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Statistical Analysis of Water Quality Data of Agra Canal, Quantifying Seasonal Variation in Haryana Stretch India

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Abstract:
The study focuses on assessing the contamination levels in the Agra Canal, a water source heavily impacted by the discharge of effluents from Faridabad, Palwal and small-scale textile bleaching operations; small colonies are situated along its banks, which ultimately flow into the Agra Canal. The primary objectives of this research are to evaluate the Agra Canal's water quality and seasonal variations in water quality. Data was collected during the summer, rainy, and winter seasons. An array of water quality parameters were examined, including pH, E.C., TDS, Turbidity, DO, BOD, COD, T.H., TA, Ca, Mg, Na, K, HCO_3, Cl, SO4 and NO_3 and Total Coliform (T.C). Sampling and analysis followed the BIS and APHA. The WQI was calculated with the mean value of all the sites per season using the data for Ca, Cl, TDS, Mg, SO_4, and nitrate. In the summer season, the WQI was 121.32, which shows the water is not suitable for any purpose; in the winter season, the WQI was 85.57, which falls in an inferior category, and in the monsoon, the WQI was 53.1, which falls in the poor quality category. The results of the Pearson correlation analysis among 16 parameters revealed a strong linear association and a high correlation coefficient between various pairs of water quality measures. Paired student Ttest values >0.001, which is significant for parameters. Seasonal variation was assessed by the CPI value, which was also in the clean to slightly polluted category for all seasons. Although all the parameters are within permissible limits, more investigation is needed to detect the effect of Agra canal water on crops and vegetables, and it will safeguard both human health and the environment.

Keywords: Water quality, Heavy Metals, Human health, Effluents, Seasonal variations.

Abbreviations- Electric Conductivity (E.C.), Total Dissolve solids (TDS),Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Alkalinity (T.A.), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Bicarbonate ($HCO3^{)}$, Chloride ($Cl^{)}$, Sulphate ($SO4^{2)}$, Nitrate (NO3), Boron (B), Copper (Cu), lead (Pb), zinc (Zn), Chromium (Cr), Cadmium (Cd), Iron (Fe), Nickel (Ni), milliequivalents per litter (me L-1), Bureau of Indian Standards (BIS), Comprehensive Pollution Index (CPI), Total Coliform (T.C.).

Introduction

In agricultural activities, water is an essential component supplied by rainfall or irrigational channels, lakes, springs, and rivers, which are sources of irrigation water facing pollution challenges (Abugu et al., 2021). Due to water scarcity, untreated wastewater is being used more frequently in agriculture, and this issue is not being addressed; there are risks to human health. Therefore, it is crucial to regularly assess the state of surface water and develop strategies for its protection. (Raychaudhuri et al., 2014.) It is critical to all living organisms, ecological systems, human health, food production, and economic development (Shukla, 2013). River pollution affects the water's physicochemical parameters, eventually degrading the biological community, upsetting the fragile food web and endangering the community's well-being (G. Singh et al., 2020). The Yamuna River sustains ecology and is therefore considered holy by the people of India (Sharma, Kumar et al., 2020). The irrigated land in the Yamuna basin is about 12.3 million hectares, and approximately half (about 49%) is irrigated exclusively from surface water (Baba et al., 2018). The use of river water for irrigation results in the transfer of metal in soils and then plant species (G. Singh et al., 2021). Water quality in the river is polluted by sewage and animal waste and can cause diseases like gastroenteritis, salmonella infection, dysentery, and hepatitis. However, due to increased human population, industrialisation, use of fertilisers in agriculture, and anthropogenic activities, it is highly polluted with harmful contaminants (Patil, 2012). Heavy metals move through the aquatic food chain, and when polluted water is used for irrigation, it can lead to severe toxic effects on the growth and yield of crops (Patel et al., 2019). Due to the prevalent use of Yamuna water for irrigation in and around Delhi, there is a risk of toxic chemicals entering the food chain, which can lead to severe health problems (Sharma et al., 2020). Since ancient times, it has been used chiefly for irrigation, primarily for crops grown during the rabi season.

Agra Canal is a lifeline for irrigation in UP, Haryana, and some parts of Rajasthan. The Agra Canal is one of the most polluted canals. According to Verma, the World Health Organization (WHO) cites Faridabad as one of the most polluted cities in the world. The region boasts numerous industrial zones, mainly concentrated in the Faridabad-Ballabhgarh complex. These zones host a diverse range of industries, encompassing thermal power generation, iron production, machinery manufacturing, pottery and ceramics, electronic goods production, textile manufacturing, chemical processing, electroplating, manufacturing, and lead batterybased operations; additionally, sewage discharge, surface runoff from contaminated areas, and road pollution add additional various pollutants increasing the overall pollution load in the Canal (Verma et al., 2022). Some industries discharge vast amounts of industrial waste directly or indirectly in the Yamuna River (Raj Sharma & Kumar Sanu, 2022) and the Agra

Canal from Faridabad and Palwal districts. Many researchers have reported that the Agra Canal receives polluted water from the Yamuna River, which is unsuitable for any purpose. It was proposed that polluted water be supplied to the Agra canal for irrigation in 638 villages. The Faridabad district grows various crops, including rice, wheat, jowar, bajra, pulses, and gramme (Choudhary et al., 2022).

Due to the sewer problems and industrial waste dumping in the Faridabad and Palwal districts, the Agra canal became polluted. It is essential to evaluate the pollutant level of the Agra canal water because its water is used in vegetable and crop production, which is directly or indirectly served on our dining tables. The pollution of heavy metals in aquatic environments is a growing problem worldwide and has reached an alarming rate (Nazir et al., 2015). Generally, the characteristic of wastewater is represented by some physical and chemical properties such as pH, Electric Conductivity (E.C.), Total dissolved solids (TDS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Hardness (T.H.), Total Alkalinity (T.A.), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Bicarbonate (HCO_3), Chloride(Cl), Sulphate (SO_4) and Nitrate (NO_3). The other minority substances, such as heavy metals (A. Singh et al., 2022), among the groups of heavy metals Cr, Cd, Ni, Zn, Cu, Pb, Fe, etc., generally evaluated for water analysis (Panigrahi & Pattnaik, 2019). Seasonal variations are analysed by calculating the Comprehensive Pollution Index (CPI). Pearson Correlation assesses the reciprocal relationship between various data sets represented by correlation.

(Burgund et al., 2023).

Sampling Sites

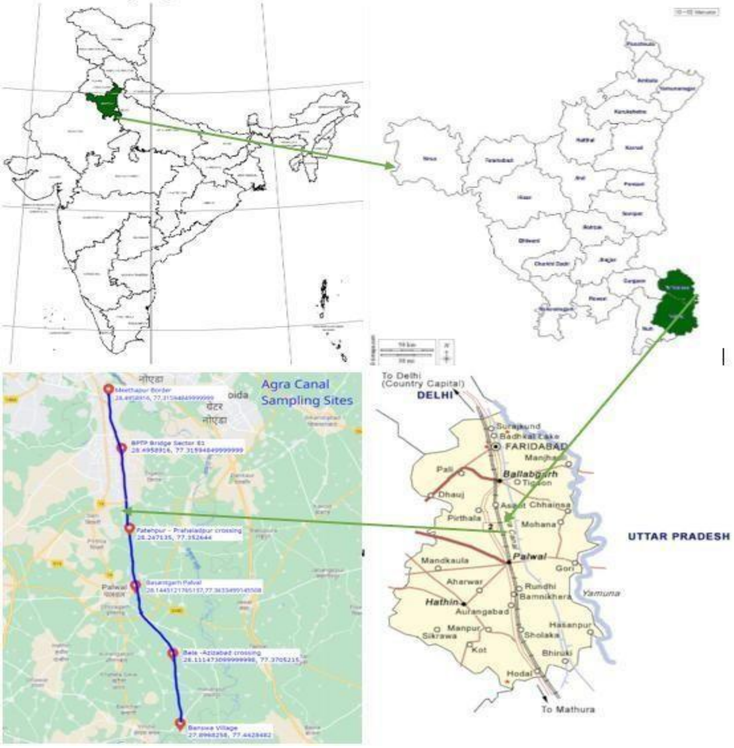
The Agra Canal originates on the right bank of the Yamuna River at Okhla Baraze. (Verma et al., 2022). The canal is 163 km long and carries a discharge of about 63.5 m3/sec. It irrigates about 138,000 hectares of land, mainly in two districts of Mathura and Agra in Uttar Pradesh (Baba et al., 2018). Agra Canal is a lifeline for irrigation in Utter Pradesh, Haryana, and some parts of Rajasthan. Sampling sites and canal length were selected after the physical survey. Six sampling sites were selected based on urban and rural areas and agriculture practices. The first three locations are from Faridabad, and the last three are from the Palwal district. Locations were marked upstream to Downstream, Location 1st (S1) was Meetha Pur border, (28°29'45.2 "N 77°18'57.4" E), 2nd (S2) Site was BPTP Brize sector 81 crossing,((28°23'22.7 "N 77°20'19.4" E)), the 3rd (S3) was Fatehpur-Prahlad Pur crossing((28°14'49.7"N 77°21'09.5"

E)), the 4th (S4) was Basant Garh Palwal, ((28°08'40.2"N 77°21'48.1" E) 5th (S5) was BelaAjijabad crossing (28°01'20.4"N 77°25'48.4" E) and 6th (S6) was Bansva village (27°53'48.6"N 77°26'34.3" E) of Palwal District, which was last village of Haryana, after that Agra Canal entered in UP. (M. Kumari et al., 2024).

Materials and Methodology

Samples were collected in the summer, monsoon, and winter seasons from August 2021 to May 2023. Sampling was done in 2nd week of May, August, and January. Sampling and Handling have been done according to BIS standards (BIS, 1999) and APHA (APHA, 1999). All the containers were washed with detergent, followed by water, diluted HNO_3, and distilled water (Alam et al., 2007). Samples were collected in polyethene bottles during the morning hours. Grab samples were taken from the canal's left, right, and midstream. The mean value is presented in the data.

Figure 1: Coordinates of Sampling Sites



(M. Kumari et al., 2024).

The 2-litre bottle was filled for general parameters, and the one-litre bottle for heavy metals, which was fixed by 1ml solution of HNO3 (CPCB, 2007),(A. Singh et al., 2022), 300 ml BOD bottle for BOD (fixed by 2ml MnSO4 and 2ml Alkali Azide), 250ml glass bottle filled for biological parameters. pH, E.C., temperature, and DO were analysed on the spot (Sharma et al., 2021). pH was analysed by a Digital pH meter (H196107), and E.C. was measured by E.C. meter-3 (Alobaidy et al., 2010). TDS was measured by TDS-3 meter, the temperature was analysed from a mercury thermometer (Dyna research German glass 50130718,0-50 C), and DO was analysed with Wrinkler's method, with the help of titration setup. All the samples were preserved in the ice box for further analysis. The analysis was conducted in an ISO 9001: 2015 certified laboratory, and the mean value was presented in the results. In laboratory turbidity analysed with Digital Nephlo Turbidity Meter 132 (INT Chem 26), Na and K concentrations were determined using a flame photometer (Systronics Flame Photometer 128), (Badmus et al., 2014), NO3 and SO4 were measured using U.V. Spectrophotometer (UV-800 Shimadzu) (Kambire et al., 2022), and Ca and Mg concentrations were measured using a complexometric titration of EDTA solution. In determining HCO_3 and Cl, potentiometric and argentometric titration procedures were applied, respectively (Abugu et al., 2021).COD was analysed using the reflux method as per BIS (BIS, 2006), and total coliform was analysed using the MPN method (Jain & Dhupper, 2020).

Calculated Analysis

CPI and WQI were analysed for seasonal variation, and Pearson correlation and paired studentT-Test were analysed for statistical analysis. The formulas used to calculate the respective values are below.

1. Water Quality Index (WQI)

WQI $= q_i w_i$ (G. Singh et al., 2022)

Where qi indicates a rating of water quality, which can be obtained as $q_i = 100\times\frac{(v_a - v_i)}{(v_s - v_i)}$

((Vn-Vo)/(Sn-V0))*100 where Va is the real value present in the water sample, and Vi represents the ideal value (0 for each parameter except for DO and pH, 14.6 mg/L and 7.0, respectively), Vs represents the standard value. wi is the unit weight that can be calculated as wi ¼ K Sn, where

K is a constant that is given as K ¼ 1
Vs1þ1=Vs2þ…þ1=VSn, and Sn is the standard value. The WQI of water is classified as excellent (0–24), good (25–49), poor (50–74), very poor (75–99), and unfit for human consumption (≥ 100) (G. Singh et al., 2020).

2. Comprehensive pollution index (CPI)

$CPI= \frac{1}{n}\sum_{i=1}^{n} P_i$ (Döndü et al., 2022; G. Singh et al., 2020).

Pi is the measured index of a single water quality parameter, and n is the Number of parameters. CPI ranges defined between 0 to 2, which classified water class as severely polluted (≥ 2.01), moderately polluted (1.01– 2.0), slightly polluted (0.41–1.00), sub-clean (0.21– 0.40), and clean (≤ 0.20). Singh et al. also applied these equations to study the Kali River water quality (G. Singh et al., 2020).

3. Pearson correlation

Analysis is an essential statistical tool for exhibiting the degree of dependency of one variable on the others. A correlation coefficient is applied to measure the interrelation and extent of associations among the variables (Belkhiri et al., 2011). Correlation coefficients can be high or low (magnitude) and positive or negative (direction). Correlation coefficients vary from -1 to +1: whereas -1 and +1 indicate perfect negative and perfect positive correlation coefficients, respectively, a correlation coefficient of 0 implies no correlation (zero relationship). Further, correlation coefficients lower than 0.40 (whether negative or positive 0.40) are said to be low, between 0.40 and 0.60 are moderate, and above 0.60 are high (Puth et al., 2014)

$$r_{xy} = \frac{\sum_i (X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_i^n (X_i - \overline{X})^2 + \sum_i^n (Y_i - \overline{Y})^2}}$$

(Burgund et al., 2023; Y. Singh & Jain, 2021a),

4. The student's paired t-test

The paired sample t-test, or the dependent t-test, is a statistical test used to compare the means of two related groups and determine whether the difference between their means is statistically significant (Pramanik et al., 2020).

$$t = \frac{\bar{d} - \mu d}{sd/\sqrt{n}}$$

$\bar{d}$ = Mean of the differences between paired observations

$\mu\bar{d}$ = hypothesised mean difference (usually 0)

$s\bar{d}$ = Standard deviation of the differences

n = Number of pairs

Results and Discussion

The location and season-wise data of Physicochemical and Biological Parameters are presented in Table 1, which shows the mean value for 2021 to 2023.

Table 1: Location and season-wise data of Physicochemical and Biological Parameters of Agra Canal Water.

Parameter	**Season**	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**Mean**
Turbidity	Summer	3.8 ± 0	4.45 ± 0.21	4.52 ± 0.26	4.15 ± 0.07	3.95 ± 0.21	3.4 ± 0.14	4.04 ± 0.42
	Monsoon	2.3 ± 1.13	2.85 ± 0.92	3.3 ± 0.28	2.5 ± 0	1.95 ± 0.78	1.8 ± 0.99	2.45 ± 0.79
	Winter	3.15 ± 0.07	3.8 ± 0.42	3.4 ± 0	3.3 ± 0.28	3.1 ± 0	3.15 ± 0.07	3.32 ± 0.29
pH	Summer	7.39 ± 0.03	7.52 ± 0.13	7.36 ± 0.02	7.41 ± 0.09	7.55 ± 0.08	7.34 ± 0.05	7.43 ± 0.1
	Monsoon	7.21 ± 0.11	7.19 ± 0.06	7.28 ± 0.13	7.26 ± 0.06	7.25 ± 0.01	7.26 ± 0.17	7.24 ± 0.08
	Winter	7.47 ± 0.16	7.61 ± 0.14	7.44 ± 0.02	7.47 ± 0.25	7.66 ± 0.21	7.49 ± 0.33	7.52 ± 0.18
Temperature	Summer	31.75 ± 0.35	31.25 ± 0.35	31.25 ± 0.35	31 ± 0	31 ± 0	31 ± 0	31.21 ± 0.33
	Monsoon	29.5 ± 0.71	29.5 ± 0.71	29 ± 1.41	29 ± 1.41	29 ± 1.41	29 ± 1.41	29.17 ± 0.94
	Winter	17.25 ± 0.35	17 ± 0	17 ± 0	17 ± 0	16.5 ± 0.71	16.5 ± 0.71	16.88 ± 0.43
EC	Summer	2379 ± 100.41	2517.5 ± 38.89	2385.5 ± 20.51	2281.5 ± 154.86	2112 ± 67.88	1923.5 ± 72.83	2266.5 ± 215.12
	Monsoon	690.1 ± 325.13	733.67 ± 315.24	733.95 ± 304.83	712.5 ± 305.05	706.7 ± 285.25	695.06 ± 269.34	711.99 ± 223.29

	Winter	969.2 ± 213.26	1025.05 ± 204.99	1006.9 ± 247.63	981.2 ± 156.69	932.8 ± 128.98	875.3 ± 133.93	965.08 ± 146.91
Bicarbonate (HCO3)	Summer	391 ± 4.24	404 ± 8.49	372 ± 25.46	364.5 ± 36.06	355.75 ± 41.37	348.5 ± 51.62	372.63 ± 31.51
	Monsoon	254.5 ± 132.23	277.05 ± 130.04	275.68 ± 122.07	269.25 ± 122.68	260.66 ± 129.18	248.35 ± 131.03	264.25 ± 95.14
	Winter	299 ± 67.88	329.12 ± 55.32	315.56 ± 63.64	295.06 ± 21.13	280.5 ± 14.85	188.34 ± 31.59	284.6 ± 59.13
Total Hardness (as CaCO3)	Summer	645.36 ± 7.35	694.82 ± 5.73	713.37 ± 32.53	591.31 ± 67.68	485.58 ± 35.61	424.51 ± 48.29	592.49 ± 114.57
	Monsoon	187.5 ± 123.74	207.79 ± 126.98	209.65 ± 109.81	206.5 ± 111.02	200.85 ± 103.02	197.2 ± 97.86	201.58 ± 83.5
	Winter	235.05 ± 63.71	305 ± 0	319 ± 41.01	302.5 ± 31.51	260 ± 28.28	178.4 ± 2.26	266.66 ± 57.36
Calcium (Ca)	Summer	140.52 ± 59.18	153.85 ± 58.67	141.92 ± 61.45	138.77 ± 60.8	133.87 ± 61.77	92.72 ± 10.46	133.61 ± 45.52
	Monsoon	50.15 ± 6.86	63.37 ± 11.12	55.75 ± 13.08	55 ± 12.02	54.75 ± 11.67	52.75 ± 8.84	55.29 ± 9.04
	Winter	77.35 ± 16.8	85.94 ± 17.59	84.84 ± 7.71	81.34 ± 8.54	75.63 ± 13.92	68.8 ± 23.05	78.98 ± 13.01
Sodium (Na)	Summer	175.05 ± 0.49	186.5 ± 8.77	185 ± 7.92	171.5 ± 2.12	176.25 ± 3.61	171.7 ± 0.42	177.67 ± 7.3
	Monsoon	46.36 ± 6	57.56 ± 6.73	53.07 ± 3.42	52.33 ± 3.01	50.35 ± 3.05	47.5 ± 0.71	51.19 ± 5.03
	Winter	74.9 ± 7.5	91.4 ± 27.01	85.75 ± 13.22	82.44 ± 19.57	77.3 ± 15.27	61.55 ± 1.63	78.89 ± 15.52
Chloride (Cl)	Summer	269.25 ± 28.78	289.8 ± 6.79	259 ± 14.14	244 ± 48.08	234.8 ± 7.21	256.5 ± 51.62	258.89 ± 29.91
	Monsoon	124.95 ± 52.4	142.18 ± 51.3	138.15 ± 48.15	130.45 ± 48.86	126.45 ± 50.28	133.45 ± 38.96	132.6 ± 36.4
	Winter	199.75 ± 70.92	221.15 ± 76.16	210.1 ± 59.11	206.64 ± 60.58	190.63 ± 41.2	178.45 ± 24.83	201.12 ± 45.31
TDS	Summer	1084 ± 9.9	1144.5 ± 62.93	1044 ± 76.37	984.5 ± 176.07	1084.5 ± 6.36	942.5 ± 201.53	1047.33 ± 111.1

	Monsoon	438.73 ± 167.9	491.34 ± 199.88	476.5 ± 181.73	459.06 ± 171.2	457.34 ± 173.01	449.95 ± 155.49	462.15 ± 130.79
	Winter	656 ± 181.02	799.5 ± 320.32	759 ± 312.54	712.72 ± 194.76	668.63 ± 179.07	596 ± 132.94	698.64 ± 184.7

Magnesium (Mg)	Summer	60 ± 5.8	61.87 ± 3.73	60.1 ± 6.51	52.9 ± 0.57	52.35 ± 0.21	48.61 ± 2.14	55.97 ± 5.91
	Monsoon	22.45 ± 7.35	27.8 ± 10.81	26.28 ± 3.5	25.81 ± 2.76	22.46 ± 3.32	20.56 ± 2.27	24.22 ± 5.09
	Winter	40.63 ± 9.34	45.43 ± 1.49	46.75 ± 5.08	45.42 ± 6.68	40.64 ± 2.09	31.57 ± 2.03	41.74 ± 6.64
Potassium (K)	Summer	24.85 ± 4.96	25.79 ± 3.77	26.22 ± 8	21.2 ± 11.54	10.72 ± 9.4	7.51 ± 5.42	19.38 ± 9.67
	Monsoon	1.93 ± 0.6	2.68 ± 0.94	2.53 ± 0.68	2.03 ± 0.04	1.67 ± 0.47	1.08 ± 0.07	1.98 ± 0.7
	Winter	14.84 ± 3.66	13.2 ± 2.6	14.92 ± 4.68	8.89 ± 2.03	6.92 ± 2.18	4.89 ± 3.58	10.61 ± 4.76
Sulphate (SO4)	Summer	43.9 ± 4.24	51.1 ± 4.38	42.92 ± 25.9	33.99 ± 18.65	22.15 ± 0.92	35.85 ± 12.52	38.32 ± 14.2
	Monsoon	18.56 ± 8.51	22.44 ± 11.79	22.71 ± 6.94	21.03 ± 6.63	17.63 ± 7.47	16.18 ± 7.15	19.76 ± 6.63
	Winter	25.75 ± 7	30.78 ± 11.14	33.14 ± 11.79	24.4 ± 2.26	21.45 ± 1.91	16.65 ± 1.34	25.36 ± 7.9
Nitrate (NO3)	Summer	3.63 ± 0.21	4.11 ± 0.15	4.04 ± 0.74	3.04 ± 1.22	2.83 ± 0.02	2.87 ± 1.02	3.42 ± 0.77
	Monsoon	2.23 ± 1.1	3.29 ± 0.26	2.46 ± 0.14	2.43 ± 1.37	2.35 ± 1.63	2.35 ± 1.56	2.52 ± 0.94
	Winter	2.52 ± 0.08	3.58 ± 0.59	2.25 ± 0.29	2.61 ± 1.23	3.14 ± 0.46	1.65 ± 0.55	2.62 ± 0.8
Total Alkalinity (CaCO3)	Summer	315.72 ± 91.86	341.72 ± 79.73	335.39 ± 85.4	314.95 ± 105.51	318.17 ± 96.41	265.14 ± 21.41	315.18 ± 67.57
	Monsoon	203.73 ± 101.43	225.79 ± 95.86	217.64 ± 99.33	214 ± 100.41	210.5 ± 99.7	210.16 ± 99.21	213.63 ± 73.72

	Winter	196.5 ± 12.02	237.73 ± 53.35	266.38 ± 7.95	225.34 ± 21.69	202.45 ± 2.2	193.38 ± 9.36	220.29 ± 32.67
Boron (B)	Summer	1.75 ± 0.14	1.82 ± 0.1	1.91 ± 0.02	1.9 ± 0.07	1.75 ± 0	1.73 ± 0.04	1.81 ± 0.1
	Monsoon	0.26 ± 0.01	0.29 ± 0.01	0.3 ± 0	0.26 ± 0.01	0.25 ± 0	0.25 ± 0	0.27 ± 0.02
	Winter	1.35 ± 0.21	1.39 ± 0.23	1.63 ± 0.39	1.6 ± 0.28	1.4 ± 0.28	1.35 ± 0.21	1.45 ± 0.24
Dissolved Oxygen (O2)	Summer	3.15 ± 0.35	2.3 ± 0.28	3.05 ± 0.21	2.85 ± 0.21	3.1 ± 0.42	3.5 ± 0.57	2.99 ± 0.47
	Monsoon	4.05 ± 0.07	3.7 ± 0	3.5 ± 0.42	3.7 ± 0	3.45 ± 0.07	3.75 ± 0.64	3.69 ± 0.31
	Winter	3.15 ± 0.07	2.11 ± 0.01	3.15 ± 0.49	3.55 ± 0.07	3.65 ± 0.35	3.8 ± 0.42	3.23 ± 0.63
COD (O2)	Summer	51.07 ± 10.28	61.49 ± 15.29	54.6 ± 7.35	51.05 ± 1.2	50.9 ± 0.28	50.07 ± 1.35	53.2 ± 7.3
	Monsoon	33.95 ± 9.97	36.25 ± 10.96	41.25 ± 1.2	36.1 ± 11.17	40 ± 7.07	39.1 ± 5.52	37.78 ± 6.76
	Winter	42.8 ± 3.39	64.73 ± 8.24	49.87 ± 10.42	46 ± 1.84	45.5 ± 7.35	50.5 ± 13.72	49.9 ± 9.74
BOD (@27°C for 3 days)	Summer	11.49 ± 0.41	16.87 ± 0.52	14.38 ± 0.11	14.2 ± 0.42	12.53 ± 1.17	10.71 ± 0.57	13.36 ± 2.19
	Monsoon	8.25 ± 2.9	8.85 ± 2.76	9.6 ± 0.57	8.85 ± 2.76	9.7 ± 1.7	9.25 ± 1.2	9.08 ± 1.68
	Winter	10.05 ± 3.18	13.08 ± 1.67	11.7 ± 0.99	10.7 ± 0.42	9.35 ± 3.04	8.8 ± 2.55	10.61 ± 2.23
Total Coliform	Summer	3650000 ± 212132.03	5400000 ± 424264.07	4100000 ± 0	4000000 ± 0	3700000 ± 282842.71	2400000 ± 989949.49	3875000 ± 980839.16
	Monsoon	250000 ± 42426.41	335000 ± 134350.29	390000 ± 42426.41	330000 ± 169705.63	450000 ± 155563.49	360000 ± 70710.68	352500 ± 106269.38

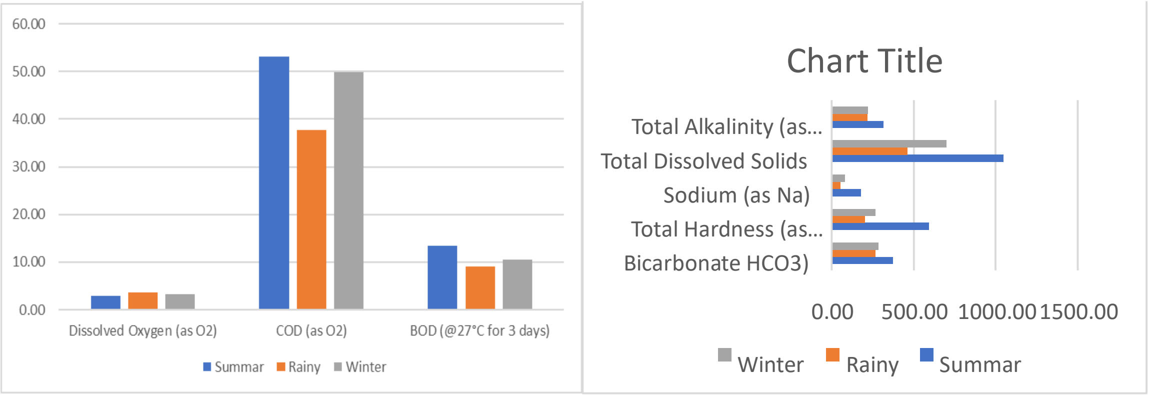
	Winter	2550000 ± 70710.68	3300000 ± 282842.71	2910000 ± 127279.22	2710000 ± 268700.58	2300000 ± 141421.36	1950000 ± 212132.03	2620000 ± 472902.07

Analysis of Water Quality Data Across Seasons

Turbidity (NTU) was highest in summer (Mean: 4.04) and winter (Mean: 3.32). The lowest is in the monsoon (mean: 2.45), indicating dilution effects due to rainfall. The pH was slightly alkaline across all seasons. The highest is in winter (Mean: 7.52), followed by summer (7.43), and the lowest is in the monsoon (7.24). Temperature (°C) was highest in summer (Mean: 31.21°C), moderate in monsoon (Mean: 29.17°C), and lowest in winter (Mean: 16.88°C) 25.5 temperature obtained by researchers (Kambire et al., 2022). Other researchers obtained an average temperature of 24° from Southwest Algeria. (Bendida et al., 2021). E.C. was highest in summer (Mean: 2266.5 µS/cm) due to evaporation increasing dissolved ions, moderate in winter (965.08 µS/cm) (G. Singh et al., 2020) and lowest in the monsoon (711.99 µS/cm) due to dilution.TDS was highest in summer (Mean: 1047.33 mg/L), moderate in winter (Mean: 698.64 mg/L) and lowest in the rainy Season (Mean: 462.15 mg/L) (Figure 2A). Significant

Ions Ca was highest in summer (Mean: 133.61) and lowest in the monsoon (55.29). Mg was highest in the summer (55.97) and lowest in the monsoon (24.22). Ca concentrations ranged from 31 to 106 mg/L (mean 52 ± 24.9 SD) during summer and 25–94 mg/L (mean 44.6 ± 23.7 SD) during winter. Na was highest in summer (177.67) and lowest in the monsoon (51.19). Cl is the highest in summer (258.89) and the lowest in monsoon (132.6). SO_4 highest in summer (38.32), lowest in the monsoon (19.76). Total Hardness was highest in summer (592.49) and lowest in the monsoon (201.58). Total Alkalinity was highest in summer (315.18) and lowest in winter (220.29). NO_3 was similar across seasons, with summer (3.42), rainy (2.52), and winter (2.62). Boron was highest in summer (1.81) and lowest in the (0.27). DO was lowest in summer (2.99) and highest in the monsoon (3.69). BOD was highest in summer (13.36), indicating a higher organic load. COD was highest in winter (49.9) (Figure 2B). Total Coliform (CFU/100mL) was Highest in summer (3,875,000) and lowest in the monsoon (352,500). Summer has the highest dissolved ions, Hardness, and TDS levels, likely due to evaporation and reduced dilution. At the same time, the monsoon has significant dilution effects, such as lowering ion concentrations, Hardness, and microbial contamination. Winter exhibits moderate values for most parameters, with higher DO and lower microbial counts than summer. The analysis indicates the influence of seasonal changes on water quality, with summer showing the poorest water quality due to higher concentrations of pollutants and microbial contamination, while the monsoon has the cleanest water due to dilution; a similar trend was obtained by (G. Singh et al., 2020) in kali River.

Figure 2 Graphical Representation of Physiological Parameters



A B

WQI

The WQI was calculated with the mean value of all the sites per season (Table 1) using the data Ca, Cl, TDS, Mg, So4, and nitrate. In the summer season, the WQI was 121.32, which shows the water is not suitable for any purpose; in the winter season, the WQI was 85.57, which falls in an inferior category, and in the monsoon season, the WQI was 53.1, which falls in the poorquality category. Other researchers analysed the water quality of the Kali River in Uttar Pradesh and obtained the WQI, which was poor, very poor, and unsuitable from 17 stations (G. Singh et al., 2020).

Table 2 WQI values of various seasons of Agra canal

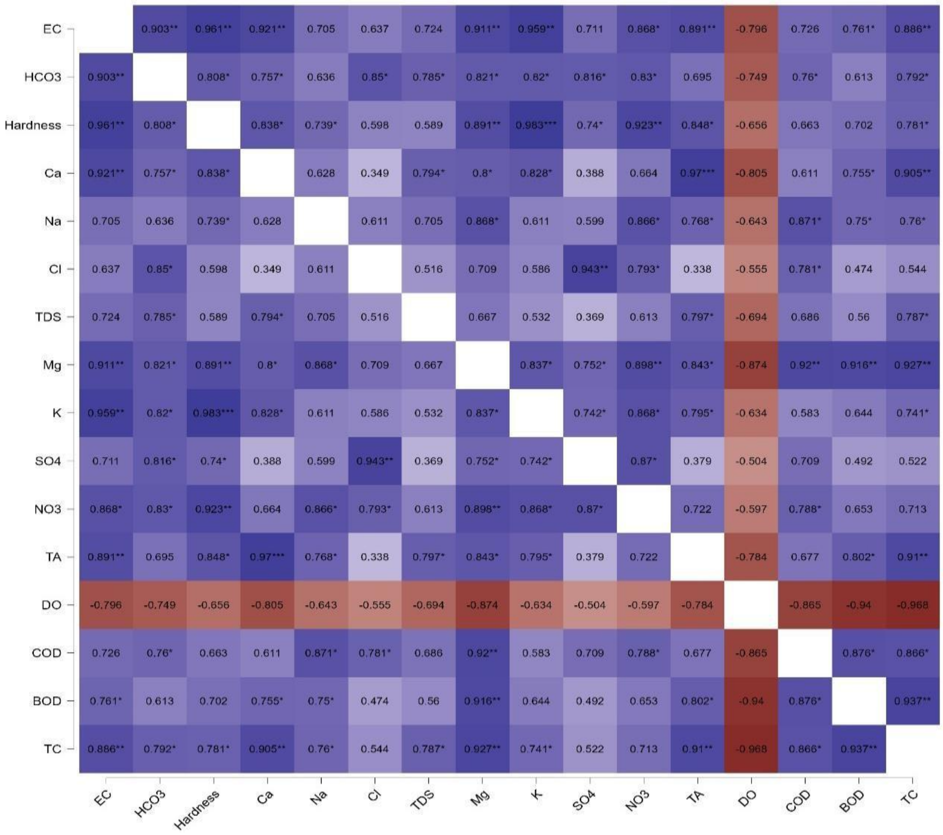
Parameters	**BIS (Sn)**	**K=1/Σ(1/Sn) Wi = K/Sn**	**Ideal Value (Vo)**	**Qn**	**WnQn**	**Summer Mean Conc.**	**Rain Mean Conc.**	**Winter Mean Conc.**
						Value (Vn)	**Value (Vn)**	**Value (Vn)**
Calcium	75	0.167	0	178.14	29.73	133.61	55.29	78.98

Chloride	250	0.050	0	103.56	5.185	258.89	132.60	201.12
TDS	500	0.025	0	209.47	5.24	1047.33	462.15	698.64
Magnesium	30	0.417	0	186.56	77.`185	55.97	24.22	41.74
Sulphate	200	0.063	0	19.16	1.199	38.32	19.76	25.36
Nitrate	45	0.278	0	7.596	2.11	3.42	2.52	2.62
WQI					121.32	121.32	53.14	85.57

Pearson Correlation

Pearson correlation has been applied to determine the relationship among the 16 physicochemical variables of Agra Canal water samples at different sampling stations using SPSS software (version 17). Statistical significance is considered at $P<0.05$. Pearson Correlation is a statistical method that quantifies the strength and direction of the association between two variables. Pearson correlation coefficient (r) has a range of -1 to 1. Correlation analysis of the physicochemical parameters in a water body involves examining the relationship between two parameters to determine their association's strength and direction. The seasonwise summer, rainy, and winter heat map with r value is presented in Figures 3,4 and 5, respectively.

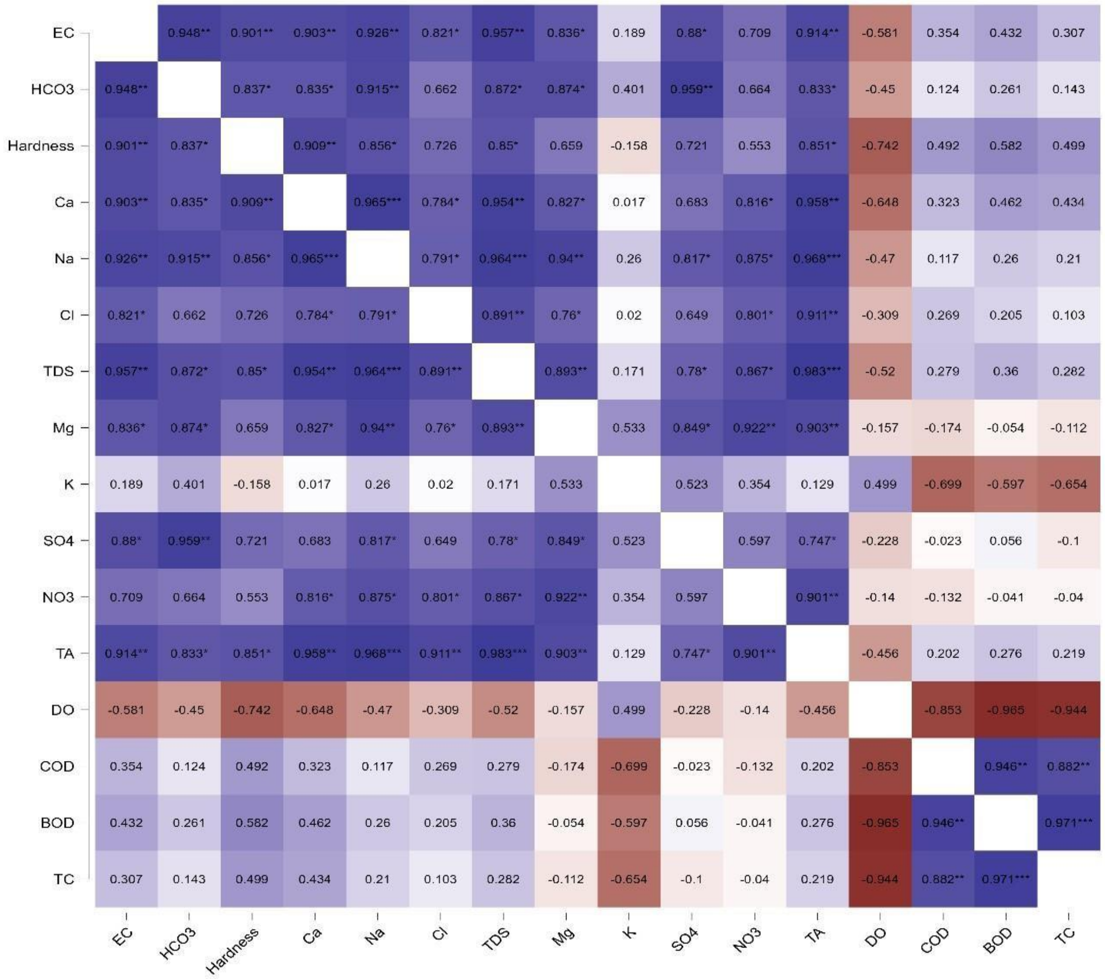
Figure. 3 Heat Map of Pearson correlation coefficient matrix of analysed variables during the summer season.



	EC	HCO3	Hardness	Ca	Na	Cl	TDS	Mg	K	SO4	NO3	TA	DO	COD	BOD	TC
EC		0.903**	0.961**	0.921**	0.705	0.637	0.724	0.911**	0.959**	0.711	0.868*	0.891**	-0.796	0.726	0.761*	0.886**
HCO3	0.903**		0.808*	0.757*	0.636	0.85*	0.785*	0.821*	0.82*	0.816*	0.83*	0.695	-0.749	0.76*	0.613	0.792*
Hardness	0.961**	0.808*		0.838*	0.739*	0.598	0.589	0.891**	0.983***	0.74*	0.923**	0.848*	-0.656	0.663	0.702	0.781*
Ca	0.921**	0.757*	0.838*		0.628	0.349	0.794*	0.8*	0.828*	0.388	0.664	0.97***	-0.805	0.611	0.755*	0.905**
Na	0.705	0.636	0.739*	0.628		0.611	0.705	0.868*	0.611	0.599	0.866*	0.768*	-0.643	0.871*	0.75*	0.76*
Cl	0.637	0.85*	0.598	0.349	0.611		0.516	0.709	0.586	0.943**	0.793*	0.338	-0.555	0.781*	0.474	0.544
TDS	0.724	0.785*	0.589	0.794*	0.705	0.516		0.667	0.532	0.369	0.613	0.797*	-0.694	0.686	0.56	0.787*
Mg	0.911**	0.821*	0.891**	0.8*	0.868*	0.709	0.667		0.837*	0.752*	0.898**	0.843*	-0.874	0.92**	0.916**	0.927**
K	0.959**	0.82*	0.983***	0.828*	0.611	0.586	0.532	0.837*		0.742*	0.868*	0.795*	-0.634	0.583	0.644	0.741*
SO4	0.711	0.816*	0.74*	0.388	0.599	0.943**	0.369	0.752*	0.742*		0.87*	0.379	-0.504	0.709	0.492	0.522
NO3	0.868*	0.83*	0.923**	0.664	0.866*	0.793*	0.613	0.898**	0.868*	0.87*		0.722	-0.597	0.788*	0.653	0.713
TA	0.891**	0.695	0.848*	0.97***	0.768*	0.338	0.797*	0.843*	0.795*	0.379	0.722		-0.784	0.677	0.802*	0.91**
DO	-0.796	-0.749	-0.656	-0.805	-0.643	-0.555	-0.694	-0.874	-0.634	-0.504	-0.597	-0.784		-0.865	-0.94	-0.968
COD	0.726	0.76*	0.663	0.611	0.871*	0.781*	0.686	0.92**	0.583	0.709	0.788*	0.677	-0.865		0.876*	0.866*
BOD	0.761*	0.613	0.702	0.755*	0.75*	0.474	0.56	0.916**	0.644	0.492	0.653	0.802*	-0.94	0.876*		0.937**
TC	0.886**	0.792*	0.781*	0.905**	0.76*	0.544	0.787*	0.927**	0.741*	0.522	0.713	0.91**	-0.968	0.866*	0.937**	

High Correlations (Significant at $p < 0.001$) are shown by Hardness and K (r = 0.983); this indicates a firm positive relationship between hardness and K levels. Ca and T.A. (r = 0.97) show a strong positive correlation. Moderate-to-high correlations (Significant at $p < 0.01$ or $p < 0.05$) are shown by E.C. with HCO3. Hardness, Ca, Mg, and T.C. indicate that ionic concentrations contribute heavily to E.C. SO4, and Cl (r = 0.943) indicate a strong positive correlation. BOD and COD (r = 0.876) expected a strong correlation that reflects organic pollution levels (G. Singh et al., 2020). Na and NO3 (r = 0.866) may point to urban/agricultural influences on DO, which shows consistent negative correlations with most variables (e.g., COD, BOD, T.C.) (Y. Singh & Jain, 2021b). It suggests that organic and chemical pollution depletes oxygen levels, a common issue in polluted water bodies.

Figure. 4 Heat Map of Pearson correlation coefficient matrix of analysed variables during the monsoon.

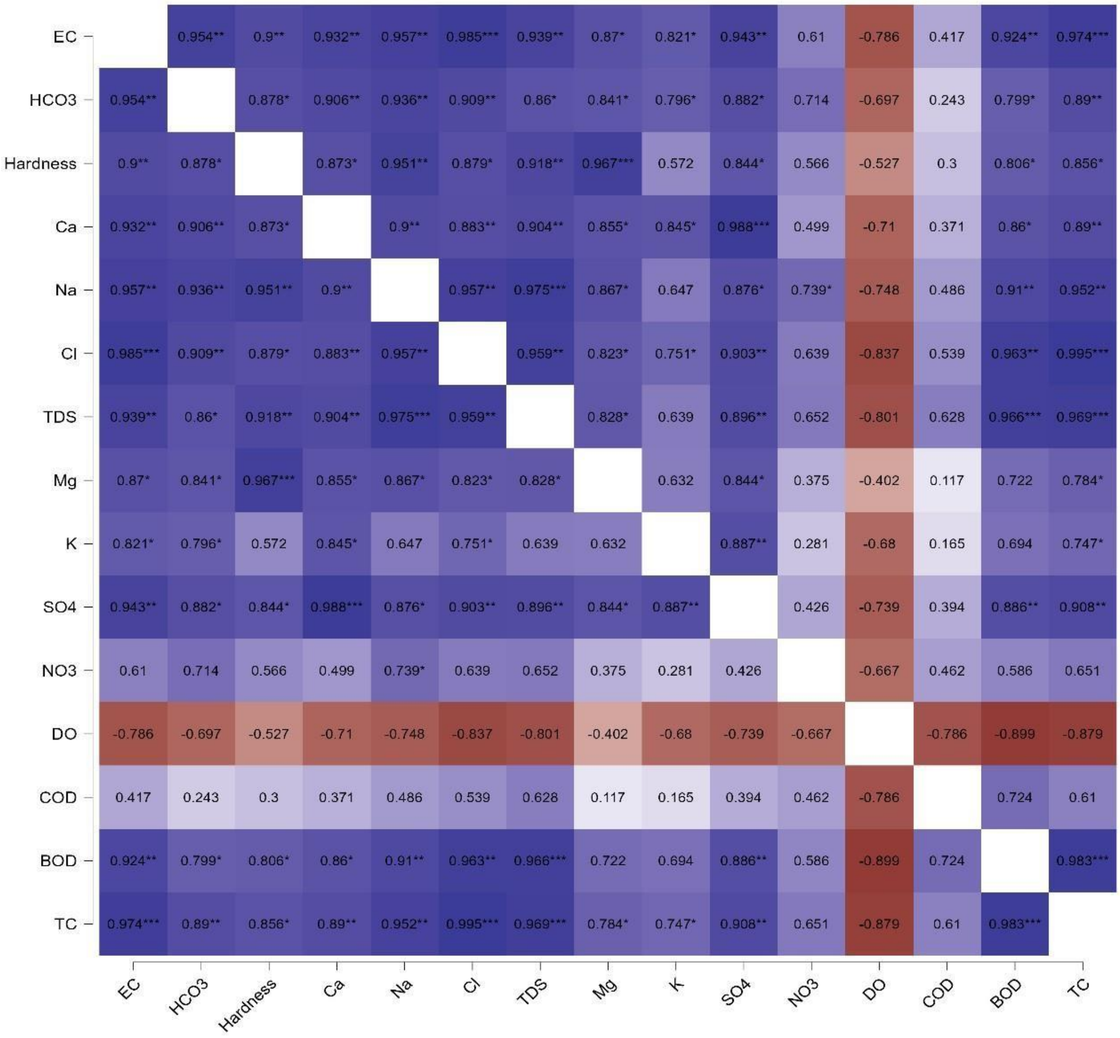


	EC	HCO3	Hardness	Ca	Na	Cl	TDS	Mg	K	SO4	NO3	TA	DO	COD	BOD	TC
EC		0.948**	0.901**	0.903**	0.926**	0.821*	0.957**	0.836*	0.189	0.88*	0.709	0.914**	-0.581	0.354	0.432	0.307
HCO3	0.948**		0.837*	0.835*	0.915**	0.662	0.872*	0.874*	0.401	0.959**	0.664	0.833*	-0.45	0.124	0.261	0.143
Hardness	0.901**	0.837*		0.909**	0.856*	0.726	0.85*	0.659	-0.158	0.721	0.553	0.851*	-0.742	0.492	0.582	0.499
Ca	0.903**	0.835*	0.909**		0.965***	0.784*	0.954**	0.827*	0.017	0.683	0.816*	0.958**	-0.648	0.323	0.462	0.434
Na	0.926**	0.915**	0.856*	0.965***		0.791*	0.964***	0.94**	0.26	0.817*	0.875*	0.968***	-0.47	0.117	0.26	0.21
Cl	0.821*	0.662	0.726	0.784*	0.791*		0.891**	0.76*	0.02	0.649	0.801*	0.911**	-0.309	0.269	0.205	0.103
TDS	0.957**	0.872*	0.85*	0.954**	0.964***	0.891**		0.893**	0.171	0.78*	0.867*	0.983***	-0.52	0.279	0.36	0.282
Mg	0.836*	0.874*	0.659	0.827*	0.94**	0.76*	0.893**		0.533	0.849*	0.922**	0.903**	-0.157	-0.174	-0.054	-0.112
K	0.189	0.401	-0.158	0.017	0.26	0.02	0.171	0.533		0.523	0.354	0.129	0.499	-0.699	-0.597	-0.654
SO4	0.88*	0.959**	0.721	0.683	0.817*	0.649	0.78*	0.849*	0.523		0.597	0.747*	-0.228	-0.023	0.056	-0.1
NO3	0.709	0.664	0.553	0.816*	0.875*	0.801*	0.867*	0.922**	0.354	0.597		0.901**	-0.14	-0.132	-0.041	-0.04
TA	0.914**	0.833*	0.851*	0.958**	0.968***	0.911**	0.983***	0.903**	0.129	0.747*	0.901**		-0.456	0.202	0.276	0.219
DO	-0.581	-0.45	-0.742	-0.648	-0.47	-0.309	-0.52	-0.157	0.499	-0.228	-0.14	-0.456		-0.853	-0.965	-0.944
COD	0.354	0.124	0.492	0.323	0.117	0.269	0.279	-0.174	-0.699	-0.023	-0.132	0.202	-0.853		0.946**	0.882**
BOD	0.432	0.261	0.582	0.462	0.26	0.205	0.36	-0.054	-0.597	0.056	-0.041	0.276	-0.965	0.946**		0.971***
TC	0.307	0.143	0.499	0.434	0.21	0.103	0.282	-0.112	-0.654	-0.1	-0.04	0.219	-0.944	0.882**	0.971***	

E.C. correlates significantly with HCO3 ($r = 0.948$, $p < 0.01$), TDS ($r = 0.957$, $p < 0.01$), Na ($r = 0.926$, $p < 0.01$), and Ca ($r = 0.903$, $p < 0.01$), indicating that dissolved ions contribute to the conductivity of water. A similarly high correlation with SO4 ($r = 0.88$, $p < 0.05$) suggests a possible influence of sulfate-rich sources, such as industrial or agricultural runoff. T.H. shows a robust correlation with Ca ($r = 0.909$, $p < 0.01$) and Mg ($r = 0.659$, $p < 0.05$), consistent with its derivation from Ca and Mg concentrations in water. Its strong association with T.A. ($r = 0.851$, $p < 0.05$) suggests that bicarbonate hardness plays a significant role in T.A. TDS strongly correlates with Na ($r = 0.964$) and Ca ($r = 0.954$, $p < 0.01$), indicating the influence of these ions on overall dissolved solids. A high correlation with T.A. ($r = 0.983$, $p < 0.001$) suggests carbonate species as a dominant contributor to TDS, with similar values obtained by (Arya & Agarwal, 2018) Moderate correlations with SO4 ($r = 0.78$) and Cl ($r = 0.89$). Na Shows Strong correlations with Ca ($r = 0.965$) and TDS ($r = 0.964$), and SO4 ($r = 0.817$, $p < 0.05$) indicates anthropogenic or natural geochemical influences. Cl correlates moderately with E.C. ($r = 0.821$) and Na ($r = 0.791$), implying potential sources from saline intrusion or wastewater. T.A.

correlates strongly with Ca ($r = 0.958$, $p < 0.001$), Na ($r = 0.968$, $p < 0.001$), and TDS ($r = 0.983$, $p < 0.001$), emphasising the role of carbonates and bicarbonates in water buffering capacity. SO_4 ($r = 0.747$, $p < 0.05$) suggests possible carbonate and sulfate system interactions. DO exhibits inverse relationships with parameters like T.H. ($r = -0.742$), T.A. ($r = -0.456$), and TDS ($r = -0.52$). BOD correlates positively with COD ($r = 0.946$, $p < 0.01$) since both reflect the organic load in the water. COD shows a positive correlation with BOD ($r = 0.946$) and T.C. ($r = 0.882$, $p < 0.01$), underlining its connection to organic carbon content. Total Coliform (T.C.) has the highest correlation with BOD ($r = 0.971$, $p < 0.001$) and COD ($r = 0.882$, $p < 0.01$), highlighting its role as a key determinant of organic pollution—similar values obtained in Ganga from Kanpur (Arya & Agarwal, 2018).

Figure. 5 Heat Map of Pearson correlation coefficient matrix of analysed variables during the Winter season.



	EC	HCO3	Hardness	Ca	Na	Cl	TDS	Mg	K	SO4	NO3	DO	COD	BOD	TC
EC		0.954**	0.9**	0.932**	0.957**	0.985***	0.939**	0.87*	0.821*	0.943**	0.61	-0.786	0.417	0.924**	0.974***
HCO3	0.954**		0.878*	0.906**	0.936**	0.909**	0.86*	0.841*	0.796*	0.882*	0.714	-0.697	0.243	0.799*	0.89**
Hardness	0.9**	0.878*		0.873*	0.951**	0.879*	0.918**	0.967***	0.572	0.844*	0.566	-0.527	0.3	0.806*	0.856*
Ca	0.932**	0.906**	0.873*		0.9**	0.883**	0.904**	0.855*	0.845*	0.988***	0.499	-0.71	0.371	0.86*	0.89**
Na	0.957**	0.936**	0.951**	0.9**		0.957**	0.975***	0.867*	0.647	0.876*	0.739*	-0.748	0.486	0.91**	0.952**
Cl	0.985***	0.909**	0.879*	0.883**	0.957**		0.959**	0.823*	0.751*	0.903**	0.639	-0.837	0.539	0.963**	0.995***
TDS	0.939**	0.86*	0.918**	0.904**	0.975***	0.959**		0.828*	0.639	0.896**	0.652	-0.801	0.628	0.966***	0.969***
Mg	0.87*	0.841*	0.967***	0.855*	0.867*	0.823*	0.828*		0.632	0.844*	0.375	-0.402	0.117	0.722	0.784*
K	0.821*	0.796*	0.572	0.845*	0.647	0.751*	0.639	0.632		0.887**	0.281	-0.68	0.165	0.694	0.747*
SO4	0.943**	0.882*	0.844*	0.988***	0.876*	0.903**	0.896**	0.844*	0.887**		0.426	-0.739	0.394	0.886**	0.908**
NO3	0.61	0.714	0.566	0.499	0.739*	0.639	0.652	0.375	0.281	0.426		-0.667	0.462	0.586	0.651
DO	-0.786	-0.697	-0.527	-0.71	-0.748	-0.837	-0.801	-0.402	-0.68	-0.739	-0.667		-0.786	-0.899	-0.879
COD	0.417	0.243	0.3	0.371	0.486	0.539	0.628	0.117	0.165	0.394	0.462	-0.786		0.724	0.61
BOD	0.924**	0.799*	0.806*	0.86*	0.91**	0.963**	0.966***	0.722	0.694	0.886**	0.586	-0.899	0.724		0.983***
TC	0.974***	0.89**	0.856*	0.89**	0.952**	0.995***	0.969***	0.784*	0.747*	0.908**	0.651	-0.879	0.61	0.983***	

E.C. is highly correlated ($p < 0.01$). with HCO_3 ($r = 0.954$), TDS ($r = 0.939$), Cl ($r = 0.985$), and Na ($r = 0.957$). It indicates that these dissolved ions significantly influence water conductivity. SO_4 ($r = 0.943$) and Ca ($r = 0.932$) also exhibit strong correlations, likely due to geochemical sources like mineral dissolution or agricultural runoff contributions. HCO_3 shows positive correlations with Ca ($r = 0.906$), Hardness ($r = 0.878$), and TDS ($r = 0.86$). Moderate to strong ($p < 0.05$) associations with SO_4 ($r = 0.882$) and Cl ($r = 0.909$, $p < 0.01$) suggest interactions between carbonate and sulfate species in water. Hardness is highly correlated with Mg ($r = 0.967$) and Ca ($r = 0.873$), reflecting its dependence on these divalent ions. Positive correlations with Na ($r = 0.951$), SO4 ($r = 0.844$), and TDS ($r = 0.918$) indicate additional contributions from other ionic species. Na correlates strongly ($p < 0.01$) with Cl ($r = 0.957$), TDS ($r = 0.975$), and E.C. ($r = 0.957$), suggesting that sodium chloride is a significant contributor to water salinity. Na indicates a moderate correlation with SO4 ($r = 0.876$, $p < 0.05$) and indicates possible anthropogenic influences like wastewater discharge. Cl exhibits strong positive relationships with E.C. ($r = 0.985$), TDS ($r = 0.959$), and Na ($r = 0.957$), consistent with its role in determining salinity and E.C. SO_4 indicates positive correlations with Ca ($r = 0.988$) and Mg ($r = 0.844$). TDS is strongly associated with Na ($r = 0.975$), Cl ($r = 0.959$), Ca ($r = 0.904$), and SO4 ($r = 0.896$). DO has a negative correlation with most parameters, such as E.C. ($r = -0.786$), TDS ($r = -0.801$), and SO_4 ($r = -0.739$), though they are not statistically significant. These relationships suggest oxygen depletion in areas with high ion or pollutant loads. BOD shows strong correlations with T.C. ($r = 0.983$) and COD ($r = 0.724$), emphasising its role as an indicator of organic pollution. BOD also shows significant associations with Cl ($r = 0.963$) and TDS ($r = 0.966$), suggesting that ionic pollution could accompany organic matter. Total Coliform (T.C.) is highly correlated with BOD ($r = 0.983$), COD ($r = 0.61$), and TDS ($r = 0.969$), indicating its relevance as a measure of organic and inorganic carbon loads (Y. Singh & Jain, 2021b).

Table 3. Analyse the Student T-Test for paired samples among all seasons.

Paired Samples T-Test in Summer					**Paired Samples TTest in Monsoon**			**Paired Samples T- Test in Winter**		
Measure 1	Measure 2	t	df	p	t	df	p	t	df	p
EC	HCO3	23.639	5	< .001	129.07	5	< .001	102.174	5	< .001

E.C.	Ca	26.663	5	< .001	99.322	5	< .001	44.315	5	< .001
Ca	Na	-6.086	5	0.002	5.113	5	0.004	-0.558	5	0.601
E.C.	Na	24.291	5	< .001	107.95	5	< .001	48.813	5	< .001
TDS	Na	30.79	5	< .001	67.016	5	< .001	23.792	5	< .001
Mg	Na	-73.894	5	< .001	-42.883	5	< .001	-16.043	5	< .001
Hardness	Ca	11.331	5	< .001	61.07	5	< .001	9.513	5	< .001
TDS	Mg	33.814	5	< .001	70.757	5	< .001	23.61	5	< .001
BOD	COD	-37.228	5	< .001	-30.931	5	< .001	-14.238	5	< .0 01

The paired t-test was performed to examine the significant differences between paired water quality parameters across three seasons: summer, monsoon, and winter. E.C. shows highly significant differences with HCO_3, Ca, and Na across all three seasons ($p < 0.001$). The observed p-values, which are less than 0.001 in all instances, provide strong evidence to reject the null hypothesis of no difference, thereby affirming the presence of a significant relationship

(Pramanik et al., 2020) The t-values for EC-HCO_3 are particularly high: Summer: 23.639, Monsoon: 129.07 (greatest difference), and in winter: 102.174, which indicates that E.C. and HCO_3 show a much stronger relationship during monsoon compared to other seasons. TDS-Na shows strong differences across all seasons ($p < 0.001$), with t-values of summer (30.79) → monsoon (67.016) → winter (23.792). The Ca and Hardness relationship is highly significant in all seasons. Summer: t=11.331t = 11.331t=11.331 Monsoon: t=61.07t = 61.07t=61.07 Winter: t=9.513t = 9.513t=9.513. The highest difference occurs during monsoon, possibly due to increased Ca leaching from soil and rocks. The paired t-test of TDS and Mg shows a strong seasonal effect ($p < 0.001$ in all cases). This season, the highest t-value in monsoon (70.757) suggests a stronger relationship between TDS and Mg. BOD and COD show negative t-values across all seasons, indicating BOD levels are consistently lower than COD (Table 3). The decreasing magnitude from summer → winter suggests a declining difference between BOD and COD over time, likely due to lower biological activity in colder months. Monsoon season shows extreme differences in E.C., TDS, and hardness-related measurements, possibly due to increased surface runoff, higher erosion, and dilution effects. Winter shows the least significant differences, particularly in Ca vs. Na, indicating a more stable water composition. Negative tvalues (e.g., Mg vs. Na and BOD vs. COD) indicate a consistently lower first parameter than the second, a similar observation obtained by (Pramanik et al., 2020).

CPI Value

Table 4 Pollution levels and parameters for six different sampling sites during three different seasons

Sampling Site	Summer	Pollution Level	Rain	Pollution Level	Winter	Pollution Level	CPI Level
S1	0.43	Slightly Polluted	0.25	Sub clean	0.32	Sub clean	<=.20 Clean
S2	0.46	Slightly Polluted	0.26	Sub clean	0.39	Sub clean	0.21 - 0.40 subclean
S3	0.41	Slightly Polluted	0.26	Sub clean	0.31	Sub clean	0.41 - 1.00 slightly polluted
S4	0.39	Slightly Polluted	0.27	Sub clean	0.32	Sub clean	1.01 - 2.0 moderately polluted
S5	0.45	Slightly Polluted	0.27	Sub clean	0.35	Sub clean	>= 2.01 Severely polluted
S6	0.47	Slightly Polluted	0.26	Sub clean	0.31	Sub clean	

Table 6 provides data on pollution levels and parameters for six different sampling sites during three seasons: Summer, rain, and winter. The CPI level measures environmental chemical pollution. (Döndü et al., 2022). The pollution levels observed during the summer season at each site are categorised as "Slightly Polluted," indicating a relatively low pollution level. The pollution level observed during the monsoon season at each site is categorised as "Sub Clean," which suggests a cleaner environment than the summer season. The pollution level observed during the winter season at each site, categorised as "Sub Clean," indicates a relatively low pollution level. The CPI levels are classified into different ranges, including "<= 0.20 Clean," "0.21 - 0.40 Sub-Clean," "0.41 - 1.00 Slightly Polluted," "1.01 - 2.0 Moderately Polluted," and ">= 2.01 Severely Polluted. Other researchers found 0.64-0.88 (in summer), 1.68-2.47 (in monsoon), and 0.54-0.72 (in winter) (Matta et al., 2018) pH, E.C., HCO3, Ca, Na, Cl, TDS, Mg, SO4, NO3, and COD are used to evaluate water quality and pollution levels, similar parameters used by other researchers (Matta et al., 2018).

Conclusion

In conclusion, this research has provided key points about the Agra Canal's health and valuable insights into the seasonal variations in water pollutant levels across different seasons. The comprehensive analysis of water samples collected during the summer, winter, and monsoons revealed a clear trend: higher concentrations of most parameters in the summer, followed by comparatively lower levels in the winter and the lowest levels during the monsoon. The sampling site S2 has a higher total coliform load than S1, which shows that effluents are added before location S2, although S2 is the point and nonpoint source of sewage discharge in the canal. The observed higher concentrations during the summer can be attributed to several factors. Elevated temperatures often lead to increased biological and chemical activities in water bodies, promoting the release of nutrients and contaminants. WQI was highest in summer, at 121.32, which shows water is unsuitable for any purpose; in winter, the WQI was 85.57, representing inferior water quality; and in monsoon season, it was 53.14, showing poor water quality. The monsoon exhibited the least pollutant presence in water samples. Dilution caused by the increased water volume during heavy rains also significantly reduces pollutant concentrations. Pearson correlation shows a significant correlation in most parameters except DO. E.C. shows a positive correlation with Na and Cl, TDS, TA, SO4, NO3, Ca, T.H., BOD, and HCO_3 in all seasons. Paired student test also shows a significant relationship among parameters. In summer, the CPI value ranged from 0.43 to 0.47, which falls under slightly polluted. In winter, the CPI ranged from 0.31 to 0.39 in the sub-sub-clean category, and in the monsoon, the range was 0.25 to 0.27, which falls under the sub-clean category. These significant correlations provide insight into the interrelated dynamics of water quality parameters and underline the need for integrated management of ionic components in aquatic ecosystems. Furthermore, this research contributes to determining the reason for the low yield of crop production and our understanding of how human activities and natural processes interact to influence water quality throughout the year. These insights can guide policymakers, environmental agencies, and industries in developing targeted interventions to mitigate water pollution and ensure the sustainability of our water resources across all seasons.

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