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ORIGINAL ARTICLE

Comparison of indices for scaling and corrosion tendency of groundwater: Case study of unconfined aquifer from Mahoba District, U.P. State

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Abstract

This paper is an attempt to utilize the various indices available to assess the degree of corrosivity and calcite formation of groundwater sampled from Indian Mk. II handpumps from the district of Mahoba in Uttar Pradesh. The indices used include Langelier Saturation Index, Ryznar Stability Index, Puckorius Scaling Index, Larson-Skold Index, and Potential to Promote Galvanic Corrosion. Corrosivity of groundwater would cause materials used in construction of pipes to leach into drinking water since the same is used for household activities and drinking purposes. Calcite formation would affect the amount of exertion used to manually pump out required quantity of groundwater from the aquifer as it reduces the convey potential of pipes. One hundred five groundwater samples were collected from Indian Mk. II handpumps tapping shallow aquifer (up to 35mbgl) from different locations that were used by locals for analysis of basic parameters like pH, TDS, EC, ions like calcium, magnesium, sodium, potassium, chloride, carbonate, bicarbonate, sulphate, etc. Overall, majority of the groundwater samples display tendency to deposit calcium carbonate within the pipes, chlorides and sulphates not interfering with natural film formation in pipes and possibility of galvanic corrosion, whereas minority of the samples indicate the alternate scenario.

Keywords Bundelkhand · Corrosion indices · Mahoba district · Scaling · Uttar Pradesh

Introduction

Incrustation is the process of deposition of precipitate from groundwater onto well installation materials or into the surrounding aquifer. The implications include reduction in open area of well screen in wells and reduction of aquifer permeability adjacent to the well in addition to causing blockages in convey pipes and increase in operational and maintenance costs. Incrustation relates directly to supersaturation of groundwater with respect to certain compounds, like calcite, carbonates, iron compounds, sulphates or manganese compounds. Water being a universal solvent dissolves many constituents from atmosphere, soil and strata in contact. These chemical constituents are directly responsible for causing corrosion, fouling and scaling.

Scaling and fouling indices have been used to predict the extent of calcium carbonate deposition onto heat transfer surfaces in industries. Once calcium carbonate is supersaturated, it precipitates as salt with an increase in temperature. Saturation indices of calcium carbonate have been determined mainly by saturation Indices (Nalco 1979) even though sophisticated methods are available (Hasson 1981).

Some authors have calculated the scale deposition and corrosion in tap waters (Al-Rawajfeh and Al-Shamaileh 2007), whereas others have described the same for river waters (Haritash et al. 2016) and others have described its usefulness in water supply networks and water treatment and supply plants (Davil et al. 2009; Mirzabeygi et al. 2017).

The study area

Mahoba district lies at the southernmost extent of Bundelkhand region of Uttar Pradesh state between 25°01′30″ to 25°39′40″ North latitude and 79°15′00″ to 80°10′30″ East longitude. The district experiences semiarid climate with low precipitation of around 864 mm/year and covers an area

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of 2884 km^2 and is divided into 4 blocks, namely Kabrai, Charkhari, Panwari and Jaitpur.

Mahoba is an agriculture-dominated district, and 72% area is actively cultivated. About 80% of the total geographical area of the district is cultivated area. The main Rabi crops include wheat, barley, red lentil, gram, pea, pigeon pea and mustard. The main Kharif crops are mung beans, millets, sesame, maize, urad, jowar, groundnut and black gram. Zaid crops are maize, black gram, mung beans and potato (CGWB 2020).

The map of the study area is attached in Fig. 1**.**

Geology and hydrogeology of study area

The district can be broadly classified into two physiographic units—southern portion with high relief and northern portion with relatively low relief and low hillocks. Geologically, the northern portion of the district comprises Quaternary alluvium underlain by Bundelkhand Granites of Precambrian age. Dolerite dykes and Quartz reefs are also seen at places but form only a fraction when compared to Granites and Alluvium, and they too were formed during Precambrian age. Granites are observed as isolated or clustered hillocks. Granites occurring in the district reflect considerable heterogeneity in colour, texture, grain size and composition. Most common Granite in the district is Alkali feldspar Granite, and less common variety is grey coloured Leucogranite. Occasionally, Quartz veins are also encountered in Granite. The Quartz reef trending NE–SW occurs as narrow ridges. These reefs are composed of fine grained compact silica material and are milky white in colour. Dolerite dykes intruding the Granite mainly display trend in EW to NW–SE direction (CGWB 2014).

Surface water from Madan Sagar, Kirat Sagar, Vijay Sagar and Kalyan Sagar lakes is a possible source of potable water but it is only fit for agriculture (Pal et al. 2013). All villages and towns depend solely upon groundwater for sustenance, since surface water bodies have either disappeared or have been polluted. Groundwater occurs up to 35 mbgl (metres below ground level) in the form of phreatic aquifer and is mainly tapped by dug wells, Indian Mk. II handpumps and shallow borewells for supplying drinking water and irrigation water, wherever possible.

Yield of dug well and shallow borewell ranges from 100 to 300 lpm. Deeper groundwater is tapped by borewells that

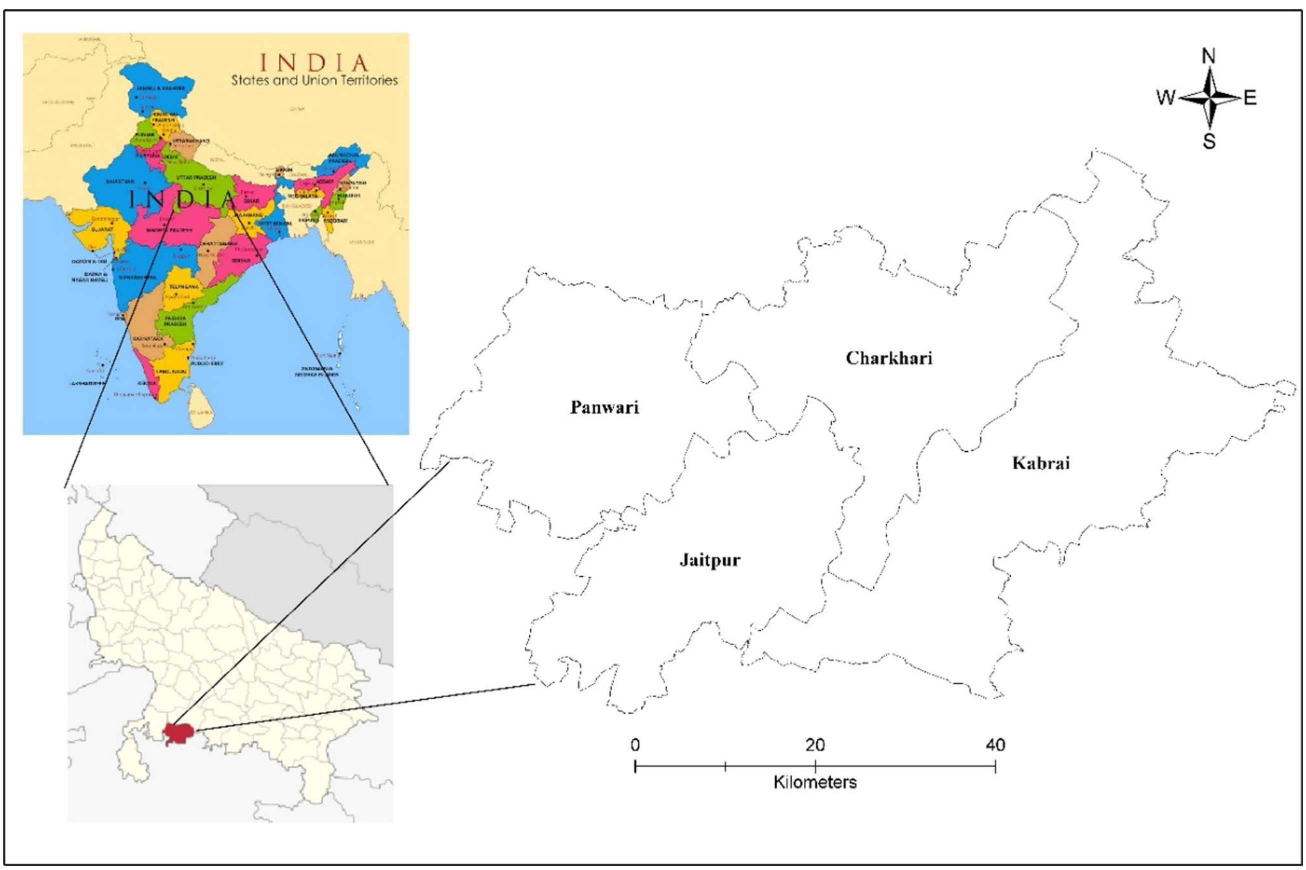


Fig. 1 Map of the study area

access fractures and joints below 35 mbgl. The Granites are profusely and extensively jointed and fractured, forming good conduit for groundwater movement. Groundwater occurs in deeper fracture zones in semi-confined to confined condition. Quartz reefs act as a barrier impeding the subsurface movement of groundwater.

Geological map of Mahoba is attached in Fig. 2.

Materials and methods

The sampling was carried out during May 2019 as a part of NAQUIM programme under the aegis of CGWB at Mahoba district that lies in the Bundelkhand region of Uttar Pradesh State. A total of 105 ground water samples were collected from Indian Mk. II handpumps tapping shallow aquifer (~20 mbgl) from different locations that were used by locals for analysis of basic parameters like pH, TDS, EC, ions like calcium, magnesium, sodium, potassium, chloride, carbonate, bicarbonate, sulphate, etc.

Sampling locations with chemical data are given in Appendix 1.

The samples were collected after removal of water column by pumping out the water from the handpumps for at least 5–10 min, and the water samples were collected in HDPE sample bottles of 1 L capacity. It was ensured that the sample bottles were free from air bubbles and they were immediately closed, labelled and transported to a NABL accredited laboratory at Panipat for analysis. Map displaying sampling locations is attached in Fig. 3.

Hydrogeochemistry

The groundwater samples collected were plotted on the Hill-Piper trilinear diagram (Piper 1944), and the samples were classified into the following categories based on the dominant cation and anion.

- 76 samples are of magnesium bicarbonate water type;
- 24 samples are of mixed type wherein no dominant cation or anion can be identified;
- 4 samples are of calcium chloride water and
- 1 sample is of sodium chloride water type.

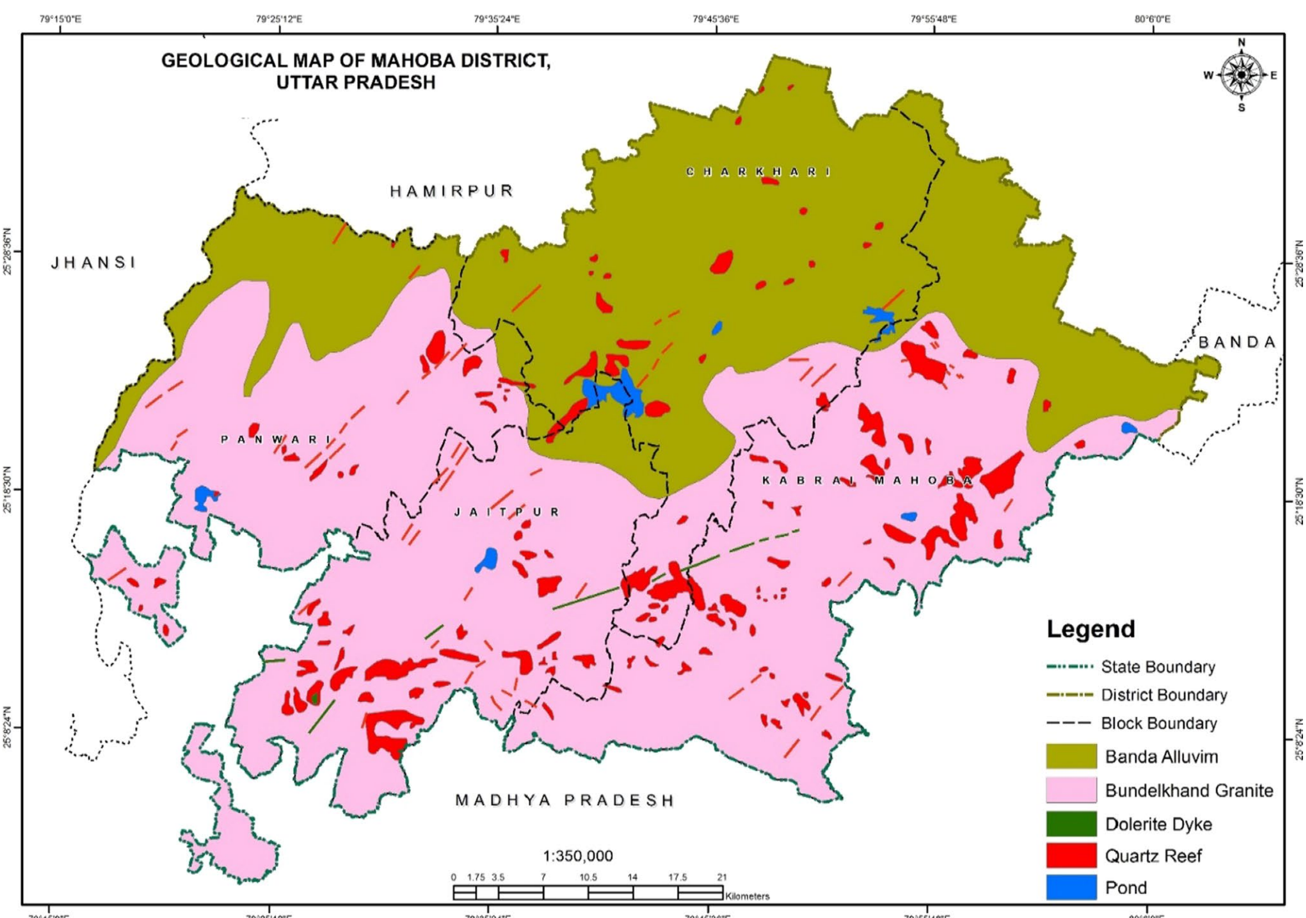


Fig. 2 Geological map of Mahoba district

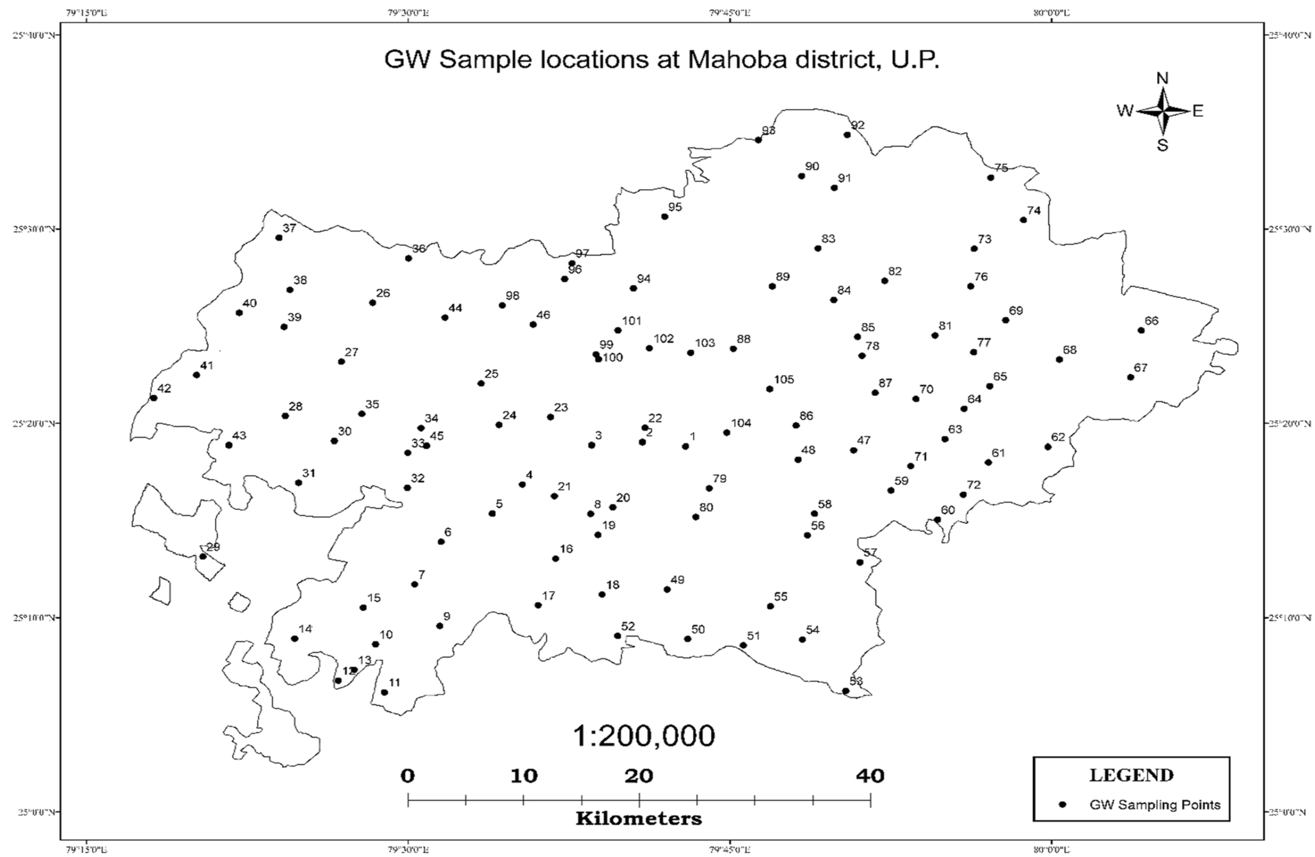


Fig. 3 Map displaying sampling locations at Mahoba district

Kabrai block is dominated by Mg-HCO_3 hydrochemical facies (62.50 %), followed by Mixed facies (31.25 %) and $CaCl_2$ facies (3.125 %) and NaCl facies (3.125 %).

Charkhari block is dominated by Mg-HCO_3 hydrochemical facies (74.07 %), followed by Mixed facies (22.22 %) and $CaCl_2$ facies (3.70 %). *Jaitpur block* is dominated by Mg-HCO_3 hydrochemical facies (79.16 %), followed by Mixed facies (16.66 %) and $CaCl_2$ facies (4.16 %).

Panwari block is dominated by Mg-HCO_3 hydrochemical facies (77.27 %), followed by Mixed facies (18.18 %) and $CaCl_2$ (4.54 %).

A closer look at the data reveals Ca> Na> Mg > K in cations and HCO_3> Cl> SO_4 > CO_3 in anions.

The plotted Hill-Piper trilinear diagrams are attached in Fig. 4.

Calculation of corrosion indices

The following indices were calculated.

Langelier saturation index

Langelier 1936 had proposed a formula to predict calcium carbonate scaling in water based on pH, TDS, temperature, total alkalinity and hardness that affect calcium carbonate solubility and was calculated by the following formula

$$LSI = pH - pHs$$

where

pH is the actual pH of water and
pHs is the pH at saturation and is calculated by pHs = (9.3+A+B)–(C+D).

- A = TDS (mg/l),
- B = temperature in Celsius,
- C = calcium hardness (mg/l of $CaCO_3$),
- D = alkalinity (mg/l of $CaCO_3$).

LSI value > 0 indicates water is supersaturated and $CaCO_3$ layer precipitates,
LSI value = 0 indicates water is in equilibrium with $CaCO_3$, and no precipitation or corrosion is possible,
LSI value < 0 indicates water is under-saturated, dissolves solid $CaCO_3$ and causes corrosion.

Puckorius scaling index

Puckorius and Brooke 1991 also proposed a formula that is calculated by the following formula

$$PSI = 2(pH_s) - pH_{eq}$$

where

pH_s is the pH at saturation and pH_{eq} is the pH at equilibrium and calculated by $pH_{eq} = 1.465 * \log_{10}(\text{Alkalinity}) + 4.54$
PSI value < 6 indicates $CaCO_3$ scale will be dissolved by water and is corrosive,
PSI value > 6 indicates $CaCO_3$ scaling may occur.

Ryznar stability index

Ryznar 1949 also proposed a formula to predict calcium carbonate scaling in water that overcame deficiencies in LSI and is calculated by the following formula

$$RSI = 2pH_s - pH$$

RSI value < 6 indicates increasing tendency for scaling with decreasing index,
RSI value between 6-7 indicates formation of no corrosion-protective film by water,
RSI value > 8 indicates tendency for corrosion by water.

Larson-Skold index

Larson and Skold 1958 gave a formula to predict the corrosivity of water towards mild steel which is calculated by the following formula

$$Larson-Skold\ Index = \frac{Cl + SO4}{HCO3}$$

All ionic concentrations in meq/l.

LS value < 0.8 indicates chloride and sulphate may not interfere with natural scale formation,
LS value between 0.8 to 1.2 indicates chloride and sulphate may interfere with scale formation and higher than desired corrosion rates expected,
LS value > 1.2 indicate very high corrosion rate by the action of chloride and sulphate.

Potential to Promote Galvanic Corrosion (PPGC)

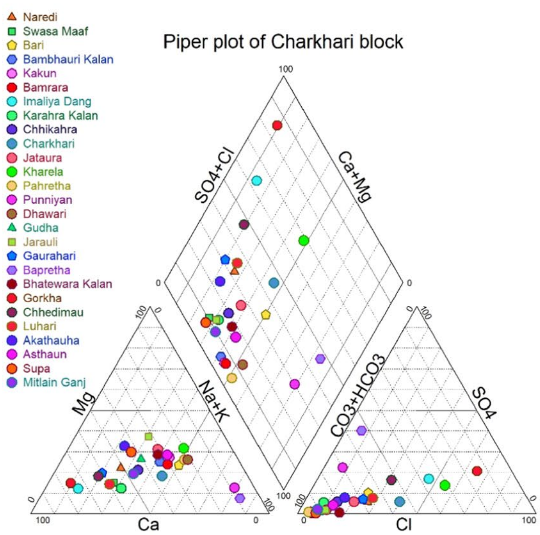
Edwards et al. (2007) proposed a formula to calculate possibility of release of lead from copper pipes wherein lead was used as solder

$$PPGC = \frac{Cl}{SO4}$$

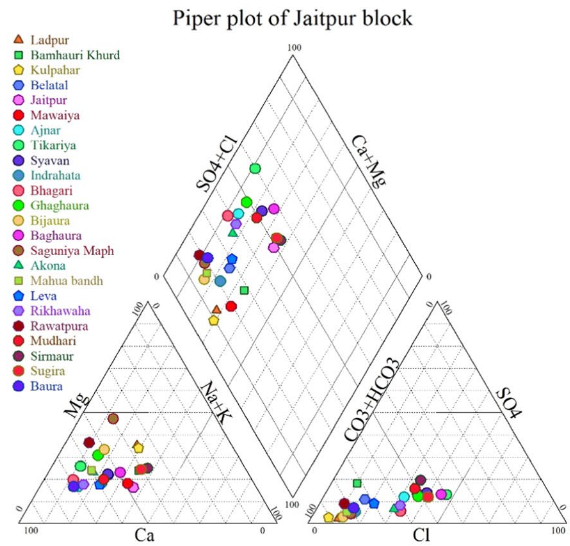
PPGC > 0.50 indicates susceptibility of galvanic corrosion by groundwater.
All ionic concentrations are in mg/l.
Computed data of corrosion indices is attached in Appendix 2.

Results and discussion

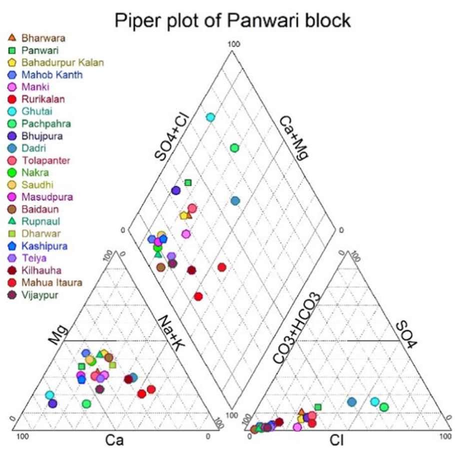
(1) The Langelier Saturation Index values range from −0.92 to 1.01 with mean value of 0.46.
4.76% samples display negative values wherein groundwater is under-saturated with respect to calcium carbonate and removes existing protective covering of pipes.
95.24% of samples display possible scale formation due to deposition of calcium carbonate.
Sample nos. 9, 10, 12, 17 and 100 display negative values, and the underlying geological formations mainly include Precambrian Granite with minority from Quartz reefs.
(2) The Puckorius Scaling Index values range from 4.12 to 7.66 with mean value of 5.83.
60.95% of samples display values less than 6.0 indicating calcium carbonate scaling might occur.
30.05% of samples are indicative of calcium carbonate scale dissolved by groundwater.
Sample nos. 9, 10, 12, 17, 28, 41, 42, 43, 51 and 60 display values greater than 6.0, and the underlying geological formations mainly include Precambrian Granite with minority from Quartz reefs.
(3) The Ryznar Stability Index values range from 5.55 to 8.55 with mean value of 6.58.
12.38% of samples display value greater than 7.0 indicating groundwater is of corrosive nature.
87.62% of samples display value lesser than 6.0 indicating possibility of scale formation due to deposition of calcium carbonate.
Sample nos. 1, 3, 9, 10, 12, 17, 42, 51, 58, 61, 78, 100 and 105 display values greater than 7.0, and the underlying geological formations mainly include Pre-



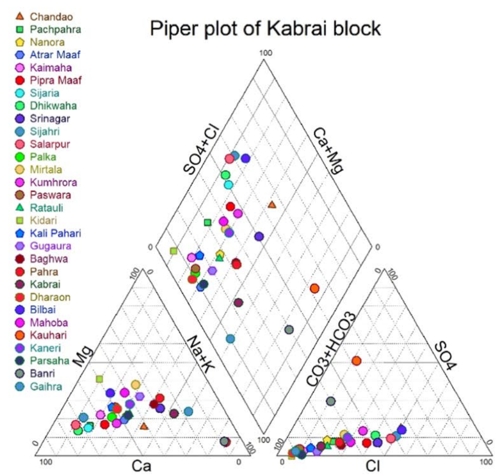
(a) : **Piper plot of Charkhari block**



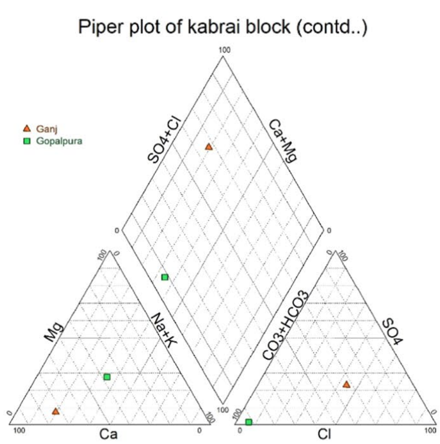
(b) : **Piper plot of Jaitpur block**



(c) : **Piper plot of Panwari block**



(d) : **Piper plot of Kabrai block**



(e) : **Piper plot of Kabrai block**

◂**Fig. 4** **a**–**e** Hill-Piper trilinear diagrams of blocks of Mahoba district. **a** Piper plot of Charkhari block, **b** Piper plot of Jaitpur block, **c** Piper plot of Panwari block, **d** Piper plot of Kabrai block

cambrian Granite with minority from Quartz reefs and Quaternary alluvium.

(4) The Larson-Skold Index values range from 0.05 to 5.89 with mean value of 0.62.

73.33% of samples indicate chlorides and sulphates may not interfere with natural film formation.

13.3% of samples indicate tendency for high corrosion.

13.33% of samples indicate higher than desired corrosion rates wherein chlorides and sulphates may interfere with natural film formation.

Sample nos. 5, 9, 12, 21, 22, 23, 52, 53, 54, 55, 60, 88, 97 and 101 display values between 0.8 and 1.2, and the underlying geological formations mainly include Precambrian Granite with minority from Quartz reefs and Quaternary alluvium.

Sample nos. 9, 15, 32, 33, 35, 48, 57, 58, 71, 73, 78, 86, 91 and 100 display values greater than 1.2, and the underlying geological formations mainly include Precambrian Granite with minority from Quartz reefs and Quaternary alluvium.

(5) The PPGC or chloride–sulphate mass ratio values range from 0 to 31.90 with mean value of 3.42.

94.28% of samples indicate possibility of galvanic corrosion.

5.71% of samples rule out the possibility of galvanic corrosion.

The groundwater samples mainly obtained from Precambrian Granites display possibility of corrosion with reference to Langelier Saturation Index, Puckorius Scaling Index, Ryznar Stability Index and Larson-Skold Index, whereas very few groundwater samples collected from Quartz reefs and Quaternary alluvium mirror the possibility of corrosion with respect to indices stated above.

It is also observed that the underlying geology has little to no bearing on corrosion with respect to PPGC (index that indicates possibility of galvanic corrosion) and about 94.28% of samples display possibility of galvanic corrosion across varied lithologies barring a few samples that possess low sulphate content.

Overall, majority of the groundwater samples display tendency to deposit calcium carbonate within the pipes, chlorides and sulphates not interfering with natural film formation in pipes and possibility of galvanic corrosion, whereas minority of samples indicate the alternate scenario.

The map of GW samples classified with respect to different corrosion indices is attached in Fig. 5.

Conclusion

It is observed that groundwater samples collected from Precambrian Bundelkhand Granites display tendency to deposit calcium carbonate as per 3 indices—Langelier Saturation Index, Puckorius Scaling Index and Ryznar Stability Index in addition to possibility of corrosion of mild steel as defined by Larson-Skold Index.

The geology of the study area was found to have none to near negligible influence on Potential to Promote Galvanic Corrosion (PPGC) index as the quantum of sulphate ion varies across different lithologies and no relation between the two is observed.

The various indices can be utilized to plan for materials used in construction of Indian Mk. II handpumps in addition to deciding the material used for borewell casing that is resistant to corrosion as calculated by different indices. The groundwater samples will require collection every month or every quarter in order to calculate values as defined by each index. Galvanic pipes containing lead as solder should be avoided since the index indicates high possibility of leaching of lead into water.

The data computed from various corrosion indices can also be utilized prior to establishment of industries that require stringent water quality standards for production, and areas free from corrosive potential of groundwater can be demarcated for investment in infrastructure in the future.

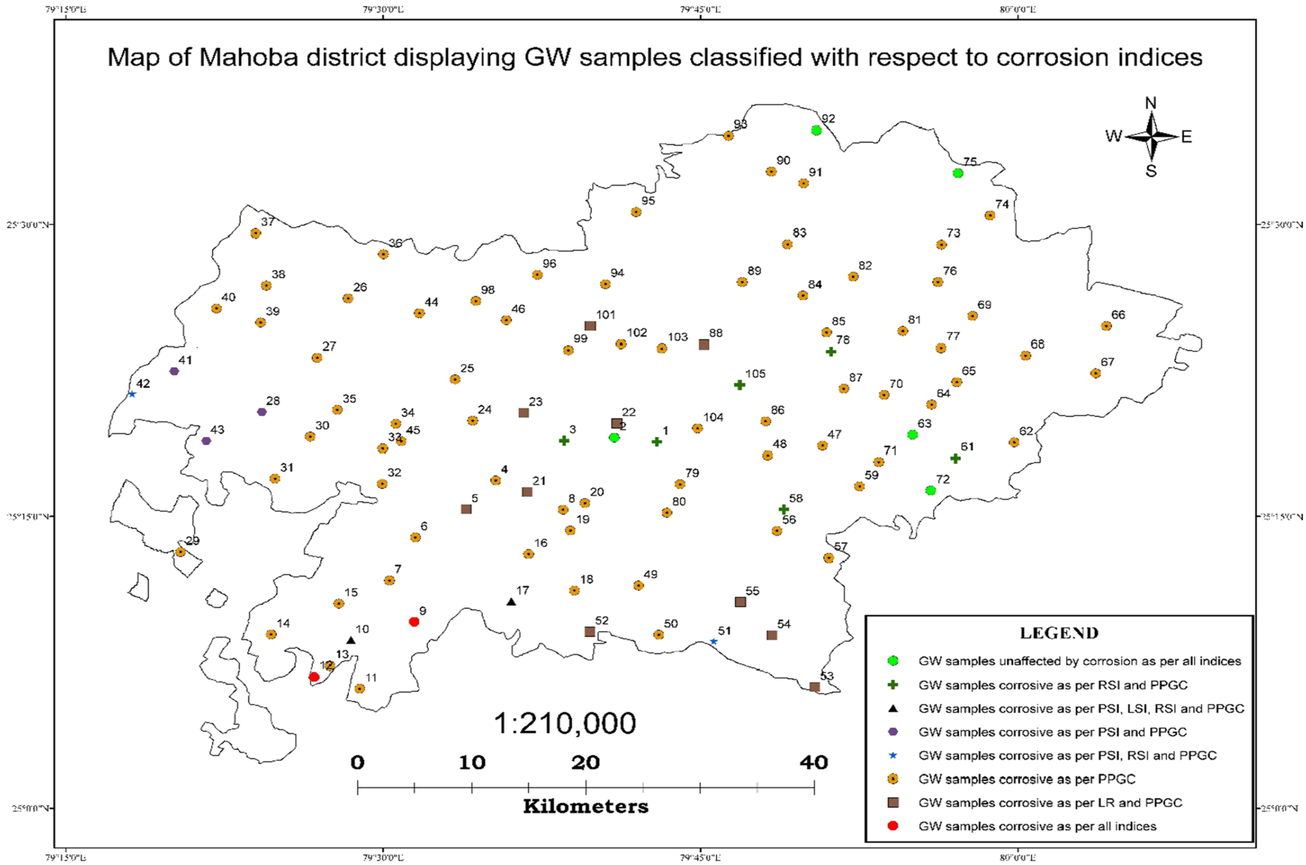


Fig. 5 Map displaying GW sampling locations classified with respect to various corrosion indices

Appendix 1

ASl. No	Village	Block	pH	TDS	EC at 25 °C	Ca	Mg	Na	K	HCO3	CO3	Cl	SO4
1	Ladpur	Jaitpur	7.53	442.8	738	58.12	34.02	51.57	0.00	402.60	0	28.36	7.70
2	Bamhauri Khurd	Jaitpur	7.41	579.0	965	84.17	29.12	78.76	1.70	445.30	0	35.45	89.00
3	Kulpahar	Jaitpur	7.44	438.6	731	56.11	31.59	51.81	0.00	414.80	0	17.73	9.60
4	Belatal	Jaitpur	7.25	549.6	916	108.22	26.65	53.68	1.28	427.00	0	56.72	50.20
5	Jaitpur	Jaitpur	7.14	1362.0	2270	244.49	50.84	211.75	3.32	756.40	0	304.87	160.00
6	Mawaiya	Jaitpur	7.40	474.0	790	80.16	18.17	61.70	1.16	427.00	0	46.09	18.90
7	Ajnar	Jaitpur	7.10	714.0	1190	164.33	24.15	40.74	0.00	378.20	0	120.53	62.60
8	Tikariya	Jaitpur	7.24	1076.4	1794	242.48	60.58	48.67	1.44	408.70	0	276.51	103.50
9	Syavan	Jaitpur	6.88	516.6	861	88.18	21.81	42.50	1.62	176.90	0	85.08	40.80
10	Indrahata	Jaitpur	7.25	307.2	512	64.13	12.10	28.20	1.01	250.10	0	28.36	13.30
11	Bhagari	Jaitpur	7.12	700.2	1167	174.35	30.23	31.95	1.05	445.30	0	138.26	32.00
12	Ghaghaura	Jaitpur	6.70	401.4	669	70.14	24.26	22.10	1.45	146.40	0	60.27	28.00
13	Bijauri	Jaitpur	7.40	507.6	846	90.18	36.42	34.26	0.00	469.70	0	39.00	12.30
14	Baghaura	Jaitpur	7.21	1254.0	2090	208.42	59.40	76.06	100.25	414.80	0	258.79	101.50
15	Saguniya Maph	Jaitpur	7.45	535.8	893	78.16	55.91	28.97	1.10	445.30	0	46.09	18.70

ASl. No	Village	Block	pH	TDS	EC at 25 °C	Ca	Mg	Na	K	HCO3	CO3	Cl	SO4
16	Akona	Jaitpur	7.30	747.6	1246	168.34	39.97	54.47	3.01	475.80	0	131.17	38.30
17	Mahua Bandh	Jaitpur	7.24	279.0	465	64.13	15.75	19.84	0.00	280.60	0	24.82	13.50
18	Leva	Jaitpur	7.44	640.2	1067	142.28	25.39	49.74	20.40	445.30	0	77.99	46.00
19	Rikhawaha	Jaitpur	7.38	660.0	1100	158.32	25.38	44.88	0.00	420.90	0	127.62	45.00
20	Rawatpura	Jaitpur	7.46	443.4	739	98.20	40.06	15.85	5.39	463.60	0	31.91	40.60
21	Mudhari	Jaitpur	7.56	777.6	1296	160.32	33.90	54.09	33.40	414.80	0	159.53	100.40
22	Sirmaur	Jaitpur	7.26	1530.0	2550	234.47	93.46	217.75	81.00	829.60	0	350.96	276.00
23	Sugira	Jaitpur	7.31	1010.4	1684	146.29	53.39	143.75	2.98	488.00	0	241.06	96.40
24	Baura	Jaitpur	7.35	516.0	860	126.25	18.11	22.67	6.84	439.20	0	46.09	30.90
25	Bharwara	Panwari	7.58	644.4	1074	100.20	46.14	66.87	1.13	488.00	0	95.72	58.60
26	Panwari	Panwari	7.46	823.2	1372	146.29	65.57	53.35	1.99	512.40	0	148.89	90.80
27	Bahadurpur Kalan	Panwari	7.65	621.0	1035	76.15	58.35	58.05	1.42	481.90	0	99.26	35.20
28	Mahob kanth	Panwari	7.79	311.4	519	50.10	30.38	15.13	5.81	353.80	0	14.18	7.70
29	Manki	Panwari	7.53	530.4	884	72.14	34.00	59.56	1.00	433.10	0	85.08	9.30
30	Rurikalan	Panwari	7.64	573.0	955	64.13	29.14	141.25	0.00	597.80	0	49.63	18.00
31	Ghutai	Panwari	6.98	1488.0	2480	386.77	64.06	50.53	1.08	402.60	0	443.13	176.00
32	Pachpahra	Panwari	7.13	1668.0	2780	348.70	55.58	198.75	2.72	420.90	0	570.75	166.00
33	Bhujpura	Panwari	7.58	490.8	818	116.23	14.47	22.14	0.00	298.90	0	70.90	25.50
34	Dadri	Panwari	7.42	1932.0	3220	204.41	134.89	216.75	273.00	677.10	0	428.95	211.00
35	Tolapanter	Panwari	7.63	612.0	1020	100.20	41.27	63.97	0.00	414.80	0	109.90	43.00
36	Nakra	Panwari	7.71	428.4	714	66.13	36.44	33.37	1.54	420.90	0	21.27	5.30
37	Saudhi	Panwari	7.72	477.0	795	74.15	41.30	33.09	3.19	439.20	0	35.45	10.70
38	Masudpura	Panwari	7.88	330.6	551	64.13	23.05	24.78	1.08	347.70	0	21.27	5.40
39	Baidaun	Panwari	7.90	405.6	676	52.10	38.90	47.01	1.17	469.70	0	14.18	2.10
40	Rupnaul	Panwari	7.84	393.0	655	56.11	38.89	36.67	1.00	427.00	0	17.73	3.50
41	Dharwar	Panwari	7.96	369.0	615	46.09	30.38	47.07	1.16	384.30	0	24.82	6.10
42	Kashipura	Panwari	8.01	228.0	380	44.09	14.56	18.83	0.00	231.80	0	17.73	6.80
43	Teiya	Panwari	7.93	343.8	573	56.11	23.06	42.44	0.00	353.80	0	28.36	5.70
44	Kilhauha	Panwari	7.74	525.0	875	56.11	32.80	90.87	0.00	475.80	0	49.63	22.80
45	Mahua Itaura	Panwari	7.88	964.8	1608	88.18	57.12	259.64	1.04	725.90	0	198.52	35.60
46	Vijaypur	Panwari	7.86	435.6	726	72.14	21.83	55.08	0.00	408.70	0	28.36	5.50
47	Chandao	Kabrai	7.22	1362.0	2270	226.45	50.86	264.50	1.44	488.00	0	404.13	164.00
48	Pachpahra	Kabrai	7.76	547.2	912	130.26	19.32	36.95	3.86	378.20	0	70.90	33.80
49	Nanora	Kabrai	8.01	622.8	1038	104.21	29.09	81.24	0.00	433.10	0	67.36	39.60
50	Atrar Maaf	Kabrai	7.53	411.6	686	76.15	18.17	55.66	1.00	390.40	0	21.27	6.10
51	Kaimaha	Kabrai	7.65	284.4	474	58.12	13.32	22.21	0.00	237.90	0	17.73	5.80
52	Pipra Maaf	Kabrai	7.34	576.0	960	120.24	20.55	55.88	0.00	286.70	0	116.99	29.30
53	Sijaria	Kabrai	7.40	563.4	939	134.27	18.10	39.20	0.00	231.80	0	116.99	26.80
54	Dhikwaha	Kabrai	7.39	625.2	1042	138.28	15.66	27.84	1.37	244.00	0	116.99	44.20
55	Srinagar	Kabrai	7.76	913.2	1522	96.19	51.02	170.00	0.00	445.30	0	226.88	51.60
56	Sijahri	Kabrai	7.36	1200.0	2000	278.56	52.01	57.06	1.63	420.90	0	311.96	90.00
57	Salarpur	Kabrai	7.17	943.8	1573	226.45	31.38	37.04	1.93	341.60	0	226.88	59.50
58	Palka	Kabrai	7.42	367.2	612	72.14	16.96	39.19	0.00	335.50	0	17.73	9.70
59	Mirtala	Kabrai	7.55	630.0	1050	80.16	53.47	72.25	2.91	414.80	0	99.26	59.20
60	Kumhrora	Kabrai	7.38	450.6	751	86.17	16.94	52.81	1.77	231.80	0	85.08	46.00
61	Paswara	Kabrai	7.75	439.2	732	80.16	25.47	45.09	0.00	414.80	0	24.82	13.90
62	Ratauli	Kabrai	7.78	501.6	836	80.16	24.25	66.49	0.00	427.00	0	70.90	24.40

ASl. No	Village	Block	pH	TDS	EC at 25 °C	Ca	Mg	Na	K	HCO3	CO3	Cl	SO4
63	Kidari	Kabrai	7.28	589.2	982	116.23	58.30	24.73	1.00	640.50	0	28.36	0.00
64	Kali Pahari	Kabrai	7.48	544.8	908	102.20	31.53	51.96	0.00	475.80	0	46.09	20.30
65	Gugaura	Kabrai	7.71	565.8	943	74.15	40.09	77.81	0.00	500.20	0	63.81	11.30
66	Baghwa	Kabrai	7.73	718.8	1198	78.16	42.52	119.25	1.08	500.20	0	116.99	35.20
67	Pahra	Kabrai	7.82	634.2	1057	62.12	43.75	112.75	0.00	469.70	0	102.81	40.60
68	Kabrai	Kabrai	7.86	581.4	969	54.11	30.37	135.00	1.13	488.00	0	67.36	26.30
69	Dharaon	Kabrai	7.67	419.4	699	78.16	24.26	46.60	0.00	414.80	0	17.73	5.40
70	Bilbai	Kabrai	7.25	1512.0	2520	254.51	108.05	108.50	2.05	536.80	0	457.31	170.00
71	Mahoba	Kabrai	7.74	760.8	1268	110.22	54.65	75.19	0.00	494.10	0	141.80	47.80
72	Kauhari	Kabrai	7.92	1692.0	2820	50.10	30.38	636.00	1.97	738.10	0	134.71	790.00
73	Kaneri	Kabrai	7.72	666.0	1110	100.20	40.06	81.55	1.90	408.70	0	106.35	51.40
74	Parsaha	Kabrai	7.84	482.4	804	80.16	23.04	63.82	1.02	469.70	0	35.45	3.50
75	Banri	Kabrai	7.99	1163.4	1939	36.07	20.65	416.50	1.39	762.50	0	77.99	290.00
76	Gaihra	Kabrai	8.24	591.6	986	42.08	35.26	167.50	0.00	640.50	0	31.91	14.20
77	Ganj	Kabrai	7.02	1260.0	2100	316.63	19.10	95.50	1.27	366.00	0	283.60	198.00
78	Gopalpura	Kabrai	7.34	414.0	690	60.12	26.71	63.94	0.00	445.30	0	17.73	6.00
79	Naredi	Charkhari	7.71	568.8	948	106.21	27.87	64.08	0.00	390.40	0	88.63	25.30
80	Swasa Maf	Charkhari	7.73	390.0	650	84.17	13.29	45.46	0.00	378.20	0	21.27	5.60
81	Bari	Charkhari	7.80	862.2	1437	76.15	41.30	140.75	45.50	567.30	0	124.08	69.80
82	Bambhauri Kalan	Charkhari	7.56	430.8	718	56.11	25.50	79.88	0.00	457.50	0	14.18	2.80
83	Kakun	Charkhari	7.51	513.6	856	56.11	32.80	100.50	1.15	579.50	0	17.73	4.70
84	Bamrara	Charkhari	7.57	428.4	714	54.11	25.50	91.17	1.06	475.80	0	17.73	1.00
85	Imaliya Dang	Charkhari	7.08	1398.0	2330	378.76	37.28	80.73	1.08	408.70	0	301.33	147.00
86	Karahra Kalan	Charkhari	7.31	400.8	668	90.18	12.07	58.46	0.00	390.40	0	21.27	19.50
87	Chhikahra	Charkhari	7.44	493.8	823	88.18	25.46	77.47	1.25	463.60	0	46.09	26.50
88	Charkhari	Charkhari	7.55	661.2	1102	82.16	25.47	113.25	13.70	396.50	0	170.16	33.40
89	Jataura	Charkhari	7.43	637.2	1062	76.15	46.17	104.75	1.24	579.50	0	95.72	35.80
90	Kharela	Charkhari	7.48	2016.0	3360	144.29	137.40	395.50	2.52	628.30	0	638.10	217.00
91	Pahretha	Charkhari	7.62	477.6	796	42.08	29.17	109.25	0.00	518.50	0	14.18	3.40
92	Punniyan	Charkhari	7.68	1042.8	1738	32.06	29.18	349.50	1.06	756.40	0	49.63	189.50
93	Dhawari	Charkhari	7.40	705.0	1175	52.10	38.90	149.00	1.32	707.60	0	53.18	11.00
94	Gudha	Charkhari	7.63	471.6	786	76.15	30.34	71.76	0.00	500.20	0	28.36	3.30
95	Jarauli	Charkhari	7.62	472.2	787	60.12	42.54	65.28	1.80	445.30	0	31.91	7.80
96	Gaurahari	Charkhari	7.34	576.0	960	128.26	25.41	48.77	0.00	384.30	0	77.99	31.30
97	Bapretha	Charkhari	7.69	1147.2	1912	40.08	20.65	443.50	0.00	713.70	0	53.18	426.00
98	Bhatewara Kalan	Charkhari	7.55	553.8	923	70.14	37.66	97.39	0.00	524.60	0	63.81	2.00
99	Gorkha	Charkhari	6.90	2130.0	3550	585.17	69.90	80.86	1.00	207.40	0	538.84	232.00
100	Chhedimau	Charkhari	7.06	566.4	944	124.25	21.76	42.57	2.26	298.90	0	102.81	73.00
101	Luhari	Charkhari	7.17	541.2	902	108.22	15.70	53.85	0.00	341.60	0	85.08	32.30
102	Akathauha	Charkhari	7.63	480.0	800	78.16	35.21	46.75	0.00	384.30	0	46.09	31.10
103	Asthaun	Charkhari	7.62	523.2	872	54.11	32.81	94.07	0.00	475.80	0	42.54	18.10
104	Supa	Charkhari	7.56	495.0	825	80.16	33.99	58.13	0.00	524.60	0	24.82	1.50
105	Mitlain Ganj	Charkhari	7.35	357.6	596	64.13	15.75	51.67	0.00	372.10	0	17.73	7.10

All constituents in mg/l.

Appendix 2

Sl. No	Village	LSI	PSI	RSI	Larson ratio	PPGC
1	Ladpur	0.25	6.31	7.01	0.14	3.68
2	Bamhauri Khurd	0.33	5.86	6.74	0.39	0.39
3	Kulpahar	0.16	6.29	7.10	0.10	1.84
4	Belatal	0.26	5.70	6.72	0.37	1.12
5	Jaitpur	0.71	4.21	5.70	0.96	1.90
6	Mawaiya	0.29	5.95	6.81	0.24	2.43
7	Ajnar	0.23	5.54	6.63	0.75	1.92
8	Tikariya	0.55	5.12	6.12	1.48	2.67
9	Syavan	-0.57	7.20	8.02	1.12	2.08
10	Indrahata	-0.17	6.91	7.59	0.26	2.13
11	Bhagari	0.34	5.24	6.42	0.62	4.32
12	Ghaghaura	-0.92	7.66	8.55	0.95	2.15
13	Bijauri	0.37	5.71	6.64	0.17	3.17
14	Baghaura	0.46	5.25	6.28	1.38	2.54
15	Saguniya Maph	0.34	5.92	6.76	0.23	2.46
16	Akona	0.53	5.18	6.22	0.57	3.42
17	Mahua Bandh	-0.12	6.73	7.49	0.21	1.83
18	Leva	0.58	5.41	6.27	0.43	1.69
19	Rikhawaha	0.54	5.41	6.28	0.65	2.83
20	Rawatpura	0.47	5.64	6.50	0.22	0.78
21	Mudhari	0.71	5.43	6.12	0.96	1.58
22	Sirmaur	0.85	4.12	5.55	1.15	1.27
23	Sugira	0.48	5.29	6.33	1.10	2.50
24	Baura	0.44	5.52	6.45	0.26	1.49
25	Bharwara	0.61	5.58	6.35	0.49	1.63
26	Panwari	0.66	5.20	6.12	0.72	1.63
27	Bahadurpur Kalan	0.55	5.83	6.53	0.44	2.81
28	Mahob kanth	0.41	6.60	6.96	0.09	1.84
29	Manki	0.37	6.03	6.77	0.36	9.14
30	Rurikalan	0.57	5.65	6.49	0.18	2.75
31	Ghutai	0.47	4.77	6.02	2.44	2.51
32	Pachpahra	0.59	4.80	5.93	2.83	3.43
33	Bhujpura	0.47	6.16	6.62	0.51	2.78
34	Dadri	0.85	4.56	5.70	1.48	2.03
35	Tolapanter	0.59	5.82	6.44	0.58	2.55
36	Nakra	0.51	6.13	6.68	0.10	4.01
37	Saudhi	0.58	5.97	6.54	0.16	3.31
38	Masudpura	0.59	6.42	6.68	0.12	3.93
39	Baidaun	0.65	6.16	6.59	0.05	6.75
40	Rupnaul	0.58	6.24	6.67	0.08	5.06
41	Dharwar	0.57	6.57	6.81	0.13	4.06
42	Kashipura	0.40	7.32	7.19	0.16	2.60
43	Teiya	0.59	6.51	6.73	0.15	4.97
44	Kilhauha	0.51	6.10	6.70	0.24	2.17

Sl. No	Village	LSI	PSI	RSI	Larson ratio	PPGC
45	Mahua Itaura	1.01	5.13	5.85	0.53	5.57
46	Vijaypur	0.68	6.10	6.48	0.13	5.15
47	Chandao	0.57	4.94	6.07	1.85	2.46
48	Pachpahra	0.80	5.72	6.15	0.43	2.09
49	Nanora	1.00	5.72	5.99	0.38	1.70
50	Atrar Maaf	0.36	6.11	6.79	0.11	3.48
51	Kaimaha	0.16	7.06	7.31	0.15	3.05
52	Pipra Maaf	0.22	6.21	6.89	0.83	3.99
53	Sijaria	0.24	6.43	6.91	1.01	4.36
54	Dhikwaha	0.26	6.34	6.86	1.05	2.64
55	Srinagar	0.71	5.78	6.32	1.02	4.39
56	Sijahri	0.74	4.97	5.87	1.54	3.46
57	Salarpur	0.38	5.44	6.40	1.36	3.81
58	Palka	0.17	6.38	7.07	0.12	1.82
59	Mirtala	0.41	6.02	6.71	0.59	1.67
60	Kumhrora	0.03	6.80	7.30	0.88	1.84
61	Paswara	0.63	5.98	6.48	0.14	1.78
62	Ratauli	0.66	5.95	6.44	0.35	2.90
63	Kidari	0.49	5.03	6.28	0.07	0.00
64	Kali Pahari	0.51	5.59	6.44	0.22	2.27
65	Gugaura	0.62	5.79	6.45	0.24	5.64
66	Baghwa	0.65	5.77	6.41	0.49	3.23
67	Pahra	0.62	6.05	6.56	0.48	2.53
68	Kabrai	0.62	6.11	6.60	0.30	2.56
69	Dharaon	0.54	6.00	6.58	0.09	3.28
70	Bilbai	0.69	4.70	5.86	1.86	2.69
71	Mahoba	0.81	5.49	6.11	0.61	2.96
72	Kauhari	0.78	5.64	6.34	1.67	0.17
73	Kaneri	0.67	5.85	6.37	0.60	2.06
74	Parsaha	0.77	5.81	6.29	0.13	10.12
75	Banri	0.74	5.85	6.49	0.65	0.26
76	Gaihra	1.01	5.91	6.20	0.11	2.24
77	Ganj	0.39	5.07	6.22	2.02	1.43
78	Gopalpura	0.12	6.12	7.08	0.08	2.95
79	Naredi	0.67	5.85	6.35	0.47	3.50
80	Swasa Maf	0.59	6.07	6.53	0.11	3.79
81	Bari	0.76	5.62	6.26	0.53	1.77
82	Bambhauri Kalan	0.32	6.15	6.90	0.06	5.06
83	Kakun	0.37	5.80	6.76	0.06	3.77
84	Bamrara	0.34	6.12	6.88	0.06	17.72
85	Imaliya Dang	0.57	4.76	5.92	1.72	2.04
86	Karahra Kalan	0.21	5.97	6.87	0.15	1.09
87	Chhikahra	0.40	5.74	6.62	0.24	1.73
88	Charkhari	0.40	6.07	6.74	0.84	5.09
89	Jataura	0.41	5.56	6.59	0.36	2.67
90	Kharela	0.73	4.98	6.01	2.18	2.94
91	Pahretha	0.31	6.22	6.99	0.05	4.17
92	Punniyan	0.38	5.95	6.90	0.43	0.26

Sl. No	Village	LSI	PSI	RSI	Larson ratio	PPGC
93	Dhawari	0.30	5.60	6.78	0.14	4.83
94	Gudha	0.56	5.75	6.49	0.10	8.59
95	Jarauli	0.40	6.13	6.81	0.14	4.09
96	Gaurahari	0.38	5.71	6.57	0.45	2.49
97	Bapretha	0.46	5.85	6.76	0.88	0.12
98	Bhatewara Kalan	0.46	5.77	6.62	0.21	31.90
99	Gorkha	0.27	5.44	6.35	5.89	2.32
100	Chhedimau	-0.02	6.12	7.10	0.90	1.40
101	Luhari	0.08	6.03	6.99	0.54	2.63
102	Akathauha	0.46	6.13	6.70	0.30	1.48
103	Asthaun	0.38	6.13	6.85	0.20	2.35
104	Supa	0.53	5.64	6.48	0.08	16.54
105	Mitlain Ganj	0.09	6.32	7.15	0.10	2.49
	Mean	**0.46**	**5.82**	**6.58**	**0.62**	**3.42**

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Declarations

Conflict of Interest The author declares that he has no conflict of interests.

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