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Consequences of Urbanization on Water Quality in the Agro-ecosystems Along the Rural-Urban and Transition zones of Bengaluru Metropolitan City

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A B S T R A C T

Urbanization and its consequences on water quality is one of the important crises that need immediate attention. It has come to a stage of utilizing all available water resources and therefore it is a matter of level of contamination and the purpose. This study is an attempt to see the water quality in the agro-ecosystems along rural urban transition zones (RUT) of Bengaluru in terms of the suitability of water for major utilities such as drinking purpose, irrigation and for livestock use. Water quality is determined based on specific physical, chemical and biological surrogates in ground water bodies (n=30) located in agriculture lands. The mean water quality index of urban ground water suggest that it is not suitable for drinking but, fairly suitable for irrigation and industrial use (C3 and C4 category), while in the transition and rural area it is again not suitable for drinking purpose but suitable for irrigation and industrial use (C2 category). Piper tri-linear diagram indicate that majority of the ground water samples belong to mixed Ca^{2+}–Mg^{2+}– Cl^{-}–SO_2^{4-} type and continuous use of this water leads to soil degradation and crop damage in agroecosystems. Results indicate that water quality in the RUT is depilating and cannot be used for human consummations. Hence there is an immediate need to put water resource management in place.

Introduction

The global demand for water is increasing at 1% annually as a function of population growth, economic development and changing consumption patterns (WWAP, 2018), on the other hand water quality is also depleting at an alarming rate. Globally, water used for drinking purpose by at least two billion people is contaminated (Anon 2018) which transmit diseases such as diarrhea, cholera, dysentery, typhoid, and polio. Contaminated water is estimated to cause 5,02,000 deaths due to diarrhea alone each year (Anon, 2018). India is ranked at 120th among 122 countries in the water quality index. In India currently, 600 million people face high to extreme water shortage, with around two lakh people dying every year due to inadequate access to potable water (NitiAayog, 2018). In the arid and semi-arid regions of the world, livestock commonly use poor or marginal quality drinking water for several months of the year. These supplies originate from small wells, canals, streams or 'water holes', only the better of which are also used for agriculture. Occasionally such water is high in salt which may cause physiological disorders or even death in livestock. The main disorder reported is depression of appetite, which is usually caused by a water imbalance rather than related to any specific ion. Most common exception is water containing high levels of magnesium which is known to cause scouring and diarrhea (Ayers and Westcot, 1994**)**. Agriculture is another most important sector that has consumed ~90% of global fresh-water resources during the past century (Shiklomanov, 2000). Agriculture is also considered to be one of the major sectors that use most of fresh water for irrigation, which vary greatly in quality depending upon the type and quantity of dissolved salts. Salts are present in irrigation water in relatively small but significant amounts (Ayers and Westcot,1994). After irrigation, some of the irrigated water move below the root zone but, when water evaporates from the soil surface these salts accumulate in the root zone (Hopmans and Immerzel, 1988) and affect the water uptake by crops to such an extent that it can reduce yields significantly (Ayers and Westcot, 1994).The concentrations of high sodium or low calcium either in soil or water reduces the rate at which water can enter the soil to such an extent that sufficient water cannot be infiltrated to supply adequate water from one irrigation to the next. Certain ions (sodium, chloride, or boron) from soil or water accumulate in a sensitive crop to concentrations high enough to cause crop damage and reduce yields (Ayers and Westcot, 1994). Bengaluru, also known as Silicon Valley and Information Technology corridor of India, occupies an area of 741 km^2. Bengaluru was a small sustainable green city until the time of economic liberalization, which led to industrial revolution in 1990's, and advent of the Information and communication sectors in 2000's. Due to these changes a sudden spurt in population is seen which increased drastically from three to eight million by 2011. The rapid urbanization has brought in fundamental changes in land use (Ramachandra *et al.,* 2012), agriculture and water. It is important to note that all these three natural resources are closely inter-connected and have serious implications on health, livelihood and economy. The impact on ground water (both quantity and quality) is very critical, as Bengaluru relies heavily on ground water resources. Ground water contributes to fifty percent of the urban requirements and eighty percent of the drinking water in rural areas (Hunse, 2008). However, urbanization has drastically depleted the ground water resources in the past few decades. As per records, till 1960 there were 262 water bodies in Bangalore and today it has only around 81, of which 34 are recognized as live lakes (Anon, 2017). In the urban Bangalore, water bodies use to cover about 5% of the land (Anon, 2017) which has diminished to 3.4 per cent by 1973, to less than 1 per cent by 2013 (Goswami, 2017). Along with the decreasing water levels nearly 85 per cent of the water bodies are severely polluted (Anon, 2017). The demand for water in expanding Bengaluru is increasing every day but the quantity and quality of the surface and ground water are decreasing rapidly. Agriculture is one such sector that gets affected as well as affects the water both in terms of quantity and quality. Globally, among prominent factors that contaminate water agriculture is considered to be the most prevalent one. Majority of nutrient emissions originate from agriculture (WWAP, 2019). More than 80% of sewage in developing countries is discharged untreated that pollute rivers, lakes and coastal areas (WWAP, 2019).

Thus increasing agriculture productions and increasing wastewater effluents associated with increasing population has affected the water bodies both in urban and adjoining rural areas of Bengaluru. However, there is no systematic analysis of water quality across the rural, urban and the transition regions of Bengaluru cosmopolitan city to that delineate the role of agriculture in water pollution. In this context present study is an attempt to assess the influence of Agriculture on water quality in the RUT zones.

Materials and Methods

Study area

To understand the water quality status in rural urban transition, we laid two transacts in north and south Bengaluru by using the survey stratification index (Hoffmann *et al.*, 2017).

The Northern transect (N-transect) is a rectangular stripe of 5 km width and 50 km length, as shown in Figure 1. The lower part of this transects represent urban Bangalore, and the upper part represent rural villages and the middle portion is considered as transition zone. The Southern transect (S-transect) is a polygon covering a total area of ca. 300 km^2 (Figure 1). The zonation in this transect into urban, rural and transition zones is same as explained above in case of N-transect.

Site selection

The list of villages and urban areas is compiled using satellite images from Bhuvan website, a mapping tool. Altogether, there were 93 villages and urban units in the N-transect and 98 villages and urban units in the S-transect. The urban units and village classification in transect is primarily based on percentage of built-up area in a defined perimeter around a village and linear distance between a village center and the city center. Both components, building density and distance, were combined for calculate the Survey Stratification Index to classify RUT (Hoffmann *et al.*, 2017). From this a total of 36 (six sites in all the three identical zones of both transects) villages and urban units were randomly selected to assess the water quality status in rural urban interface.

Water sample collection

In identical zones of RUT, rural and transition zone shares 12 villages each and 12 unban units (six sites in all the three identical zones of both transects)were selected total of 60 water samples were collected during October 2017 and October 2018. In each identical zone 10 bore wells (underground) water samples (five bore well sampled in all the three identical zones of both transects) were collected to quantify the underground water quality status of Agroecosystemin RUT (sample location details are given in Table 5). Water bodies were selected with in one kilometer radius of agricultural activities in the villages and in urban units. The ground water samples were collected after 10 min of pumping of bore wells and stored in polyethylene bottles.

Water sample analysis for physical and chemical properties

The water samples were analyzed for pH, Conductivity, Salinity, TDS, and Turbidity, using combined water analyzer (Systronics, Model-371, India). The quality assessment is based on the quantification of Potassium, Magnesium, and heavy metals using the Inductively Coupled Plasma Optical Emission Spectrometry (ICPSOES) (Thermo Scientific iCAP 7000 Series, India).Total hardness was calculated using the expression total hardness= 4,1(Mg^{2+})+2,5(Ca^{2+}), Sodium using Flame Photometric method. Calcium (EDTA Titrimetric Method), Chloride (Argentometric

Method), Sulfates (IS: 3025 (Part-24)), Bicarbonates (Titration method), Nitrates (Chromotropic acid method) were analyzed by using standard protocols.

Data analysis

Water Quality Index (WQI)

WQI was calculated by using Horton's method the expression given in Equation.

$WQI = \Sigma q_n W_n / \Sigma W_n$

Where,

q_n= Quality rating of n^{th} water quality parameter.

W_n= Unit weight of n^{th} water quality parameter.

Quality rating (qn)

The quality rating (qn) is calculated using the expression given in Equation.

$q_n = [(V_n - V_{id}) / (S_n - V_{id})] \times 100$

Where,

Vn= Estimated value of n^{th} water quality parameter at a given sample location.

V_{id}= Ideal value for n^{th} parameter in pure water.

(V_{id} for pH = 7 and 0 for all other parameters)

S_n= Standard permissible value of n^{th} water quality parameter.

Unit weight (Wn) (Table 4)

The unit weight (Wn) is calculated using the expression given in Equation.

$W_n = k / S_n$

Where,

S_n= Standard permissible value of n^{th}water quality parameter.

k = Constant of proportionality, calculated by using the Equation.

$k = [1 / (\Sigma 1/ S_{n=1,2,..n})]$

Sodium absorption ratio (SAR)

$SAR= Na^{+}/ (Ca^{2+} + Mg^{2+} / 2)^{-1}$

Where all ionic concentrations are expressed in meq/L.

All the data analysis were carried out in Microsoft XL. 2013 and XL SAT. Software. Maps were created by using QGIS open software and Google earth. In addition to this the analytical values obtained for ground samples are plotted on Piper (1994) trilinear diagram using Microsoft XL. 2013 to know the hydrochemical regime of the study area. In addition to this, US Salinity Laboratory hazard diagram was employed to classify and determine the suitability of ground and surface water for irrigation by correlating sodium absorption ratio/electrical conductivity.

Results and Discussion

The analytical results of water quality assessed in agroecosystems across the RUT are presented here. The results are discussed in the light of various quality guidelines prescribed for specific water uses such as for human drinking purpose, irrigation of agriculture land and for livestock consumption along the rural, urban and transition zones of Bengaluru. The results presented here are based on the data obtained for two consecutive years of 2017 and 2018 during the month of October.

Water quality index

The water quality index of ground water along the RUT, urban water quality index ranges from 16.60–249.29 in 2017 and 16.43–249.29 in 2018, water quality index ranges in between C1 (Excellent Drinking, Irrigation and Industrial) and C6 (Unfit for Drinking Proper treatment required before use) however mean water quality was 72.58 in 2017 and 74.52 in 2018 which falls in C3 category (Fair Irrigation and Industrial) (Table 1).

In transitional zone water quality ranged from 14.11–83.33 in 2017 and 12.20–63.29 in 2018, water quality falls in between C1 (Excellent Drinking, Irrigation and Industrial) and C4 (Poor Irrigation)range but mean water quality of ground water of transition zone was 32.44 in 2017 and 33.00 in 2018, which falls in C2 (Good Domestic, Irrigation and Industrial) category. Rural water quality of ground water ranges from 3.51 to 46.53 in 2017 and 1.39 to 47.77 in 2018, which shows that water quality index in rural ground water falls in between C1 (Excellent Drinking, Irrigation and Industrial) to C2 (Good Domestic, Irrigation and Industrial)category but the mean water quality was 46.35 in 2017 and 39.43 in 2018 which falls in C2 (Good Domestic, Irrigation and Industrial) category. The parameters selected for quantification of Water quality index and there classification was given in supplementary tables 6 and 8 respectively.

The above results indicate that the water quality is better as we move towards the rural zone from the urban zone among the RUT of Bengaluru. Similar studies conducted earlier (Ravikumar *et al.,* 2013) in two water bodies in Bengaluru (Sankey tank and Mallathahalli lake) found that, Sankey tank water falls under good water class (50-100) while Mallathahalli lake water fall under poor water (100-200) category.

Comparison of physicochemical properties of water

One of the important water quality determining factors is the pH of water, which is a numerical expression of degree to which water is acidic or alkaline or the corrosive nature of water. Lower pH value tends to make water corrosive and higher pH leads to bad taste and has negative impact on skin and eyes (Rao and Rao, 2010). The maximum and minimum, pH of the ground water in the RUT ranged from 6.32 to 7.95 (2017) and 6.20 to 8.67 (2018) while pH value of ground water in urban areas is in the range of slightly acidic to neutral, in case of transition and rural zones it was in the range of slightly acidic to slightly alkaline. On the whole mean values of urban, transition and rural ranges it is found to be slightly acidic to neutral (Table 2 and 3). Though the pH values did not exceed the standards prescribed for drinking, irrigation as well as for livestock use at present, there is every possibility that the values would reach the undesirable limits soon in ground water (BSI, 2012).

Electrical conductivity of water is a function of total dissolved salts and is used as an indicator to represent the concentration of soluble salts in water (Purandara *et al.*, 2003; Gupta *et al.*, 2008) whose concentration beyond certain levels render water unfit for drinking, irrigation and livestock uses. The mean conductivity values recorded in ground water in rural region were higher than in the urban and transition zones (Table 2 and 3), but well within the permissible limits for drinking, irrigation and livestock use. Classification of water bodies based on Electrical conductivity illustrates that the water ranges from low (C1) salinity to very high (C4) salinity (Fipps, 2003; Ravikumar *et al.,* 2013) along the RUT zones of Bengaluru (Tables 7 and 8). Similar trends were reported from earlier studies, and is attributed to high degree of anthropogenic interferences such as waste disposal, sewage inflow and agriculture runoff in the rural areas (Pandit, 2002).

Total dissolved solids (TDS) that mainly consists of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium etc, and small amount of organic matter. The mean concentration of TDS for potable water in the agro-ecosystem along the RUT was in the range of 616 – 871.50 mg/L (2017), 873.50 – 547.80 mg/L (2018) for ground water. For ground water, maximum concentration of TDS was fund in the rural zone (2420 mg/L) followed by the transition (1430mg/L) and urban zones (960mg/L) (Table 2 and 3). TDS concentration in RUT ground water for drinking purpose exceeded the desirable limits of BSI standards but within the acceptable limit (2000 mg/L). Though the TDS value does not cross the desirable limits for irrigation and livestock water in the RUT, results suggests that along the RUT it is in the alarming condition for ground water (BSI, 2012).

Turbidity is the measure of relative clarity of a liquid. Material that cause turbidity of water include clay, silt, finely divided inorganic and organic matter, algae, soluble colored organic compounds, and plankton and other microscopic organisms presence in the water. Urban ground water was showing highest mean turbidity [1.57 NTU (2017); 1.60 NTU (2018)), compared to rural (1.052 NTU (2017); 0.908 NTU (2018)] and transition [0.717 NTU (2017); 0.76 NTU (2018)] in the agro-ecosystems along RUT. The mean turbidity of urban ground water exceeded the prescribed BSI standards for drinking water, while in case of transition and rural areas ground water turbidity was within the desirable limits. The ground water of urban area was detected with high turbidity because of more inorganic salts, suggesting higher rates of pollution in the ground water (Table 2 and 3). Turbidity doesn't affect human health directly, but provides a congenial atmosphere for microbial growth which in turn causes diseases in human and animal upon consumption (Anon, 2019).

The Mean total hardness of ground water was found highest in rural areas in 2017 (313.75 mg/L), however in 2018 it was in urban areas (306.8 mg/L), followed by transition areas in 2017, but in 2018 both in rural and transition (Table 2 and 3) zones. The total hardness of ground water for drinking purpose are within the acceptable limits, however maximum values crossed the desirable limits for ground water. The total hardness of water is due to the presence of polyvalent cat-ions (ions with a charge greater than +1). Presence of cat-ions in irrigation water helps in supplying secondary nutrients to the plants. Hardness mitigates metal toxicity in fish culture, because Ca^{2+} and Mg^{2+} help keep fish from absorbing metals such as lead, arsenic, and cadmium into their blood stream through their gills. The greater the hardness, the harder it is for toxic metals to be absorbed (Anon, 2019).

Table.1 Water quality index in RUT zones of Bengaluru over two consecutive years

Water Quality Index						
	Ground water 2017			Ground water 2018		
Zones	Average	Max.	Min.	Average	Max.	Min.
Urban	72.58	249.29	16.60	74.52	236.67	16.43
Transitions	32.44	83.33	14.11	33.00	63.29	12.20
Rural	24.02	46.23	3.51	26.23	47.77	1.39

Table.2 Minimum, maximum, and mean values of physico-chemical parameters of ground water

Sl. no	Category	Characteristics	Max			Min.			Mean			BSI (2012) Acceptable limit	Maximum permissible limits FAO, BSI, Fipps (2003)	
			Oct/17			Oct/17			Oct/17					
			U	**T**	**R**	**U**	**T**	**R**	**U**	**T**	**R**	**DW**	**IW**	**LW**
1	General parameters	pH	7.09	7.95	7.76	6.44	6.56	6.64	6.79	7.23	7.26	6.5-8.5	6.5-8.5	6.5-8.5
		EC (µS/L)	1600	2210	4010	650	180	152	1028.10	1026.3	1447.50	2000	750-2000	1500
		Salinity (mg/L)	580	760	880	240	50	50	363	359	516	-	-	-
		TH (mg/L)	503.01	551.54	603.43	173.04	158.60	149.76	308.80	258	313.75	200-600	-	300
		TDS (mg/L)	960	1430	2420	388	64.7	91	623.40	616.87	871.50	500-1000	450-2000	3000
		Turbidity (NTU)	2.8	1.9	3.10	0.56	0.16	0.14	1.57	0.717	1.052	1	-	-
2	Major cations	K (mg/L)	22.79	15.91	6.285	2.44	1.043	1.857	7.40	7.45	3.9642	10	2	-
		Na(mg/L)	98.3	95.23	89	67.32	63.23	44.3	84.49	74.20	70.441	100	69	-
		Mg(mg/L)	48.11	101.41	70.775	18.41	0.805	11.35	25.86	32.23	35.8047	30	-	250
		Ca(mg/L)	122.3	138.2	125.3	38.9	24.3	24.3	81.1	61.14	66.78	75	-	500
3	Major anions	NO_3(mg/L)	112.30	79.40	89.20	59.30	52.30	47.8	80.77	67.61	68.55	45	-	100
		Cl(mg/L)	165.30	252.30	234.30	68.30	78.10	78.3	105.13	148.06	119.43	250	141.6	-
		SO_4(mg/L)	98.30	75.60	85.30	21.30	23.30	21.3	47.10	47.95	50.00	200	-	500
		HCO_3(mg/L)	189.93	256.30	230.30	89.64	38.20	98.66	138.03	136.02	139.22	-	-	500
4	Heavy Metals	Al(mg/L)	2.98	5.67	6.28	0.98	1.01	4.94	0.518	1.571	1.122	0.03	5.0	5.0
		As(mg/L)	0.015	0.01	0.009	0.001	0.001	0.001	0.0071	0.0036	0.003	0.01	0.10	0.2
		Ag(mg/L)	0.015	0.05	0.009	0.001	0.001	0.001	0.006	0.0085	0.0036	0.1	NA	NA
		B(mg/L)	0.005	0.012	0	0.001	0.006	0	0.0006	0.0018	0	0.5	0.7	5.0
		Fe(mg/L)	0.5	0.56	0.8	0.001	0.001	0.001	0.1057	0.1465	0.1254	0.3	5.0	NA
		Co(mg/L)	0.015	0.02	0.001	0.002	0.001	0.001	0.002	0.0025	0.0001	-	0.05	1.0
		Ni(mg/L)	0.275	0.007	0.006	0.002	0.002	0.001	0.0297	0.0014	0.0012	0.02	0.2	NA
		Zn(mg/L)	1.245	0.186	0.5	0.012	0.002	0.002	0.2032	0.0328	0.1167	5	2.0	24
		Pb(mg/L)	0.008	0.01	0.013	0.003	0.001	0.001	0.0042	0.005	0.0037	0.01	5.0	0.1
		Mn(mg/L)	2.888	0.72	0.164	0.002	0.006	0.003	0.4044	0.1008	0.0375	0.1	NA	0.05
		Cu(mg/L)	0.002	0.004	0.003	0.001	0.001	0.001	0.0006	0.0012	0.0009	0.05	0.2	0.5

Table.3 Minimum, maximum, and mean values of physico-chemical parameters of ground water

Sl. no	Category	Characteristics	Max			Min.			Mean			BSI (2012) Acceptable limit	Maximum permissible limits FAO, BSI, Fipps (2003)	
			Oct/18			Oct/18			Oct/18					
			U	T	R	U	T	R	U	T	R	DW	IW	LW
1	General parameters	pH	7.10	7.84	7.72	6.42	6.32	6.65	6.81	7.15	7.19	6.5-8.5	6.5-8.5	6.5-8.5
		EC (µS/L)	1625	2220	4024	245	181	157	1047.8	1038	1454.50	2000	750-2000	1500
		Salinity (mg/L)	581	761	881	750	52	51	370.60	361.90	518.90	-	-	-
		TH (mg/L)	492.84	548.18	471.35	158.32	162.73	166.19	306.83	281.60	302.79	200-600	-	300
		TDS (mg/L)	821	1430	2430	196	78	96	547.80	616.90	873.50	500-1000	450-2000	3000
		Turbidity (NTU)	2.9	2	3.10	0.56	0.16	0.14	1.60	0.76	0.908	1	-	-
2	Major cations	K (mg/L)	21.78	14.67	6.28	2.04	1.256	1.20	7.78	7.10	3.49	10	-	-
		Na (mg/L)	99.32	96.23	97.3	69.32	67.23	43.2	85.894	75.508	74.801	100	69	-
		Mg (mg/L)	46.23	102.41	71.45	18.542	0.805	12.03	26.19	31.60	36.35	30	-	250
		Ca(mg/L)	121.31	140.23	114.2	28.91	24.31	24.3	79.78	60.81	61.49	75	-	500
3	Major anions	NO_3 (mg/L)	113.65	72.31	86.30	54.32	51.23	46.82	79.90	61.29	66.88	45	-	100
		Cl(mg/L)	165.32	252.32	224.30	69.31	70.31	78.30	112.85	145.35	118.26	250	141.6	-
		SO_4 (mg/L)	98.30	75.60	85.30	21.3	23.30	21.30	47.10	47.95	44.84	200	-	500
		HCO_3 (mg/L)	168.23	256.34	167.32	57.34	39.21	38.34	115.75	145.21	103.25	200	-	500
4	Heavy Metals	Al (mg/L)	2.45	5.95	5.21	1.98	0.95	4.23	0.675	1.534	0.944	0.03	5.0	5.0
		As (mg/L)	0.018	0.012	0.009	0.003	0.001	0.003	0.0075	0.0038	0.003	0.01	0.10	0.2
		Ag (mg/L)	0.018	0.054	0.009	0.002	0.001	0.002	0.0068	0.014	0.0036	0.1	NA	NA
		B (mg/L)	0.008	0.008	0	0.002	0.001	0	0.0009	0.0012	0	0.5	0.7	5.0
		Fe (mg/L)	0.5	0.56	0.2	0.003	0.003	0.004	0.1066	0.2255	0.0458	0.3	5.0	NA
		Co (mg/L)	0.065	0.021	0.001	0.005	0.002	0.001	0.008	0.0032	0.0001	-	0.05	1.0
		Ni (mg/L)	0.275	0.006	0.006	0.002	0.001	0.001	0.0297	0.0013	0.0012	0.02	0.2	NA
		Zn (mg/L)	1.245	0.182	0.3	0.012	0.003	0.002	0.2032	0.0447	0.0667	5	2.0	24
		Cr(mg/L)	0	0.004	0.002	0	0.001	0.001	0	0.0005	0.0003	0.05	0.1	1.0
		Pb(mg/L)	0.008	0.012	0.013	0.003	0.002	0.001	0.0042	0.0046	0.0044	0.01	5.0	0.1
		Mn(mg/L)	2.888	0.72	0.087	0.002	0.002	0.007	0.4044	0.1232	0.0378	0.1	NA	0.05
		Cu(mg/L)	0.03	0.004	0.003	0.001	0.001	0.001	0.0057	0.0016	0.0014	0.05	0.2	0.5

Fig.1 Map of the North and South transects of Bengaluru where study was conducted

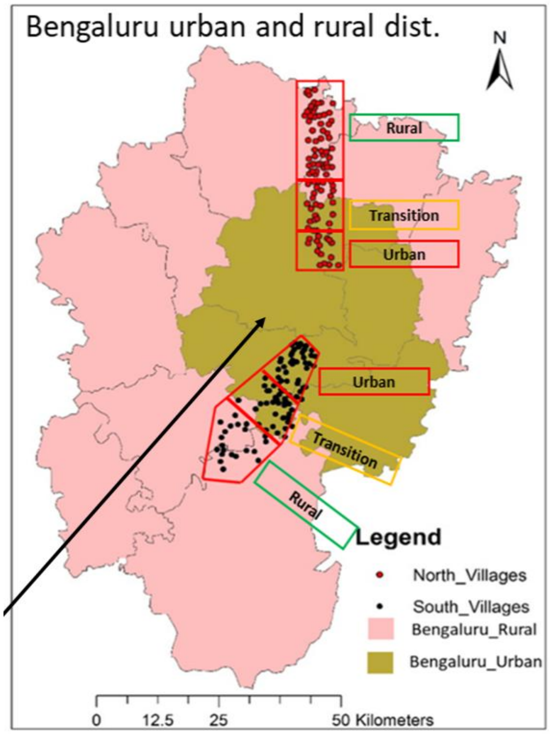


Fig.2 Piper diagram ground water samples of 2017

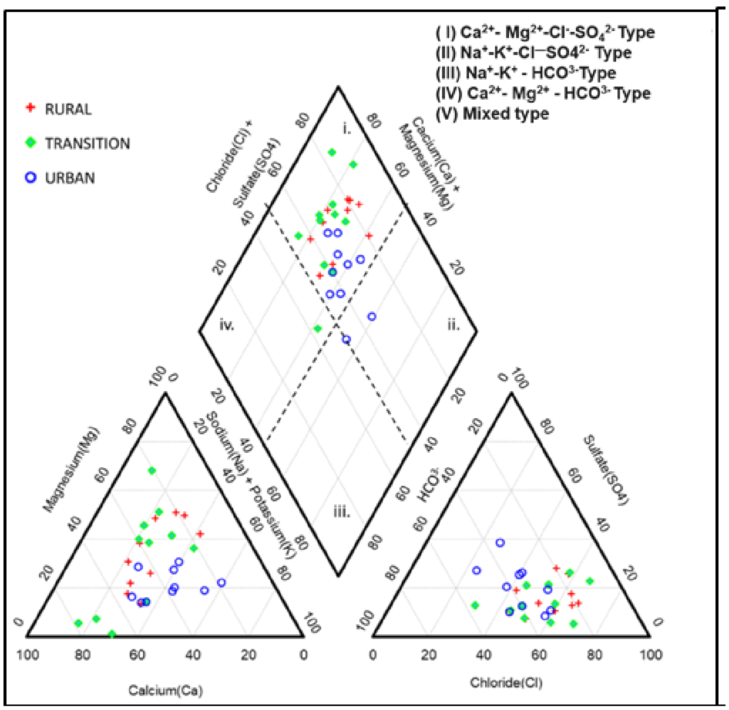


Table.4 The k-value and unit weight of each of the physicochemical parameters used for WQI determination

Parameters	S_n	k-value	W_n
As	0.01	0.003166	0.316606
Ag	0.1	0.003166	0.031661
B	0.5	0.003166	0.006332
Fe	0.3	0.003166	0.010554
Ni	0.02	0.003166	0.158303
Zn	5	0.003166	0.000633
Cr	0.05	0.003166	0.063321
Pb	0.01	0.003166	0.316606
Mn	0.1	0.003166	0.031661
K	10	0.003166	0.000317
Cu	0.05	0.003166	0.063321
Na	100	0.003166	0.000032
Mg	30	0.003166	0.000106
Ca	75	0.003166	0.000042
No3	45	0.003166	0.000070
Cl	250	0.003166	0.000013
Sulphate	200	0.003166	0.000016
Ph	8.5	0.003166	0.000372
TDS	500	0.003166	0.000006
EC	2000	0.003166	0.0000016
total hardness	300	0.003166	0.000011
		ΣWn = 1.000	

Fig.3 Piper diagram ground water samples of 2018

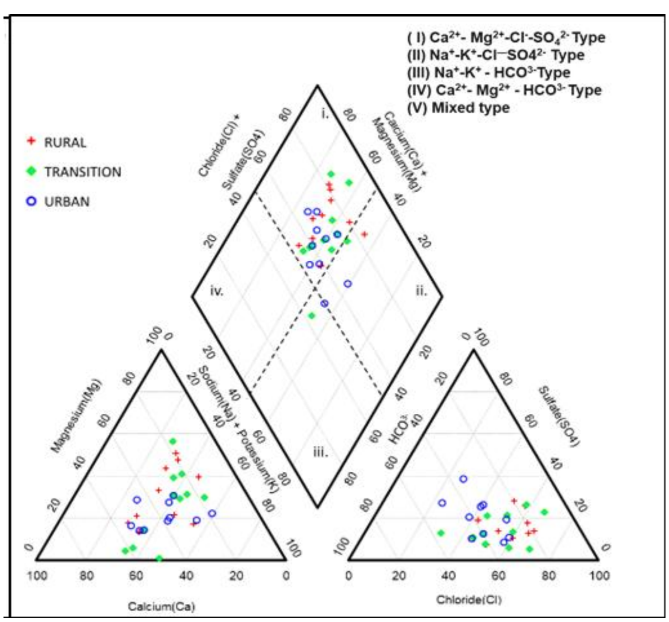


Table.5 Ground water samples locations

Transect zones	Latitudes	Longitudes
South urban	12°53'2.45"N	77°34'26.55"E
South urban	12°52'46.66"N	77°34'43.64"E
South urban	12°51'22.28"N	77°35'54.55"E
South urban	12°50'50.70"N	77°35'50.51"E
South urban	12°51'45.28"N	77°31'10.92"E
South transition	12°48'27.41"N	77°30'44.91"E
South transition	12°48'27.33"N	77°31'30.25"E
South transition	12°45'57.06"N	77°32'29.47"E
South transition	12°46'8.95"N	77°31'37.36"E
South transition	12°48'54.16"N	77°33'5.40"E
South rural	12°47'0.77"N	77°28'5.39"E
South rural	12°46'30.73"N	77°28'19.96"E
South rural	12°43'41.60"N	77°29'29.03"E
South rural	12°43'54.88"N	77°28'52.83"E
South rural	12°45'20.34"N	77°26'16.28"E
South urban	77°35'18.39"E	13° 4'4.51"N
South urban	77°36'33.16"E	13° 4'57.27"N
South urban	77°36'12.38"E	13° 5'29.49"N
South urban	77°36'54.36"E	13° 6'18.21"N
South urban	77°34'1.35"E	13° 7'0.77"N
South transition	77°34'51.83"E	13° 7'56.60"N
South transition	77°35'5.93"E	13° 8'25.49"N
South transition	77°36'31.24"E	13° 9'39.16"N
South transition	77°36'53.48"E	13° 9'52.70"N
South transition	77°35'15.97"E	13°12'42.38"N
South rural	77°35'53.91"E	13°15'12.22"N
South rural	77°35'6.06"E	13°16'28.19"N
South rural	77°36'20.92"E	13°20'6.52"N
South rural	77°35'39.24"E	13°20'10.12"N
South rural	77°34'33.41"E	13°22'46.66"N

Table.6 Water quality classification based on water quality index

Category of water	Range of water quality	Uses
C1	0 – 25	Excellent Drinking, Irrigation and Industrial
C2	25 – 50	Good Domestic, Irrigation and Industrial
C3	51 -75	Fair Irrigation and Industrial
C4	76 – 100	Poor Irrigation
C5	101 -150	Very Poor Restricted use for Irrigation
C6	Above 150 Unfit for Drinking Proper treatment required before use.	

Table.7 Classification of irrigation water based on electrical conductivity (Ravikumar, 2013)

	Type of water	**Suitability for irrigation**
1	Low salinity water (C1) conductivity between 100 and 250 µS/cm	Suitable for all types of crops and all kinds of soil.Permissible under normal irrigation practices exceptin soils of extremely low permeability
2	Medium salinity water (C2) conductivity between 250 and 750 µS/cm	Can be used, if a moderate amount of leaching occurs.Normal salt tolerant plants can be grown withoutmuch salinity control
3	High salinity water (C3) conductivity between 750 and 2,250 µS/cm	Unsuitable for soil with restricted drainage. Only highsalttolerant plants can be grown
4	Very high salinity (C4) conductivity more than 2,250 µS/cm	Unsuitable for irrigation

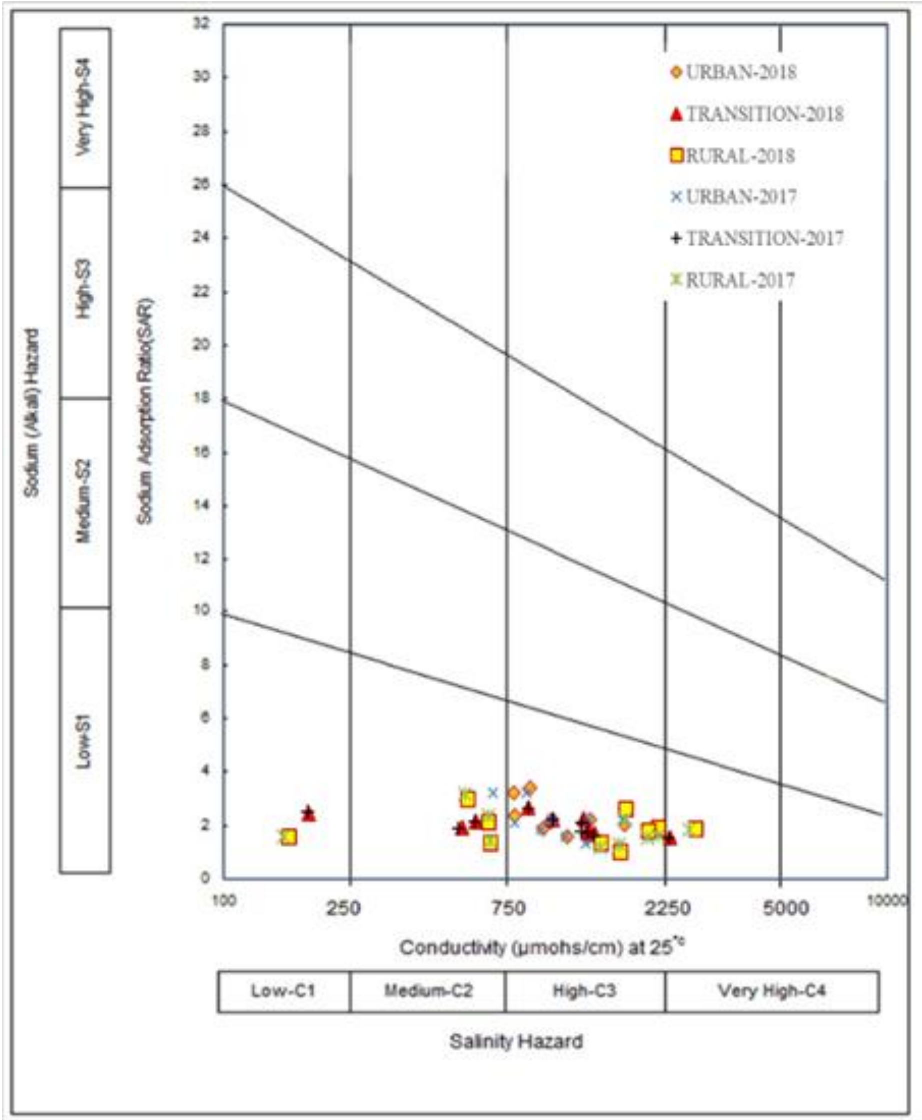
Table.8 Classification of salinity hazard based on the electric conductivity given by USSL, 1954

Categories	Salinity hazard	Interpretation
C_1	Low-salinity water	Used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.
C_2	Medium-salinity water	Used if a moderate amount of leaching occurs. Plants with moderate salt- tolerance can be grown in most cases without special practices for salinity control.
C_3	High-salinity water	Used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.
C_4	Very high salinity water	Not suitable for irrigation under ordinary conditions, but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching and very salt-tolerant crops should be selected.

Table.9 Classification of sodium hazard based on the electric conductivity given by USSL, 1954

Categories	Sodium hazard	Interpretation
S_1	Low-sodium water	Used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However sodium-sensitive crops such as stone fruit trees and avocados may accumulate injurious concentrations of sodium
S_2	Medium-sodium water	Certain fine-textured soils having high cation-exchange capacity under low leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils with good permeability.
S_3	High-sodium water	Produce harmful levels of exchangeable sodium in most soils and will require special soil management
S_4	Very high sodium water	Generally unsatisfactory for irrigation unless special action is taken, such as addition of gypsum to soil (Lyerly and Longenecker, 1957). Whereas USSL diagram classify irrigation water based on EC and SAR.

Fig.4 USSLH diagram for ground water samples



In the RUT ground water ranged in between moderately hard to very hard range (McGowan, 2000; WHO, 2011).

The mean concentration of an-ion and cat-ion was in the order of HCO_3>Cl>NO_3>SO_4 and Na>Ca>Mg>K respectively in ground water of agro-ecosystems along RUT, while the maximum concentration is in the order of HCO_3>Cl>NO_3>SO_4 and Ca>Na>Mg>K respectively during the years 2017 and 2018 (Table 2 and 3).

The NO_3concentration of ground water along the RUT has exceeded the desirable limits for the drinking water, but was within the permissible limits for the livestock use. The maximum concentrations of anion and cations exceeded the desirable limits in urban and transition zone for drinking purpose but the concentration is in alarming condition for rural zone. The anion and cation mean concentrations are within the acceptable prescribed standards for drinking, irrigation and livestock use in the RUT of Bengaluru at present but may not take too long to exceed the stipulated limits.

The heavy metals concentrations in the ground water of agro-ecosystems along the RUT were tabulated in table 2 and 3. Aluminum (Al) concentration in ground water along the RUT ranged between 0.98 – 6.28 mg/L in 2017, however in 2018 Al concentration in ground water ranged between 0.95–5.92 mg/L. The mean Al concentration was found maximum in ground water of transition zone followed by rural and urban regions during 2017 and 2018, (Table 2 and 3). The concentration of aluminum crossed the acceptable limits of BSI for drinking, irrigation and livestock uses.

Other heavy metals such as arsenic, cobalt, nickel, zinc, lead, and manganese mean concentration were found highest in urban, ground water followed by transition and rural zones in both the years but in 2018 chromium was also detected. Silver, boron and iron were detected with highest mean concentration in transitional ground water followed by urban and rural ground water for both the years. Among the RUT, rural areas were found with less concentration of all heavy metals compared to urban and transition zones (Table 2 and 3). Though heavy metal concentration is within the prescribed standards for drinking, irrigation and livestock uses, results indicate that they are fast increasing to alarming levels for all selected end uses of ground water. A very small concentration of heavy metal is capable of producing adverse health effect on human, livestock, plants and other organisms.

Hydrochemical facies

The groundwater water were subject to an analysis based on the Cation and anion concentration using the piper diagram approach (Fig. 2 and 3). From this approach it is found that strong alkalies (Ca^{2+} and Mg^{2+}) significantly exceed the weak alkilies (Na^{+} and K^{+}), and strong acids (Cl^{-} and SO_4^{2-}) significantly exceed the weak acids (HCO_3^{-} and CO_3^{2-}) in ground water of agroecosystems along the RUT of Bengaluru. Most of the ground water samples were of mixed Ca-Mg-Cl type followed by Na-Cl along the RUT of Bengaluru (Fig. 2 and 3). From this analysis it is possible to know the relative abundance of common ions in water samples which helps to understand the future effect on soil health, Bioaccumulation of ions in the food chain (ex. Bioaccumulation of chlorine) and negative and positive effects on crops in the agroecosystems.

Salinity status of water in agroecosystems

We have also used US Salinity Laboratory hazard standards (Richards 1954), constructed based on the correlations of sodium absorption ratio and electrical conductivity, which indicate that all the samples of groundwater from urban zone fall in the C3-S1 (High-salinity water and low hazard sodium) category followed by transition (7 samples out of 10) and rural (5 samples out of 10) zones. In the rural area three samples were found in the category of C2-S1 (Medium-salinity water and low sodium hazard) followed by transition (2 samples). One sample of rural and transition falls in the C1-S1 (Low-salinity water and low sodium hazard) category. Only one sample found in very high salinity water and low sodium hazard (C4-S1) category in rural areas, this is because of harvesting of ground water from deeper depths for irrigation (Fig 4; Table 8 and 9). Most of the ground water samples in the RUT fall in C3-S1 (High-salinity water and low hazard sodium) category (Fig. 4; Table 8 and 9). This means in near future the soil in the RUT will become more saline and may not support many crops that are currently under cultivation in these regions. However in urban areas all the water samples fall in the C3-S1 (High-salinity water and low hazard sodium) category, which means these soils may not be amenable for cultivation where the drainage is inadequate. Despite adequate drainage, special management for salinity control may be required and plants with good salt tolerance may have to be used for cultivation (Mirabbasi, 2008).

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