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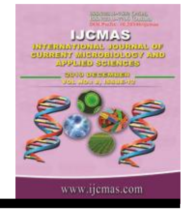

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Consequences of Urbanization on Surface Water bodies Water Quality along the Rural-Urban and Transition Zones of Bengaluru

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A B S T R A C T

Water contamination is one of the many consequential concerns of urbanisation that need immediate attention in most cosmopolitan cities. In Bengaluru, one of the fast growing metropolitan cities in India, most of the water bodies are contaminated. Thus it is critical to ascertain the extent of as well the source of contamination. This study is an attempt to see the water quality in the agro-ecosystems along rural urban transition zones (RUT) of Bengaluru. Water quality is determined based on specific physical, chemical and biological surrogates in both surface water (n=30) bodies located within one kilometer radius of agriculture lands. The mean water quality index of urban surface 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 surface water samples belong to mixed Ca^{2+}–Mg^{2+}– Cl^{-}–SO_2^{4-} type. 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

Urbanization is a contemporary global trend resulting from population growth and migration in search for job opportunities, better education, infrastructure and security. It raises the concentrated demand for food, energy and construction materials at specific locations and leads to the establishment of a rural-urban gradient with targeted flows of basic natural and human resources reflecting major changes in ecosystem services. In developing countries like India, China and Nigeria will account for 35% of the projected growth of the world's urban population between 2018 and 2050 (UN DESA, 2019); in this process, cities may eventually occupy an area equivalent to 7 percentage of the world's arable land, compared with 3percentageduring 2005 (Angel *et al.*, 2005).

Mega cities, urban conglomerations with a population of more than 10 million inhabitants, represent the most advanced state of urbanization. Their effects on surrounding agroecosystems and even at the global ecological scale (Seto *et al.*, 2013) are evident in many Asian cities such as Beijing and Jakarta, but also in rapidly growing Indian cities such as Mumbai and Bengaluru. In the Global South, megacities are growing especially rapidly (Sorensen and Okata, 2010). Three of the world's 19 cities with more than 10 million inhabitants are located in India (Delhi, Mumbai, and Kolkata) and Bengaluru, Hyderabad and Chennai are likely to pass this threshold in the near future (Taubenböck*et al.*, 2008). Bengaluru has been the fastest-growing Indian city over the last 40 years (Narayana, 2011).

Global demand for water is increasing at one per cent annually as a function of population growth and economic development (WWAP, 2018). The UN estimates of waste water production of about 1,500 km^3 $year^{-1}$, six times more water that exists in all the rivers of the world (WWAP, 2003), suggests that the global water scarcity is largely due to deterioration in the quality rather than the physical scarcity of the resource. In India alone, 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).

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 hasonly 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 surface 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 transect 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 water ponds (five water pond sampled in all the three identical zones of both transects) were collected to quantify the surface water quality status of Agroecosystem in RUT (sample location details are given in Supplementary Table 2). Water bodies (mostly ponds) were selected with in one kilometer radius of agricultural activities in the villages and in urban units (Fig. 1a).

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) (Supplementary Table.1)

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 was 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 and surface 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 drinking water (DW), irrigation water (IR) and for livestock consumption (LC)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 surface water in urban zone ranged from 5.85 to 255.65 in 2017 and 8.86 to 232.30 in 2018 and the mean water quality index of urban surface water was 78.56 which falls in C4 (Poor Irrigation and not fit for drinking) category, but it ranges from C1 (Excellent Drinking, Irrigation and Industrial) and C6 (Unfit for Drinking, Proper treatment required before use) category (Table 1). In transitional zone water quality ranged from 2.95–98.87 in 2017 and 5.56–91.10 in 2018, water quality falls in between C1 (Excellent Drinking, Irrigation and Industrial) and C4 (Poor Irrigation and not fit for drinking) but mean water quality of surface water of transition zone was 26.72 in 2017 and 33.80 in 2018 which falls in C2 (Good Domestic, Irrigation and Industrial) category.

Rural zone's water quality index of surface water ranges from 4.89 to 115.82 in 2017 and 6.40 to 102.41 in 2018 which shows that water quality index in rural surface water falls in between C1 (Excellent Drinking, Irrigation and Industrial) to C5 (Very Poor Restricted use for Irrigation) but the mean water quality was 46.35 in 2017 and 39.43 in 2018 which falls in C2 category. In urban area 80% percent of the water bodies analyzed WQI were unsuitable for drinking. The parameters selected for quantification of Water quality index and there classification was given in supplementary tables 1 and 3 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). pH value in the surface water along the RUT vary from 6.7 to 8.67 (2017) and 6.2 to 8.09 (2018) while in the surface water bodies in the urban, transition and rural zones it was slightly acidic to alkaline (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 surface water bodies (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 surface water bodies in rural region were higher than in the urban and transition zones (Table 2 and 3), but 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 (Supplementary table 5). 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 surface water in the agro-ecosystem along the RUT was in the range 472.90 – 296.63 mg/L (2017), 473 – 307.10 mg/L (2018). For surface water the maximum concentration of TDS was found in transition zones followed by rural and urban areas (Table 2 and 3). TDS concentration of surface water, for drinking water is in the desirable limit of BSI standards but the maximum concentration 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 surface 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. Rural surface water was more turbid (98 NTU (2017); 91.5 NTU (2018) than the transition (33 NTU (2017); 38 NTU (2018)) and urban (26 NTU (2017); 28 NTU (2018)) in the agro-ecosystems along RUT. The mean turbidity of urban surface exceeded the prescribed BSI standards for drinking water, while in case of transition and rural areas it was within the desirable limits. Highest turbidity of water was observed in surface water of rural area along RUT, which can be attributed to runoff from the agricultural lands (Table 2 and 3). Turbidity doesn't affect human health directly, but provides a congenial atmosphere for microbial growth which in turn cause diseases in human and animal upon consumption (Anon, 2019). The transition zone mean total hardness of surface water was highest in 2017 followed by rural and urban areas but in 2018 it was highest in rural area followed by transition and urban areas (Table 2 and 3). The total hardness of surface water for drinking purpose are within the acceptable limits, however maximum values crossed the desirable limits for both ground and surface 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).

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

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

Water Quality Index						
	Surface water 2017			**Surface water 2018**		
Zones	Average	Max.	Min.	Average	Max.	Min.
Urban	78.56	255.65	5.85	84.20	232.30	8.86
Transition	26.72	98.87	2.95	33.80	91.10	5.56
Rural	46.35	115.82	4.89	39.43	102.41	6.40

Table.2 Minimum, maximum, and mean values of physico-chemical parameters of surface water (U-urban, T-transition, R- rural)

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	7.97	7.78	8.67	6.93	6.7	6.58	7.55	7.43	7.50	6.5-8.5	6.5-8.5	6.5-8.5
		EC (µS/L)	1600	2210	2540	650	180	152	1028.10	1026.30	1300.50	2000	750-2000	1500
		Salinity (mg/L)	450	570	580	160	40	30	305.60	140.00	166	-	-	-
		TH (mg/L)	302.82	603.39	406.01	109.97	118.50	76.86	190.79	262.93	243.41	200-600	-	300
		TDS (mg/L)	830	800	1140	222	72.3	44.90	472.90	296.63	330.46	500-1000	450-2000	3000
		Turbidity (NTU)	26	33	98	5.6	0.8	2	16.66	8.01	32.02	1	-	-
2	Major cations	K (mg/L)	32.28	12.53	20.81	1.30	2.80	0.76	14.65	6.18	8.87	10	-	-
		Na (mg/L)	145.30	97.20	33.80	31.40	18.30	18.30	76.08	43.75	25.57	100	69	-
		Mg (mg/L)	28.21	8.84	82.39	7.25	2.46	2.13	18.82	5.60	16.09	30	-	250
		Ca(mg/L)	98.30	162.3	152.30	22.30	32.9	23.30	45.45	85.02	70.97	75	-	500
3	Major anions	NO_3 (mg/L)	62.30	45	52.30	1.25	12.3	13.20	24.96	21.67	31.70	45	-	100
		Cl(mg/L)	256.54	235.25	245.20	125.30	78.90	98.90	196.25	128.94	151.80	250	141.6	-
		SO_4 (mg/L)	75.90	85.60	63.30	21.30	18.90	25.10	46.87	46.39	38.01	200	-	500
		HCO_3 (mg/L)	231.65	231.65	231.65	37.20	89.64	47.60	123.75	134.36	111.86	200	-	500
4	Heavy Metals	Al (mg/L)	5.4	5.43	2.65	2.01	0.29	0.044	0.741	0.876	0.3944	0.03	5.0	5.0
		As (mg/L)	0.012	0.011	0.012	0.001	0.001	0.001	0.0059	0.0025	0.005	0.01	0.10	0.2
		Ag (mg/L)	0.03	0.011	0.012	0.002	0.001	0.002	0.008	0.0036	0.0042	0.1	NA	NA
		B (mg/L)	0.111	0.001	0.029	0.001	0	0.024	0.0112	0.0001	0.0053	0.5	0.7	5.0
		Fe (mg/L)	1.75	0.49	6.542	0.038	0.015	0.012	0.8701	0.1351	1.2934	0.3	5.0	NA
		Co (mg/L)	0	0	0.002	0	0	0	0	0	0.0002	-	0.05	1.0
		Ni (mg/L)	0.18	0.014	0.033	0.001	0.001	0.001	0.0226	0.0029	0.005	0.02	0.2	NA
		Zn (mg/L)	0.036	0.045	0.215	0.001	0.002	0.002	0.0054	0.0084	0.0287	5	2.0	24
		Cr (mg/L)	0.01	0.02	0.04	0.003	0.002	0.019	0.001	0.0022	0.0065	0.05	0.1	1.0
		Pb(mg/L)	0.053	0.03	0.018	0.001	0.002	0.004	0.011	0.0045	0.0057	0.01	5.0	0.1
		Mn(mg/L)	1.886	0.098	0.418	0.003	0.001	0.002	0.4136	0.0278	0.0858	0.1	NA	0.05
		Cu (mg/L)	0.152	0.012	0.004	0.004	0.001	0.002	0.0208	0.0042	0.0016	0.05	0.2	0.5

Table.3 Minimum, maximum, and mean values of physico-chemical parameters of surface water (U-urban, T-transition, R- rural)

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	7.97	7.78	8.09	6.31	6.2	6.32	7.45	7.27	7.49	6.5-8.5	6.5-8.5	6.5-8.5
		EC (µS/L)	1625	2220	2648	245	181	157	987.80	1038	1316.90	2000	750-2000	1500
		Salinity (mg/L)	581	576	581	245	45	31	370.60	147.50	169.50	-	-	-
		TH (mg/L)	300.70	415.53	399.62	108.55	120.30	73.00	190.10	231.67	241.50	200-600	-	300
		TDS (mg/L)	835	801	1140	121	78	45	473	307.10	331.54	500-1000	450-2000	3000
		Turbidity (NTU)	17	38	98	0.56	2.5	2	3.03	11.61	32.33	1	-	-
2	Major cations	K (mg/L)	33.46	14.58	21.32	2.30	1.81	1.66	15.27	6.31	8.61	10	-	-
		Na (mg/L)	144.30	96.09	33.72	31.45	20.15	18.30	76.12	41.70	25.53	100	69	-
		Mg (mg/L)	27.56	9.13	82.65	8.57	1.70	1.13	19.02	5.34	15.90	30	-	250
		Ca(mg/L)	97.32	162.30	151.32	23.34	33.62	23.30	44.86	83.91	70.53	75	-	500
3	Major anions	NO_3 (mg/L)	62.30	47.32	52.34	2.24	12.3	14.52	26.05	23.00	31.82	45	-	100
		Cl(mg/L)	256.54	165.32	245.31	125.31	78.90	98.99	194.96	120.79	150.14	250	141.6	-
		SO_4 (mg/L)	75.90	85.60	63.30	21.30	18.90	25.10	46.87	46.39	38.01	200	-	500
		HCO_3 (mg/L)	182.31	231.65	168.34	56.30	47.32	34.62	118.16	131.39	98.29	200	-	500
4	Heavy Metals	Al (mg/L)	4.23	5.96	3.21	1.75	0.89	0.12	0.598	1.109	0.612	0.03	5.0	5.0
		As (mg/L)	0.01	0.021	0.032	0.002	0.002	0.001	0.0056	0.0057	0.0077	0.01	0.10	0.2
		Ag (mg/L)	0.071	0.072	0.009	0.001	0.002	0.002	0.0224	0.028	0.0034	0.1	NA	NA
		B (mg/L)	0.111	0.001	0.032	0	0.001	0.001	0.0111	0.0001	0.0056	0.5	0.7	5.0
		Fe (mg/L)	1.69	0.49	1.25	0.001	0.019	0.013	0.643	0.1536	0.4472	0.3	5.0	NA
		Co (mg/L)	0	0	0.003	0	0	0	0	0	0.0003	-	0.05	1.0
		Ni (mg/L)	0.18	0.032	0.033	0.001	0.004	0.002	0.0236	0.0036	0.0059	0.02	0.2	NA
		Zn (mg/L)	0.046	0.123	0.215	0.003	0.003	0.001	0.0084	0.0187	0.0292	5	2.0	24
		Cr (mg/L)	0.02	0.03	0.04	0.001	0.002	0.001	0.0022	0.0033	0.0051	0.05	0.1	1.0
		Pb(mg/L)	0.005	0.006	0.006	0.001	0.001	0.001	0.0018	0.0023	0.0022	0.01	5.0	0.1
		Mn(mg/L)	1.886	0.452	0.063	0.025	0.016	0.002	0.3528	0.0764	0.03	0.1	NA	0.05
		Cu (mg/L)	0.051	0.09	0.051	0.001	0.001	0.002	0.01283	0.0236	0.0141	0.05	0.2	0.5

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

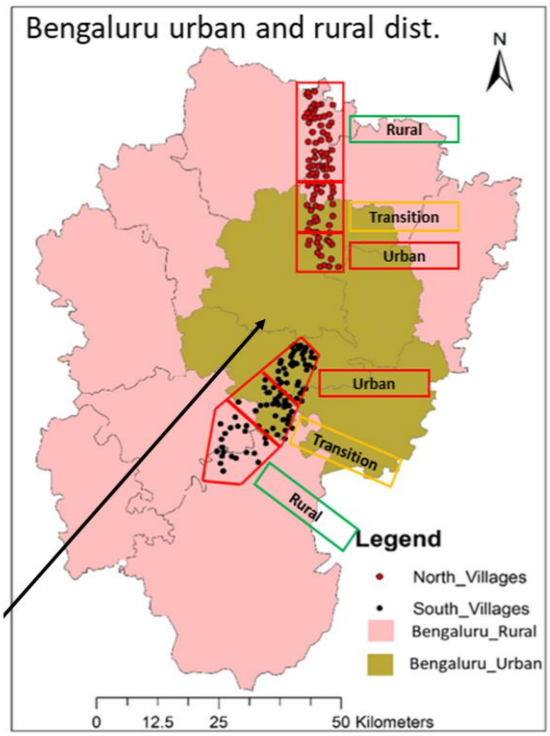


Fig.1a Map showing the location of representative sample sites from where ground and surface water samples were drawn with in the 1 km radius of agricultural lands in urban zone of north transect

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.2 Piper diagram surface water samples of 2017

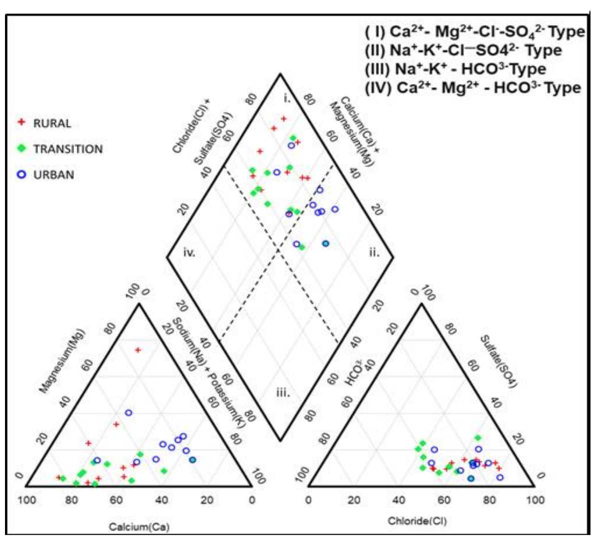


Table.5 Surface water points

Transect zones	Water body name	Latitudes	Longitudes
South urban	Avalahalli lake	12^0 51’ 55.3” N	77^0 34’ 00.0” E
South urban	Krishna nagarkere	12^0 52’ 25.0” N	77^0 34’ 46.2” E
South urban	Gattigere lake	12^0 51’ 10.3” N	77^0 35’ 25.7” E
South urban	Chikkammannahalli pond	12^0 50’ 56.6” N	77^0 36’ 13.0” E
South urban	Chunchugatta lake	12^0 53’ 15.0” N	77^0 34’ 30.6” E
South transition	Tharalu pond	12^0 47’ 15.6” N	77^0 31’ 24.7” E
South transition	Mariapura lake	12^0 46’ 29.7” N	77^0 32’ 13.6” E
South transition	Kaggalipura lake	12^0 47’ 50.4” N	77^0 30’ 21.8” E
South transition	Gulakamale lake	12^0 48’ 23.9” N	77^0 31’ 40.9” E
South transition	Kuppareddykere	12^0 50’ 28.4” N	77^0 31’ 05.4” E
South rural	Gabbadikere	12^0 42’ 34.7” N	77^0 29’ 00.3” E
South rural	Kaggalahallikere	12^0 43’ 49.6” N	77^0 29’ 20.3” E
South rural	KG Gollarapalaya	12^0 44’ 42.0” N	77^0 28’ 03.8” E
South rural	Bhramangala lake	12^0 45’ 40.9” N	77^0 25’ 26.4” E
South rural	Nelaguli lake	12^0 46’ 41.5” N	77^0 29’ 33.9” E
North urban	Jakkur lake	13°05'08.8"N	77°36'39.1"E
North urban	Palanahalli lake	13°06'56.7"N	77°36'59.4"E
North urban	Allalasandra lake	13°05'26.7"N	77°35'13.4"E
North urban	Amrutahalli lake	13°03'41.5"N	77°35'55.5"E
North urban	Yelahankakere	13°06'47.1"N	77°35'33.7"E
North transition	Kamenahalli	13°12'31.0"N	77°35'32.1"E
North transition	Suradhenupura	13°13'09.1"N	77°33'20.1"E
North transition	Nagadasanahalli	13°09'21.1"N	77°34'21.8"E
North transition	Gantiganahalli	13°08'32.2"N	77°35'25.2"E
North transition	Gantiganahalli lake	13°08'17.5"N	77°34'38.6"E
North rural	K.G Govindapura,	13°16'58.3"N	77°33'08.9"E
North rural	DoddaballapuraKere	13°19'28.2"N	77°32'10.2"E
North rural	Marahalli	13°21'38.8"N	77°35'56.8"E
North rural	ShivapuraKere	13°18'58.2"N	77°34'06.8"E
North rural	Kollurkere	13°20'45.6"N	77°30'52.0"E

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.3 Piper diagram surface water samples of 2018

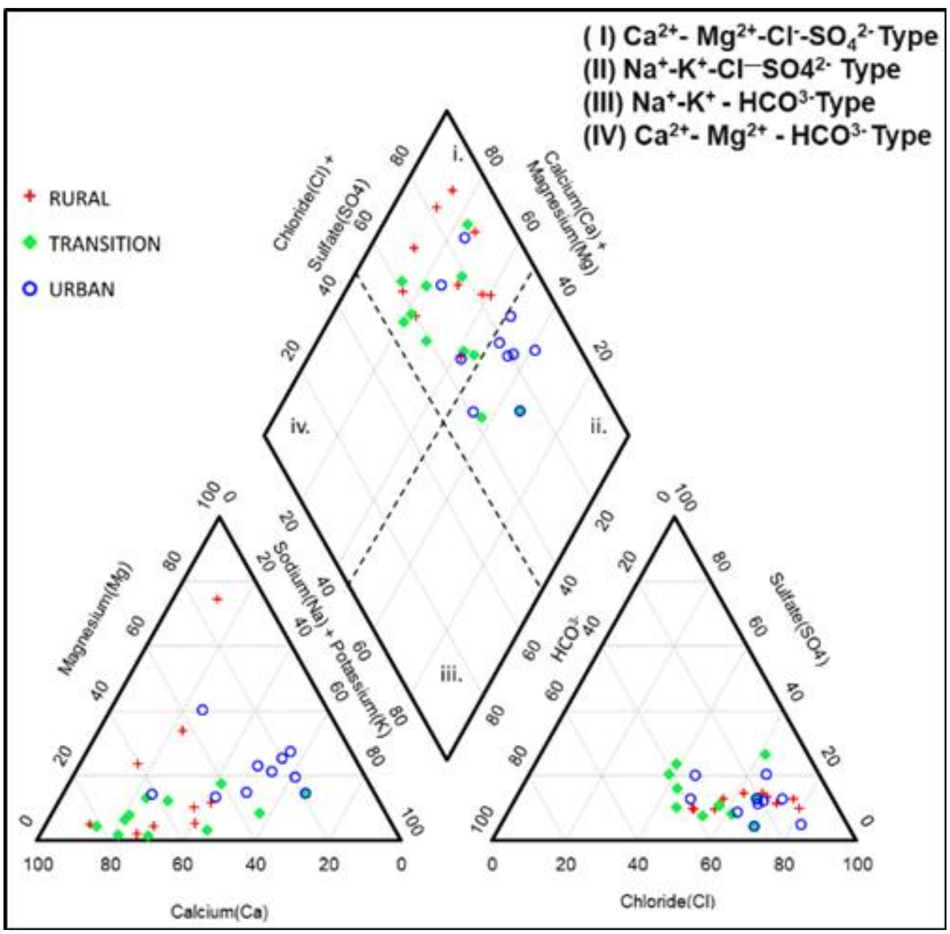
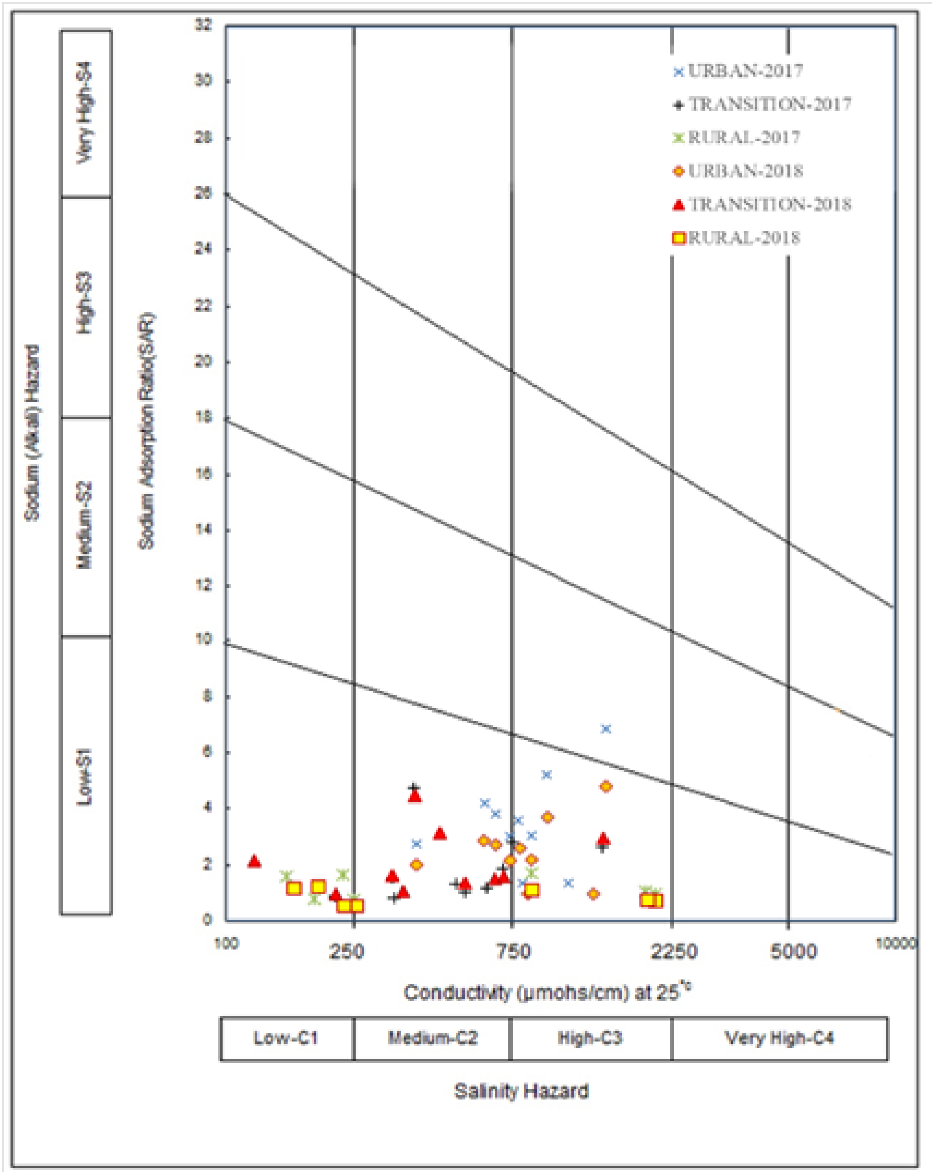


Fig.4 USSLH diagram for surface water samples



The an-ion and cat-ion mean concentration for the urban and rural zone in surface water trend was in the order of Cl>HCO_3>SO_4>NO_3 and Ca>Na>K>Mg respectively, but in transitional zone an-ion and cat-ion trend was in the order of HCO_3>Cl>SO_4>NO_3 and Ca>Na>K>Mg respectively (Table 2 and 3). The K, Na, Ca, NO_3 and Cl maximum concentrations of surface water exceeded the desirable limits for drinking water in urban zone, while Na was found to exceed the acceptable limits for irrigation purpose in urban zone. In the transition and rural zones Ca, K, and NO_3maximum concentration crossed the desirable limits for drinking purpose, but Cl was found to be higher than the prescribed levels for irrigation. However the an-ion and cat-ion mean concentration of surface water were found within the permissible limits for all selected end uses (Table 2 and 3).

The heavy metals concentrations in the surface water of agro-ecosystems along the RUT were tabulated in Table 2 and 3. Aluminum (Al) concentration in surface water along the RUT ranged between 5.4–0.29 mg/Lin 2017, however in 2018 Al concentration in surface water ranged between 5.96–0.12 mg/L. The mean Al concentration was found maximum in surface water of transition zone followed by rural and urban regions during 2017 and 2018, but during 2017 in surface water it was more in urban than rural zones (Table 2 and 3).The concentration of aluminum crossed the acceptable limits of BSI for drinking, irrigation and livestock uses.

Heavy metals like silver, boron, iron, nickel, lead, manganese and copper, mean concentrations were found highest in urban surface water and in transition zone only copper was found highest and in rural zone arsenic, zinc, and chromium were found highest during 2017. But in 2018 heavy metals like boron, iron, nickel, manganese mean concentration was detected with highest concentration in urban surface water, in transition zone, copper was highest and in rural areas arsenic, silver, cobalt, zinc, chromium and lead were found highest (Table 2 and 3). Though heavy metal concentrations are within the prescribed standards for all said end uses at present, results suggests that along the RUT they are increasing at alarming rates for all selected end uses of surface water. It is important to note that very small concentration of heavy metals are capable of producing adverse health effect on human, plants and other organisms.

Hydrochemical facies

The surface water was 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 surface water of agroecosystems along the RUT of Bengaluru. Most of the surface water samples were of mixed Ca-Mg-Cl type followed by Ca-Mg-Cl-SO_4 type and Na-K-Cl-SO_4 type 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. For example micro nutrients like Ca, Mg will be supplied to the plant root zone and helps to solve the problem of Mg defiance in crops but due to harvesting of this type of water from the underground increases the Mg concentration in surface water bodies through the runoff from agricultural fields this increased concentration of magnesium will cause scouring and diarrhea in livestock.

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 indicates that all surface water shows significant variation from C1-S1 (Low-salinity water and low sodium hazard) to C3-S1 (High-salinity water and low hazard sodium) category (Fig. 4 and Supplementary Table 5a and 5b). But most of the urban water falls in the C3-S1 (High-salinity water and low hazard sodium) category followed by transition C2-S1 (Medium-salinity water and low sodium hazard) and rural (C1-S1) (Low-salinity water and low sodium hazard) (7 out of 10 samples) but 3 samples in rural zone come under C3-S1 (High-salinity water and low hazard sodium) category. From the USSLH diagram (Fig. 4 and Supplementary Table 5a and 5b) it can be seen that sodium hazard is more in urban area compared to rural and transition zone, which is mainly due to higher sewage draining into water bodies compared to transition and rural zone. Use of urban surface water without proper treatment and soil management practices will lead to soil pollution and increases the salinity and alkalinity which make these vital resources unfit for cultivation of crops in the urban agro-ecosystems.

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