Seasonal variation in chemical composition of sewage effluent at Bhagwanpur sewage treatment plant Varanasi and it's suitability for irrigation

Abstract

During the year 2018, seasonal variation in the physico-chemical characteristics of the influent and effluent of Varanasi's Bhagwanpur sewage treatment plant was examined. Water samples from the plant's inlet, aerator, and outlet tanks were taken in order to determine the water's suitability for irrigation. These samples were then tested for parameters including pH, EC, TDS, BOD, COD and dominant anions and cations as well as heavy metals. Higher concentrations of some heavy metals were a notable concern that will require close attention and ongoing monitoring in the near future if effluent water is to be used for irrigation.

Keywords: Influent, effluent, Sewage treatment, irrigation.

Introduction

Despite being replenished by nature, fresh water is a scarce resource. The amount of water per person which depends on the population of the nation, is steadily decreasing in India. In 2001 and 2011, the average annual water availability per person was estimated to be 1,816 cubic metres and 1,545 cubic metres, respectively which may further decline due to increase in population. (Annual report 2020-2021, GOI). The waste and waste waters from humans or household operations that are discharged to water bodies or otherwise enters a treatment works is known as domestic sewage. Before approaching its targeted destiny, this domestic sewage enriched with lots of extraneous materials through contacting the various industrial wastes, pharmacy waste, agricultural runoff and other sources of water pollution. According to the National Commission for Integrated Water Resources Development's (NCIWRD) research, 72.48% of the water consumed overall in 2025 under the high demand scenario will be used for irrigation. Therefore, using sewage water as a source of irrigation is a commendable strategy to meet the increased demand for water for agricultural production. By offering a substitute for the direct discharge of sewage effluent into water bodies and by supplying a sizable amount of carbon, major nutrients, and micronutrients to the soil that are crucial for crop production, it has been proven to be an environmentally beneficial strategy. However, the continual use of sewage water to irrigate agricultural areas may also increase the heavy metal load in the soil, rendering it unsuitable for growing crops due to their bio-transfer pattern through the chain: sewage-soil-vegetation-animal-humans. The physicochemical characteristics of sewage water must therefore be continuously monitored, either before it is used for irrigation or before it is discharged into water bodies. The quality of effluent may vary significantly in different seasons. Therefore, the present study was planned and executed to better understand the seasonal changes in the quality of sewage effluent at the Bhagwanpur sewage treatment plant in Varanasi, Uttar Pradesh, India.

Material and Method

Sample collection

Sewage water samples were collected from three different tanks viz infilteration tank, sedimentation tank and outlet tank at Bhagwanpur Sewage Treatment Plant Varanasi, Uttar Pradesh. Sampling was done in the month of February (autumn), May (pre monsoon), August (rainy) and November (post monsoon) during the year 2018 to assess the seasonal variation in physico-chemical properties of sewage effluent. Samples were collected in polythene water bottles which were thoroughly washed and then rinsed with the same effluent water samples prior to sampling.

Laboratory analysis

Immediately after collection, samples were preserved by various parameter wise standard preservation methods (EPA 1983). The samples were analyzed for various physico chemical properties viz, pH EC, TSS TDS, BOD COD, nitrate nitrogen, phosphate, potassium, carbonate, bicarbonate, sulphate and heavy metals viz. Fe, Cu, Mn, Zn, Pb, Cd, Ni, Cr (APHA, 2005).

Data Analysis

Mean values with the standard deviations from mean values for the collected data sets from laboratory analysis were calculated and compared for analyzing the seasonal variation in the composition of sewage effluent and difference due to treatment of sewage water at plant level. To establish the relationship between physicochemical parameters in the sample Pearson's correlation was used.

Result and Discussion

Samples of sewage water were taken from each tank at the sewage treatment facility at Bhagwanpur and were then examined for several chemical parameters. Table 1 displays the annual mean of the various physico-chemical characteristics of influent, effluent, and aerator tank water samples and table 2, 3 and 4 display the seasonal variations in the same. Indicating its alkaline character, the pH of sewage water was neutral to slightly alkaline and seasonally varied from 7.2 to 7.8 before treatment and from 7.4 to 8.0 after treatment. It was discovered that the influent's annual average pH was 7.6, whereas the effluent's was 7.7. Water's electrical conductivity, which corresponds to the dominating ions that are the result of ion exchange and solubilization in the water, is a key factor in determining whether it is suitable for irrigation. The EC of influent fluctuates seasonally from 962 to 1054 µs cm^{-1} with an average mean of 1002 µs cm^{-1}, and the EC of effluent varies seasonally from 584 to 644 µs cm^{-1} with an average mean of 610 µs cm^{-1}. Both the influent and effluent's EC have a strong positive correlation with TDS, as well as with the cations Ca, Na, K, and Mg and the anions carbonate and bicarbonate, among others (Tables 5 and 6). Sewage influent had an annual average total alkalinity of 564 mg L^{-1}, with seasonal variations ranging from 542 to 579 mg L^{-1}, whereas effluent had an annual average total alkalinity of 342 mg L^{-1}, with seasonal variations ranging from 321 to 374 mg L^{-1}. Nitrate levels in influent and effluent samples vary seasonally from 20.96 to 25.36 and 11.52 to 15.88 mg L^{-1}, respectively, with yearly averages of 22.87 and 13.73 mg L^{-1}. The nitrate concentration in sewage effluent corresponds to the household stuffs, runoffs from agricultural fields, cattle yards etc. According to reports, sewage discharge is a significant source of phosphate from a variety of sources, which causes eutrophication of aquatic bodies. The phosphate content of the influent sample ranged from 12.23 to 16.36 mg L^{-1} with an average yearly concentration of 13.60 mg L^{-1}, while the phosphate content of the effluent ranged from 5.86 to 9.50 mg L^{-1} with an average annual concentration of 7.29 mg L^{-1}. One of the important contributing factors for concentration of potassium ion in the water sample is rain water (Davis and De Wiest 1967). While the potassium ion content in the influent sample varies from 9.93 to 10.13 mg L^{-1} with an average annual value of 9.98 mg L^{-1}, it is 6.97 to 7.97 mg L^{-1} with an average annual value of 7.50 mg L^{-1} in the effluent sample. The biological oxygen demand (BOD) is typically employed as an index to quantify the level of organic contamination in waste water which can be decomposed by bacteria under anaerobic condition. Seasonal variation in BOD of influent at Bhagwanpur STP was from 173 to 213 mg L^{-1} with an annual average of 190 mg L^{-1} and of effluent was from 55 to 77 mg L^{-1} with an average of 66 mg L^{-1}. Whereas, COD of the influent varied seasonally from 415 to 534 mg L^{-1} and that of effluent from 183 to 219 mg L^{-1}. Year around average COD of the influent and effluent was 456 and 199 mg L^{-1} respectively. Average content of calcium, magnesium and sodium in influent was 92.59 mg L^{-1}, 23.70 mg L^{-1} and 21.21 mg L^{-1} respectively, whereas the same in effluent was 88.5 mg L^{-1}, 20.41 mg L^{-1} and 11.52 mg L^{-1} respectively. Average RSC of the influent was 4.37 meq L^{-1} (toxic as per BIS,2019) and that of effluent was 1.00 meq L^{-1} (good as per BIS, 2019). Whereas the SAR of the influent and effluent was 0.51 and 0.29 respectively which was good as per BIS, 2019.

Due to their toxicity and accumulative behaviour in the system, heavy metal load in sewage water has drawn a lot of attention in recent years. These pollutants undergo a worldwide ecological cycle and are non-biodegradable in comparison to other polluting substances (CPCB 2001). Due to their inability to biodegrade, these substances enter the food chain through a variety of channels, where they accumulate in the organs of people and animals over time as a result of prolonged exposure to contaminated environments (Jain et al 2010). Tables 1 and 4 show the seasonal variation and annual average of heavy metal levels in influent and effluent at Bhagwanpur STP. Before utilising the effluent as an alternate source for irrigation, it is advised to continuously monitor it since the concentration of cadmium, chromium, manganese, copper and zinc in the effluent are above permissible limit (BIS, 2019). The iron, lead and nickle content were found within the desirable limits prescribed by BIS / FAO for irrigation water. Although iron concentration was within the permissible limit but it is not recommended for micro irrigation purpose as iron content of more than 0.3 mg L^{-1} results in oxidized insoluble forms that could cause black or brown stains on foliage of plants if used with sprinkler irrigation (BIS, 2019). A considerable negative shift was observed in the heavy metal load of influent vs effluent samples which was due to chelation of metal cations with organic matter present in the raw sewage influent which was further transformed into sludge throughout the treatment process.

A statistical indicator of the interdependence of two or more random variables is the correlation coefficient (r). Correlation analysis measures the closeness and degree of linear association between independent and dependent variables. The correlation coefficient 'r' for water quality parameters of influent and effluent sample are presented in table 5 and 6 respectively. Although EC and TDS were shown to have a substantial positive link, EC also showed a positive correlation with cations like calcium, magnesium, and sodium as well as anions like carbonate and bicarbonate. Pearson correlation coefficient between BOD and COD exhibited a significant positive correlation. Nitrate also showed significant positive correlation with phosphates. The amount of dissolved oxygen and phosphates in the effluent water were inversely correlated. A significant positive correlation was observed between pH and alkalinity of the effluent sample.

Conclusion:

This study provides a collective information regarding sewage water quality at Bhagwanpur sewage treatment plant, Varanasi throughout the treatment process. The quality parameters of influent and effluent samples were compared with BIS standards and revealed that effluent qualities meet acceptable standard in physicochemical parameters, like pH, temperature and electrical conductivity and it can be used for agricultural use with the continuous monitoring of heavy metals concentration of cadmium, chromium, manganese, copper and zinc which fell short of regularity limits for agricultural use.

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Tables:

Table 1: Characteristics of influent, aerator tank water and effluent (Annual mean ± standard deviation)

Parameter	Influent	Aerator Tank	Effluent
Temperature	26.7 ± 0.05	26.7 ± 0.03	26.7 ± 0.04
pH	7.64 ± 0.05	7.66 ± 0.00	7.69 ± 0.02

EC	1002 ± 25	842 ± 3	610 ± 16
TDS	594 ± 05	552 ± 3	413 ± 3
DO	1.70 ± 0.02	2.14 ± 0.02	3.00 ± 0.02
BOD	190 ± 4	185 ± 1	66 ± 02
COD	465 ± 3	432 ± 01	199 ± 6
Nitrate N	22.87 ± 0.28	21.88 ± 1.08	13.73 ± 0.66
Phosphate	13.60 ± 0.79	13.14 ± 0.59	7.29 ± 0.50
Potassium	9.98 ± 0.05	9.52 ± 0.12	7.5 ± 0.09
Calcium	92.59± 0.88	89.5 ± 1.39	88.5 ± 1.32
Magnesium	23.70 ± 0.44	22.97 ± 0.69	20.41 ± 0.61
Sulphate	35.13 ± 0.36	33.73 ± 0.43	33.18 ± 1.10
Sodium	21.21 ± 0.25	20.54 ± 0.59	11.52 ± 0.75
Alkalinity	564 ± 03	504 ± 02	342 ± 08
Iron	1.39 ± 0.01	1.16 ± 0.03	0.52 ± 0.01
Copper	0.536 ± 0.01	0.488 ± 0.013	0.238 ± 0.02
Zinc	2.623 ± 0.06	2.599 ± 0.05	1.376 ± 0.05
Manganese	0.722 ± 0.02	0.651 ± 0.01	0.445 ± 0.02
Lead	0.410 ± 0.01	0.374 ± 0.01	0.254 ± 0.003
Cadmium	2.827 ± 0.06	2.743 ± 0.03	2.168 ± 0.06
Chromium	0.237 ± 0.03	0.227 ± 0.03	0.169 ± 0.01
Nickel	0.153 ± 0.005	0.129 ± 0.001	0.081 ± 0.01
RSC	4.37 ± 0.06	3.51 ± 0.13	1.00 ± 0.18
SAR	0.51 ± 0.01	0.50 ± 0.02	0.29 ± 0.02

***** *All the parameters are expressed in mg L^{-1}, except Temperature (°C), pH and EC (μs cm^{-1}), RSC (meq L^{-1}) and SAR.*

Table 2: Seasonal variation in physicochemical characteristics of sewage water from Bhagwanpur STP (mean ± standard deviation)

Season / Parameter	Influent Characteristics (Mean value)									
	Temperature	pH	EC	TDS	DO	BOD	COD	Nitrate N	Phosphate	Potassium
Spring 2018	23.1 ± 0.06	7.78 ± 0.11	1013 ± 44	621 ± 11	1.88 ± 0.06	185 ± 08	445 ± 07	23.53 ± 1.06	13.47 ± 2.21	10.10 ± 0.36
Summer 2018	32.3 ± 0.10	7.28 ± 0.04	980 ±33	576 ±9	0.98 ± 0.05	213 ±05	534 ± 09	25.36 ±0.70	16.36 ± 2.01	10.13 ± 0.50
Rainy 2018	28.7 ± 0.06	7.65 ± 0.06	962 ±50	544 ±11	1.87 ± 0.05	173 ±06	415 ± 12	21.63 ± 0.55	12.23 ± 1.57	9.77 ± 0.35
Winter 2018	22.7 ± 0.06	7.85 ±0.08	1054 ±50	636 ±12	2.04 ± 0.06	187 ±05	466 ± 07	20.97 ±0.84	12.35 ± 1.65	9.93 ± 0.42
	Aerator tank water characteristics (Mean value)									
	Temperature	pH	EC	TDS	DO	BOD	COD	Nitrate N	Phosphorus	Potassium
Spring 2018	23.2 ± 0.10	7.79 ±0.04	852 ± 34	559 ±9	2.20 ± 0.07	182 ±05	412 ± 07	23.62 ± 1.81	12.90 ± 1.80	9.87 ± 0.31
Summer 2018	32.3 ± 0.10	7.23 ±0.03	820 ± 16	553 ±6	1.90 ± 0.07	206 ±04	503 ± 05	21.65 ±0.73	15.39 ± 1.98	9.80 ± 0.40
Rainy 2018	28.6 ± 0.06	7.64 ±0.06	879 ± 30	515 ±7	2.14 ± 0.04	174 ±06	396 ± 08	21.47 ±1.96	12.00 ± 1.45	9.63 ± 0.35
Winter 2018	22.6 ± 0.06	7.96 ±0.06	818 ± 24	580 ±8	2.34 ± 0.05	179 ±04	418 ± 09	20.78 ± 1.10	12.28 ± 1.62	8.77 ± 0.45
	Effluent Characteristics (Mean value)									
	Temperature	pH	EC	TDS	DO	BOD	COD	Nitrate N	Phosphorus	Potassium
Spring 2018	23.3 ± 0.06	7.74 ±0.06	599 ± 25	423 ±6	2.97 ± 0.05	68 ±07	196 ± 12	11.52 ± 0.92	7.43 ± 1.12	6.97 ± 0.25
Summer 2018	32.4 ± 0.06	7.43 ±0.05	644 ±59	462 ±6	2.73 ± 0.05	77 ±03	219 ± 07	15.88 ± 1.49	9.50 ± 1.80	7.57 ± 0.21
Rainy 2018	28.8 ± 0.10	7.57 ±0.05	584 ±34	358 ±6	3.14 ±0.06	55 ±04	183 ± 06	13.95 ±1.57	6.35 ± 1.13	7.50 ± 0.36
Winter 2018	22.5 ± 0.06	8.04 ±0.07	611 ±17	409 ±7	3.16 ± 0.06	64 ±05	199 ± 10	13.57 ±0.99	5.86 ± 0.71	7.97 ± 0.40

**** All the parameters are expressed in mg L^{-1}, except Temperature (°C), pH and EC (μs cm^{-1}).***

Table 3: Seasonal variation in physicochemical characteristics of sewage water from Bhagwanpur STP (mean ± standard deviation)

Season / Parameter	Influent Characteristics (Mean value)						
	Calcium	Magnesium	Sodium	Sulphate	Total alkalinity	RSC	SAR
Spring 2018	94.00 ± 2.00	24.54 ± 0.62	20.52 ± 2.10	28.86 ± 0.29	576 ± 10	4.46 ± 0.25	0.49 ± 0.056
Summer 2018	92.00 ± 2.00	21.61 ± 1.34	20.85 ± 0.96	41.18 ± 0.30	542 ± 04	4.11 ± 0.14	0.51 ± 0.03
Rainy 2018	88.67 ± 3.06	22.86 ± 1.10	21.08 ± 1.37	39.51 ± 0.52	561 ± 05	4.55 ± 0.15	0.52 ± 0.03
Winter 2018	95.67 ± 2.08	25.78 ± 0.91	22.38 ± 1.92	30.95 ± 1.45	579 ± 01	4.37 ± 0.20	0.52 ± 0.04
	Aerator tank water characteristics (Mean value)						
	Calcium	Magnesium	Sodium	Sulphate	Total alkalinity	RSC	SAR
Spring 2018	92.67 ± 2.52	22.81 ± 0.66	20.23 ± 1.18	28.09 ± 0.47	533 ± 02	3.88 ± 0.11	0.49 ± 0.03
Summer 2018	91.33 ± 3.06	23.72 ± 1.13	19.51 ± 1.08	40.14 ± 0.99	486 ± 08	3.02 ±0.03	0.47 ± 0.03
Rainy 2018	86.67 ± 3.06	20.64 ± 0.72	21.33 ± 1.67	39.30 ± 1.08	488 ± 11	3.46 ±0.17	0.53 ± 0.04
Winter 2018	87.33 ± 3.06	24.71 ± 1.32	21.08 ± 1.84	27.40 ± 1.13	510 ± 06	3.66 ±0.25	0.51 ± 0.04
	Effluent Characteristics (Mean value)						
	Calcium	Magnesium	Sodium	Sulphate	Total alkalinity	RSC	SAR
Spring 2018	91.33 ± 4.16	21.52 ± 0.60	12.35 ± 1.10	26.73 ± 1.46	374 ± 09	1.29 ± 0.05	0.30 ± 0.03
Summer 2018	86.67 ± 2.31	17.65 ± 0.73	10.14 ± 1.20	40.13 ± 1.56	321 ± 08	0.93 ± 0.32	0.26 ± 0.03
Rainy 2018	85.33 ± 3.06	19.55 ± 1.30	12.03 ± 1.37	38.43 ± 1.84	327 ± 11	0.97 ± 0.16	0.31 ± 0.04
Winter 2018	90.67 ± 3.06	22.90 ± 1.50	11.54 ± 1.33	27.44 ± 1.10	347 ± 06	0.80 ± 0.32	0.28 ± 0.04

***** All the parameters are expressed in mg L^{-1}, except RSC and SAR.***

Table 4: Seasonal variation in heavy metal concentration of sewage water from Bhagwanpur STP (mean ± standard deviation)

Season / Parameter	Influent Characteristics (Mean value)							
	Iron	Copper	Manganese	Zinc	Lead	Cadmium	Chromium	Nickle
Spring 2018	1.41 ± 0.05	0.592 ± 0.02	0.757 ± 0.03	2.729 ± 0.12	0.462 ± 0.02	2.875 ± 0.10	0.249 ± 0.04	0.134 ± 0.02
Summer 2018	1.47 ± 0.04	0.561 ± 0.03	0.653 ± 0.04	2.535 ± 0.12	0.320 ± 0.03	2.751 ± 0.08	0.223 ± 0.05	0.153 ± 0.03
Rainy 2018	1.31 ± 0.06	0.476 ± 0.02	0.688 ± 0.03	2.408 ± 0.15	0.411 ± 0.01	2.994 ± 0.15	0.227 ± 0.07	0.185 ± 0.06
Winter 2018	1.39 ± 0.10	0.513 ± 0.02	0.789 ± 0.01	2.822 ± 0.17	0.448 ± 0.06	2.687 ± 0.22	0.251 ± 0.06	0.139 ± 0.03
	Aerator tank water characteristics (Mean value)							
	Iron	Copper	Manganese	Zinc	Lead	Cadmium	Chromium	Nickle
Spring 2018	1.16 ± 0.04	0.527 ± 0.04	0.684 ± 0.02	2.712 ± 0.25	0.422 ± 0.04	2.718 ± 0.10	0.231 ± 0.04	0.111 ± 0.01
Summer 2018	1.22 ± 0.02	0.499 ± 0.02	0.619 ± 0.02	2.491 ± 0.12	0.296 ± 0.02	2.741 ± 0.08	0.216 ± 0.04	0.129 ± 0.04
Rainy 2018	1.08 ± 0.05	0.464 ± 0.01	0.610 ± 0.02	2.396 ± 0.10	0.363 ± 0.01	2.831 ± 0.14	0.214 ± 0.07	0.154 ± 0.04
Winter 2018	1.17 ± 0.09	0.463 ± 0.02	0.690 ± 0.05	2.797 ± 0.20	0.413 ± 0.05	2.683 ± 0.07	0.248 ± 0.04	0.123 ± 0.04
	Effluent Characteristics (Mean value)							
	Iron	Copper	Manganese	Zinc	Lead	Cadmium	Chromium	Nickle
Spring 2018	0.53 ± 0.04	0.281 ± 0.03	0.429 ± 0.02	1.474 ± 0.21	0.268 ± 0.01	2.276 ± 0.12	0.185 ± 0.04	0.076 ± 0.01
Summer 2018	0.62 ± 0.06	0.221 ± 0.03	0.439 ± 0.05	1.297 ± 0.22	0.223 ± 0.02	2.355 ± 0.19	0.164 ± 0.03	0.067 ± 0.02
Rainy 2018	0.46 ± 0.03	0.206 ± 0.04	0.424 ± 0.03	1.037 ± 0.17	0.249 ± 0.01	2.059 ± 0.09	0.147 ± 0.02	0.096 ± 0.01
Winter 2018	0.46 ± 0.06	0.243 ± 0.05	0.486 ± 0.01	1.695 ± 0.16	0.275 ± 0.02	1.981 ± 0.13	0.181 ± 0.02	0.084 ± 0.01

***** All the parameters are expressed in mg L^{-1}.***

Table 5: Correlation matrix of raw sewage of Bhagwanpur STP showing Pearson's correlation coefficient between parameters

	Temp.	pH	EC	TDS	DO	BOD	COD	NO_3^-	PO_4^{-3}	K^+	Ca^{++}	Mg^{++}	SO_4^{-2}	Na^+	CO_3^{-2}	HCO_3^-
Temp.	1															
pH	-0.948	1														
EC	-0.805	0.648	1													
TDS	-0.797	0.579	0.956*	1												
DO	-0.851	0.974*	0.486	0.384	1											
BOD	0.517	-0.750	0.002	0.102	-0.873	1										
COD	0.500	-0.722	0.058	0.124	-0.841	0.992**	1									
NO_3^-	0.607	-0.804	-0.395	-0.175	-0.884	0.803	0.726	1								
PO_4^{-3}	0.681	-0.879	-0.305	-0.150	-0.962*	0.936	0.892	0.951*	1							
K^+	0.079	-0.388	0.207	0.435	-0.578	0.791	0.733	0.811	0.779	1						
Ca^{++}	-0.686	0.447	0.948	0.984*	0.243	0.256	0.286	-0.085	-0.018	0.506	1					
Mg^{++}	-0.972*	0.931	0.881	0.815	0.838	-0.466	-0.420	-0.694	-0.694	-0.149	0.730	1				
SO_4^{-2}	0.963*	-0.835	-0.801	-0.868	-0.697	0.337	0.344	0.369	0.475	-0.182	-0.767	-0.898	1			
Na^+	-0.399	0.447	0.664	0.419	0.433	-0.143	-0.024	-0.704	-0.466	-0.400	0.454	0.604	-0.219	1		
CO_3^{-2}	-0.965*	0.963*	0.822	0.738	0.897	-0.567	-0.520	-0.769	-0.777	-0.263	0.641	0.992**	-0.866	0.607	1	
HCO_3^-	-0.984*	0.977*	0.689	0.679	0.914	-0.654	-0.644	-0.661	-0.769	-0.197	0.546	0.934	-0.927	0.325	0.948	1

*Correaltion is significant at $\alpha_{0.05}$ (2- tailed) and ** Correaltion is significant at $\alpha_{0.01}$ (2- tailed)

Table 6: Correlation matrix of effluent from Bhagwanpur STP showing Pearson's correlation coefficient between parameters

	Temp.	pH	EC	TDS	DO	BOD	COD	NO_3^-	PO_4^{-3}	K^+	Ca^{++}	Mg^{++}	SO_4^{-2}	Na^+	CO_3^{-2}	HCO_3^-
Temp.	1															
pH	-0.914	1														
EC	0.486	-0.296	1													
TDS	0.240	-0.203	0.901	1												
DO	-0.654	0.693	-0.802	-0.845	1											
BOD	0.338	-0.310	0.911	0.994**	-0.898	1										
COD	0.426	-0.289	0.988*	0.956*	-0.846	0.962*	1									
NO_3^-	0.834	-0.541	0.677	0.311	-0.483	0.367	0.570	1								
PO_4^{-3}	0.707	-0.745	0.781	0.803	-0.997**	0.864	0.818	0.517	1							
K^+	0.046	0.359	0.280	-0.077	0.298	-0.111	0.150	0.565	-0.298	1						
Ca^{++}	-0.864	0.763	-0.049	0.273	0.191	0.177	0.049	-0.711	-0.264	-0.171	1					
Mg^{++}	-0.982*	0.969*	-0.468	-0.295	0.733	-0.397	-0.435	-0.730	-0.783	0.137	0.803	1				
SO_4^{-2}	0.971*	-0.861	0.312	0.011	-0.453	0.110	0.228	0.824	0.517	0.140	-0.959*	-0.926	1			
Na^+	-0.705	0.451	-0.933	-0.696	0.724	-0.730	-0.874	-0.897	-0.728	-0.437	0.380	0.645	-0.595	1		
CO_3^{-2}	-0.945	0.983*	-0.464	-0.353	0.790	-0.454	-0.453	-0.640	-0.835	0.268	0.726	0.989*	-0.865	0.599	1	
HCO_3^-	-0.800	0.518	-0.351	0.068	0.191	0.003	-0.219	-0.927	-0.244	-0.596	0.870	0.674	-0.878	0.664	0.559	1

*Correaltion is significant at $\alpha_{0.05}$ (2- tailed) and ** Correaltion is significant at $\alpha_{0.01}$ (2- tailed)