 to 93.69, while the spatial mean is 91.24. The pre-monsoon 2012 GQI map shows low values in the north and north-eastern part corresponding to relatively poor groundwater quality. The southern part shows high GQI and thus relatively good quality. Post-monsoon GQI values range from 88.18 to 93.45, while the spatial mean is 90.85. The post-monsoon GQI map shows a band of low GQI (relatively poor groundwater quality) extending along the upper segment of Kali river.

While the spatial means of GQI for both the seasons reveals relatively good groundwater quality (higher values of GQI), the spatial variability in the GQI values may be linked to land-use activities. The spatial mean of GQI is

Table 1 Groundwater quality data (parameters selected for GQI mapping) in mg/l

S. no.	Location	TDS	Ca	Mg	Na	SO_4	Cl	NO_3
May 2012								
1	Danpur	1340	16.03	77.97	290.00	392.32	173.24	65.12
2	Kheriya Bakhsh	437	19.24	24.36	130.00	144.03	22.72	17.28
3	Daulatpur Khurd	653	17.64	38.01	175.00	52.67	96.56	28.35
4	Maurajpur	477	12.83	45.81	140.00	310.84	17.04	4.87
5	Ahmadgarh	1037	12.83	45.81	220.00	336.60	124.96	18.16
6	Bhaiyanpur	347	20.02	38.11	80.00	290.27	11.36	22.15
7	Surjaoli	736	16.03	30.21	250.00	257.85	56.80	7.97
8	Lalner	298	29.24	19.59	70.00	276.53	8.52	21.26
9	Jagdishpur	1162	11.81	60.42	275.00	401.62	159.04	5.76
10	Utrawali	706	8.02	39.96	210.00	381.05	59.64	23.48
11	Pahasu	414	32.06	26.31	65.00	255.86	22.72	34.55
12	Banail	856	11.22	30.68	200.00	192.58	99.40	40.76
13	Aterna	277	28.86	31.19	18.00	65.02	11.36	17.72
14	Bedrampur	564	11.22	30.68	105.00	67.49	18.52	15.06
15	Kamauna	418	16.03	29.24	70.00	101.23	19.88	10.19
16	Kali	678	8.02	46.78	160.00	180.16	31.24	16.83
17	Chaundhera	806	16.41	36.06	260.00	265.83	34.08	42.09
18	Akbarpur	1138	8.02	38.98	210.00	43.62	159.04	31.01
19	Salabad	543	17.64	20.47	190.00	219.34	38.40	27.91
20	Bigupur 1	648	8.02	38.98	165.00	117.69	59.64	20.38
21	Bigupur 2	695	8.02	44.83	105.00	120.16	42.60	19.49
22	Darora	260	48.10	4.87	40.00	88.06	17.04	16.83
23	Chhatari	337	12.83	40.93	71.00	195.62	11.36	14.62
24	Pindrawal	510	11.22	35.09	80.00	277.06	22.72	6.20
25	Bahlolpur	317	16.03	36.06	43.00	178.85	8.52	23.92
26	Teori	679	8.02	65.30	70.00	209.03	56.80	9.30
27	Daudpur Kota	378	9.62	26.31	88.00	49.38	11.36	27.46
28	Sikanderpur Kota	457	12.41	35.09	115.00	35.64	17.04	27.02
29	Tamkoli	409	14.41	40.93	60.00	83.12	14.20	24.80
30	Barauli	585	18.41	25.34	120.00	113.99	8.52	18.16
31	Paharpur	572	14.81	39.96	160.00	260.88	45.44	23.48
32	Sonana	818	6.41	49.70	116.00	88.68	71.00	82.40
33	Nagola.	492	14.81	31.19	110.00	25.51	5.68	33.67
34	Qasimpur	188.6	19.24	14.62	32.00	95.92	8.52	27.47
35	Pilona	414	8.02	23.39	66.00	110.28	11.36	5.32
36	Gopalpur	373	17.64	16.57	90.00	130.86	14.20	8.86
37	Kheda Buzurg	420	12.83	22.42	130.00	179.41	14.20	7.53
38	Chhalesar	399	18.02	42.06	44.00	134.35	22.72	9.30
39	Sikharna	527	23.21	30.93	100.00	116.04	45.44	16.83
40	Kazimabad	789	16.41	46.78	150.00	131.68	107.92	17.72
41	Chauganpur	497	19.62	42.88	50.00	127.32	36.92	49.62
42	Ash Pond	603	12.83	30.21	165.00	156.37	38.52	15.95
November 2012								
1	Danpur	456	27.25	37.03	180.00	244.41	42.60	24.80
2	Kheriya Bakhsh	562	20.84	50.68	185.00	332.05	14.20	12.85
3	Daulatpur Khurd	750	16.03	66.27	200.00	219.69	99.40	26.14
4	Maurajpur	484	20.84	43.86	155.00	244.87	25.56	22.15

Table 1 continued

S. no.	Location	TDS	Ca	Mg	Na	SO_4	Cl	NO_3
5	Ahmadgarh	973	12.83	74.07	225.00	385.56	144.84	15.06
6	Bhaiyanpur	732	12.83	74.07	190.00	362.35	85.20	7.97
7	Surjaoli	855	11.22	65.30	295.00	438.52	73.84	2.21
8	Lalner	536	16.03	58.48	140.00	224.66	76.68	14.18
9	Jagdishpur	452	12.83	58.48	90.00	215.15	59.64	4.87
10	Utrawali	682	14.43	58.48	230.00	337.43	79.52	23.92
11	Pahasu	822	12.83	85.76	120.00	304.71	73.84	146.19
12	Banail	465	14.43	47.75	165.00	120.98	19.88	11.52
13	Aterna	211	30.46	23.39	80.00	83.12	11.36	15.50
14	Bedrampur	570	16.03	44.83	235.00	213.16	22.72	8.86
15	Kamauna	504	16.03	67.25	90.00	216.78	31.24	9.30
16	Kali	430	12.83	49.70	145.00	230.02	25.56	5.76
17	Chaundhera	751	8.02	54.58	280.00	312.21	42.60	30.57
18	Akbarpur	862	8.02	64.32	285.00	338.12	122.12	10.63
19	Salabad	461	25.65	54.58	85.00	164.13	79.52	57.59
20	Bigupur 1	658	12.83	48.73	140.00	229.61	28.40	23.04
21	Bigupur 2	708	8.02	80.89	180.00	326.41	51.12	22.15
22	Darora	251	35.27	21.44	115.00	211.29	17.04	1.33
23	Chhatari	312	20.84	46.78	110.00	197.42	11.36	10.63
24	Pindrawal	500	12.83	60.42	100.00	174.47	19.88	3.99
25	Bahlolpur	577	11.22	49.70	155.00	138.67	25.56	19.05
26	Teori	325	20.84	38.01	40.00	115.78	14.20	3.54
27	Daudpur Kota	370	12.83	38.98	125.00	159.25	14.20	21.26
28	Sikanderpur Kota	484	20.84	22.42	190.00	203.69	25.56	2.21
29	Tamkoli	375	17.64	47.75	85.00	141.04	14.20	11.52
30	Barauli	628	9.62	53.60	190.00	267.80	42.60	14.18
31	Paharpur	1073	9.62	57.50	210.00	147.07	156.20	52.72
32	Sonana	378	12.83	49.70	75.00	105.45	17.04	12.40
33	Nagola	370	16.03	40.93	110.00	137.87	11.36	3.54
34	Qasimpur	164.4	27.25	15.59	80.00	91.64	11.36	1.33
35	Pilona	489	12.83	49.70	155.00	245.00	14.20	11.08
36	Gopalpur	376	16.03	38.01	110.00	131.30	14.20	0.00
37	Kheda Buzurg	356	14.43	37.03	110.00	92.83	14.20	4.87
38	Chhalesar	308	19.24	39.96	95.00	151.54	25.56	0.00
39	Sikharna	497	14.43	57.50	120.00	179.00	48.28	9.30
40	Kazimabad	743	11.22	78.94	145.00	182.71	110.76	23.04
41	Chauganpur	608	12.83	75.04	125.00	112.34	53.96	26.14
42	Ash Pond	567	11.22	56.53	160.00	191.76	14.20	5.76

very effective for comparing the overall groundwater quality scenario between the pre-monsoon and the post-monsoon seasons. In this case, we find a slight decrease in the mean GQI value from pre-monsoon to post-monsoon, indicating that the overall groundwater quality has slightly decreased from pre-monsoon to the post-monsoon season. This may be due to the flushing of contaminants accumulated in the vadose zone down into the groundwater zone by the strongly seasonal recharge during the monsoons.

Land-use map of the study area is shown in Fig. 6. The major land-use categories outlined here are those that are potentially capable of contaminating the groundwater. Dominant part of the study area is covered by cropland followed by plantations, wastelands, and human settlements. Groundwater quality assessment is usually made at specific locations (wells), however, it is influenced by the land use in the immediate vicinity as well as the potential 'catchment' of the well in the upflow direction, in regions

Table 2 Statistics of the selected groundwater quality parameters with the respective WHO maximum desirable limits (all values are in milligrams per liter (mg/l))

Groundwater quality parameter	WHO threshold value	Pre-monsoon 2012				Post-monsoon 2012			
		Min.	Max.	Mean	Std. dev.	Min.	Max.	Mean	Std. dev.
TDS	600	188.60	1340.00	577.49	255.64	164.40	1073.00	539.89	204.11
Ca	300	6.41	48.10	15.81	7.78	8.02	35.27	15.96	6.13
Mg	300	4.87	77.97	35.60	13.46	15.59	85.76	52.00	16.16
Na	200	18.00	290.00	125.90	70.53	40.00	295.00	150.00	60.35
Cl	200	5.68	173.24	44.20	44.53	11.36	156.20	44.90	38.38
SO_4	250	25.51	401.62	172.88	102.13	83.12	438.52	212.42	87.31
NO_3	50	4.87	82.40	22.78	15.61	0.00	146.19	17.46	23.84

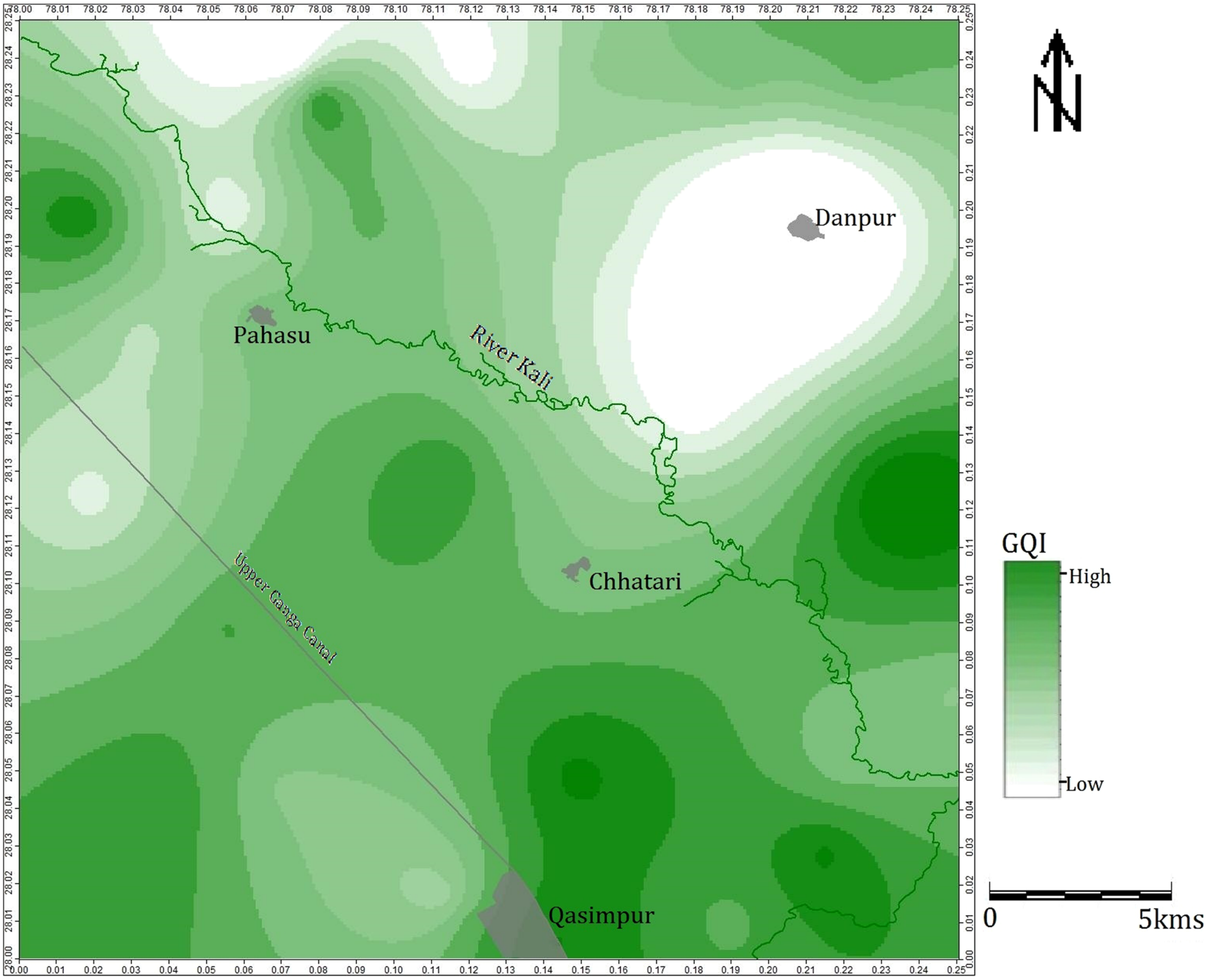

Fig. 4 Groundwater quality index map for pre-monsoon 2012

with little topographic variations. Deciphering the areal extent of land that is influencing the groundwater quality in a particular well is quite difficult, owing to the dynamic nature of the cones of depressions of each well, and well interference. Thus, comparing ground water quality with overlying land use is not a straightforward exercise. One approach is to measure the acreage of nearby land-use categories and correlate it with the overall groundwater

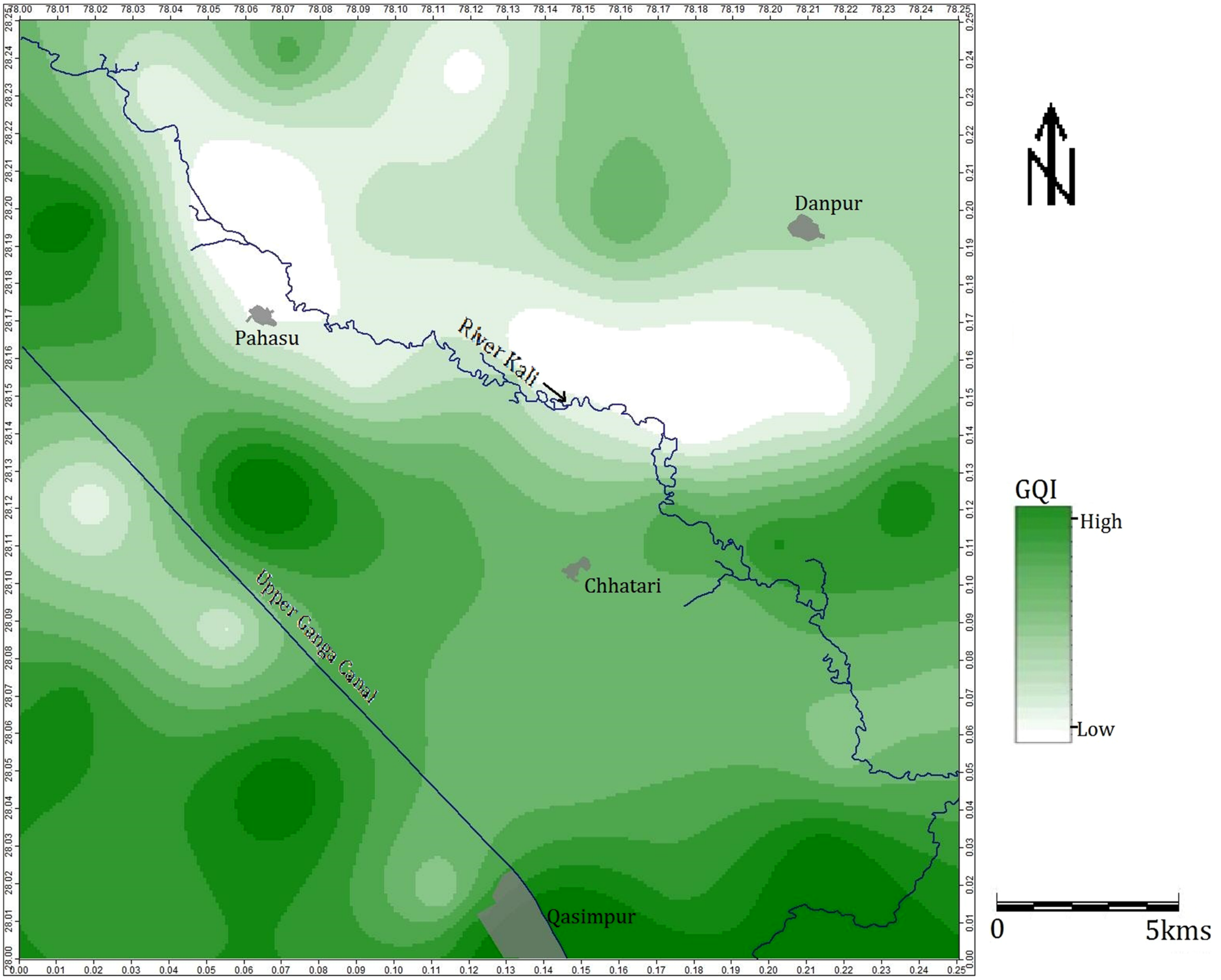

Fig. 5 Groundwater quality index map for post-monsoon 2012

quality in a well. Alternatively, the groundwater quality can be processed into a groundwater quality index, as used in the present study, and the GQI, which is a continuously varying field, as opposed to the point observations of groundwater quality, can be correlated with the land use using GIS overlay tools.

In the present work, the latter technique has been employed to decipher the influence of land-use on groundwater quality. The polygon of each land-use category was overlaid on the GQI map of the pre-monsoon as well as post-monsoon periods. The mean as well as the standard deviation of all the GQI grid cells within each polygonal land-use category were calculated using overlay tools in SAGA GIS. The statistical results are shown in Table 3.

Land use has its bearing on groundwater quality; however, the intensity of impact depends on the type of land-use class. As for example, in largely agricultural areas, generally, the impact on groundwater quality is not highly variable due to similar land-use practice in the entire area. Built up land shows wide variation in groundwater quality depending upon the contaminant loading at various places.

From the statistics (Table 3), it is evident that the mean GQI value is almost similar in all land-use categories during the pre- as well as post-monsoon periods. This suggests that the groundwater in the region is having minimal influence from land-use conditions, probably because the agricultural and plantation lands are profusely spread over the entire region. However, it can be seen that the standard deviation is slightly higher for settlements during both the seasons. A high standard deviation points towards a greater spatial variation of groundwater quality within the settlements, which is not a desirable parameter for sustainability of groundwater use. Sustainability of groundwater use is based on low overall contamination and low variability in contamination. Hence, a greater variability in contamination within a particular land-use category either temporally or spatially will lower the sustainability of groundwater use.

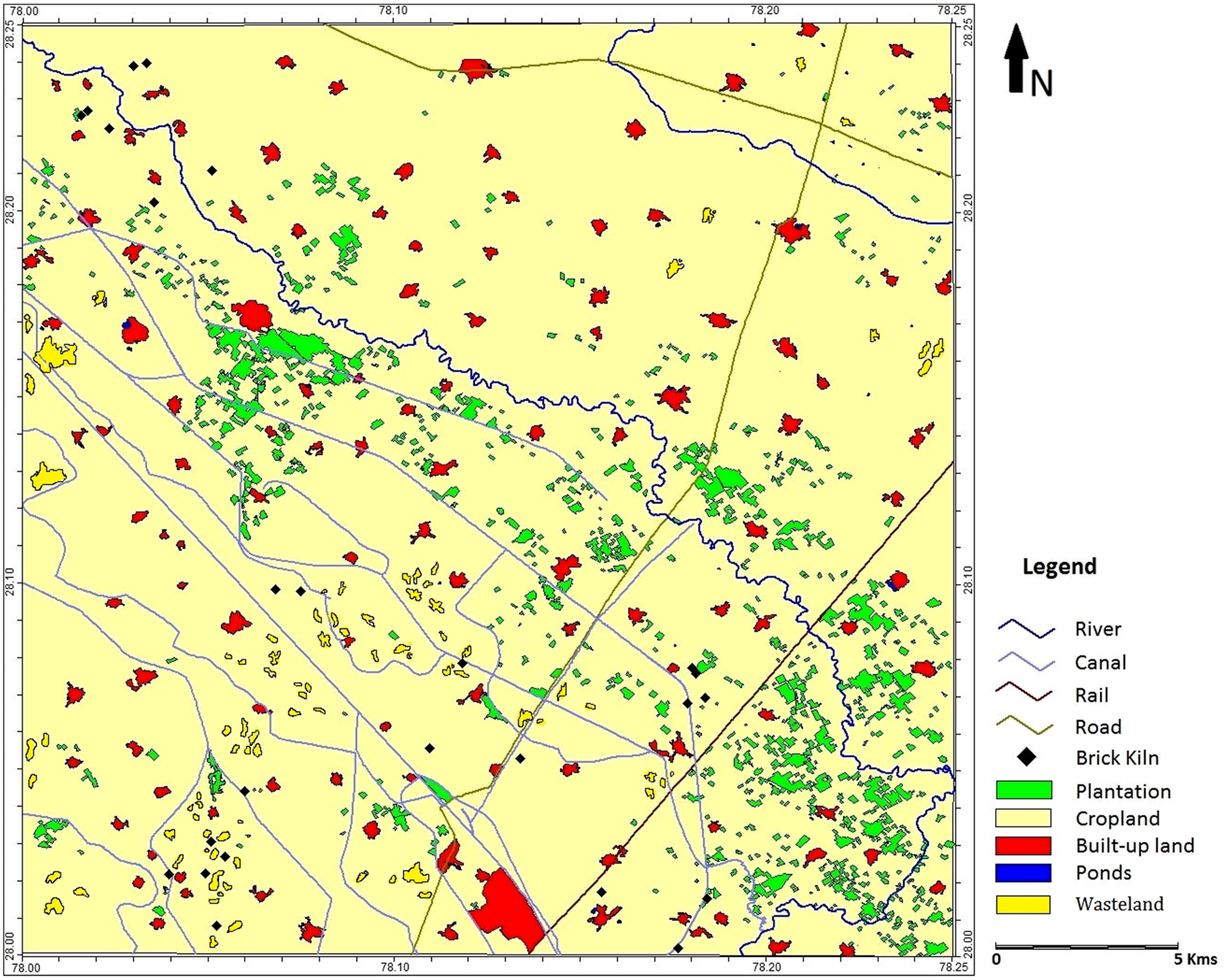

Fig. 6 Land-use map of the study area using google earth imagery 2012

Table 3 GQI statistics for each land-use class

Land use	GQI pre-monsoon 2012		GQI post-monsoon 2012	
	Mean	Std. dev.	Mean	Std. dev
Cultivated land	91.11	1.05	90.79	0.94
Plantation	91.48	0.69	90.95	0.93
Settlement	91.24	1.19	90.97	1.16
Wasteland	91.22	0.97	91.17	0.75

Conclusion

The assessment of actual groundwater quality using the GQI maps is an interesting exercise at regional scales to provide overall contamination scenario. The study outlines a unique approach to assign water quality status to each land-use class by extracting the mean GQI value for each land-use class. This helps to link land-use, which is a spatially varying parameter, and groundwater quality, which is observed at specific points. The comparison of water quality (in the form of GQI map) and the land use was done using GIS tools, and links between the observed land-use and the underlying water quality were highlighted, on a regional scale. Groundwater quality index for both the seasons suggests good groundwater quality. The GQI values in pre-monsoon season range from 86.66 to 93.69. The pre-monsoon 2012 GQI map shows low values in the north and north-eastern part corresponding to poor groundwater quality. The southern part shows high GQI and thus relatively good quality. Post-monsoon GQI values range from 88.18 to 93.45. The post-monsoon map also shows more or less the same trend as observed in pre-monsoon, with low GQI values in the north and eastern part and high values in the south and south west.

Impact assessment of land use on groundwater quality of the study area revealed that the mean GQI value is almost similar in all land-use categories during the pre- as well as post-monsoon periods. The groundwater in the region is having minimal influence from land-use conditions, probably because the agricultural and plantation lands are profusely spread over the entire region. Settlements, however, show a greater temporal variability of groundwater quality.

Since groundwater quality is an evolving and ever-changing parameter, and hence, its monitoring and assessment should continue in the study area. This can provide a temporal database on water quality evolution in the region that can be compared to the land-use transformations over time, providing better insight into groundwater quality and land-use relationships.

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