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RESEARCH ARTICLE

STUDIES ON TREATMENT OF POLLUTED YAMUNA RIVER WATER BY ELECTROCHEMICAL PROCESS

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ABSTRACT

Very expensive water treatment technologies are not capable for the treatment of polluted Yamuna river water and the conventional water processes based on chemical, filtration and/or biological treatment process are also not suitable to remove TDS. Generally untreated wastewater contains high level of organic and inorganic materials, numerous pathogenic microorganisms, nutrients and many other toxic compounds. Delhi has been suffering the problems of increasing amount of sewage water and industrial effluents into Yamuna river for the last few decades due to horizontal and vertical expansion of the city. Yamuna river is main source of water to well qualified, high populated Delhi peoples and Agra canal originated from Okhala barrage. In the present study the impact of urban runoff on the water quality of Yamuna River at Delhi has been investigated which supplies into Agra canal for irrigation purposes. Water samples were collected from five different points and analyzed for various physicochemical parameters such as pH, total suspended solids (TSS), total dissolved solids (TDS), Total Hardness (TH), total alkalinity (TA), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Electrical Conductivity (EC), Chloride, Sulphate, nitrate, toxic metals and Microbial Population (MP) levels. Electrochemical technique was successfully applied to the treatment of each sample and the concentration of selected parameters reduced considerably to the admissible limit. Experimental results reported that drastic variations were found in each water samples after treatment. Indicating water pollution levels was manifold higher than the prescribe limit by the pollution control authorities for irrigation. Overall, the study concluded that water quality of Yamuna river water was very poor and not suitable for irrigation or any other purposes.

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INTRODUCTION

The Yamuna river, the largest tributary of the holy Ganga river has been one of the most prominent and important rivers of India. Unfortunately, almost stretches of Yamuna River in Delhi are much polluted (Fig. 1). Various urban centers e.g. Delhi, Mathura, Agra etc., which are located on the banks of Yamuna river, draw fresh river water for various activities. The pollution of Yamuna has been characterized by several investigators (Prebha and Selvapathy, 1997; Zuane, 1990; CPCB, 1980–81; CSE, 2009; Banerji and Martin, 1997). The trend in pollution load contribution through domestic and industrial wastewater outfalling from various drains into the Yamuna river, indicates that it is continuously rising day-by-day. The most polluted Yamuna in its Delhi stretch is characterized by bad odour, ugly look, high organic and inorganic load, excessive pathogens and high dissolved oxygen depletion. On the basis of different geological and ecological parameters, the Yamuna river has been divided into five segments as shown in Table 1. Among various chemical and microbial water pollutants, metal ions are toxic, dangerous and harmful due to their nature of tissue degradation. Heavy metals are also bio-accumulative and relatively stable, as well as carcinogenic and therefore require close monitoring[5]. The poisoning of arsenic, cadmium, chromium and lead is quite well known. The toxicities of metal ions have attracted scientists towards their detection in natural water resources. Among various natural water resources, almost rivers are highly polluted by heavy metals due to the direct discharge of municipal and industrial effluents into the rivers. River water is being used for domestic water supply in

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different parts of the world and, therefore, the analysis of toxic pollutants in river water has received great attention. In view of the hazardous nature of pollutants, an attempt has been made to study the pollution potential of chemicals and heavy metals in the Yamuna at Delhi. It is necessary to immediate attention for the enhancement of the water quality of the river. The improvement of the water quality of this segment cannot be delayed any further, especially because there exists an abstraction point at the Okhla water works which supplies 30,000 kiloliters of drinking water daily to about 4,2,30,000 peoples of Delhi. The health and welfare of these people is intimately connected with the quality of drinking water. Furthermore, there are many bathing ghats at which peoples come and daily use these Ghats for various purposes. The huge amount of polluted water is supplying in Agra canal for irrigation of 638 village's agricultural land. The Yamuna river is highly polluted due to the chemicals and toxic pollution load of the city.

In the modern concept, most of the rivers in the urban regions are the end point of wastewater discharged from the domestic and industries, which create major problem for river water quality management. The wastewater discharges contributes to significant river water degradations, reduces agricultural products quality, land fertility and ultimately affect the public health. The Delhi segment of Yamuna from the Wazirabad barrage to the Okhla barrage converted into drain due to receiving industrial and domestic effluents. The present work was conducted to evaluate water quality of Yamuna river at various location of in Delhi segment. The water samples were collected from five main points of Yamuna river. The main objective of present investigation was to assess the Yamuna water quality and also evaluate the treatment of water qualities by electrochemical technique.

Experimental Procedure

The water samples were collected from midstream from 20 cm depth using sterile capped plastic containers. Two sets of samples were collected during the pre-monsoon (April 20, 2015). The brief description of water sampling (WS) point is as follows:

1. WS-1: Water sample was collected from Najafgarh drain falling into Yamuna river.
2. WS-2: Water sample collected from Sen Nursing Home drain out falling into Yamuna river.
3. WS-3: Water sample was collected from main stream of Yamuna near to Nizamuddin Bridge 14 km downstream from Wazirabad barrages at Delhi
4. WS-4: Water sample collected from Okhala barrage near to origin point of Agra canal.
5. WS-5:Water sample collected from just origin point of Agra canal.

All the chemicals and reagents used were of analytical grade and were procured from Glaxo, India. All glasswares and other containers were thoroughly cleaned and finally rinsed with double glass distilled water several times prior to use. Water samples were analyzed for various physicochemical parameters such as pH, total suspended solids (TSS), total dissolved solids (TDS), total hardness (TH), total alkalinity (TA), biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), electrical conductivity (EC), chloride, sulphate, nitrate, toxic metals, and microbial population (MP) levels by following the standard method. Detail analytical processes are described in Table-2

RESULTS AND DISCUSSION

According to Central pollution Control Board (CPCB), River Yamuna is the sub-basin of the holy Ganga river system, and out of the total catchment's area of 861404 sq km of the Ganga basin, the Yamuna River and its catchment together contribute to a total of 345848 sq. km area which 40.14% of total Ganga basin. Various studies had been carried out at Yamuna river from last 5 to 6 decades by various organizations. The rapid and random urbanization, industrialization and other developments on Yamuna bank and basin are main cause of Yamuna pollution. Generally, all developmental processes including irrigation are water dependable and the water requirements are fulfill from the Yamuna river. It is well known fact that human activities requires fresh water and generates waste water final dispose-off into river. The Delhi segment comprises the 22 km that the river traverses in Delhi from the Wazirabad barrage to the Okhla barrage. The analysis results of present investigation points are given in Table 1.

Physicochemical characteristics of Yamuna River

Natural river systems are more essential component for rural and urban development. The economy of country is directly influenced by clean natural river system. The uncontrolled cities development and industrial growth are main cause of pollution which directly influences surface water system particularly in urban areas. However, organic and inorganic chemical quality assessments of such surface water resources can be directly reflect the pollution level and anthropogenic load on Yamuna river water. The analysis results of investigation sites are given in Table 3. pH of the water samples were indicate basic in nature. Mean pH of Yamuna water varied from 7.5 to 11.8 at different sampling points. At WS-2 and WS-4, pH was approximately equal, not showing statistically significant difference. Higher pH at some sample collection point could be due to bicarbonates and carbonate of calcium and magnesium in wastewater. The main source of such pollutants should be urban runoff and/or industrial effluent. The electrical conductivity of sample water was slightly different among all sampling points which varying from 7.24 to 9.86mS. High conductivity at WS-1, WS-3 and WS-5 sampling points due to the mixing of highly flow of drains in main stream of Yamuna river. Electrical conductivity decreased in downstream of Yamuna water due to the dilution by industrial effluents and urban runoffs. Electrical conductivity decreased with increasing current density and electrolysis period. Experimental results indicated that maximum conductivity decreased in each studied case by electrochemical technique as represented in Table 3. TDS parameter represents the salinity nature of water of Yamuna river. TDS of all water samples was represented in Table 3. The maximum TDS range was observed in all studied samples, indicating the mixing of large amount of fine chemical pollutants are completely dissolve in water samples.

Fig. 1. Yamuna River Pollution by Direct Injection of Various Drains in Delhi

Table 1. Independent Segments ofYamunaRiver

S. No	Segments	Length	Distance (kms)
1	Himalayan Segment	Origin to Tajewala Barrage	172
2	Upper Segment	Tajewala Barrage to Wazirabad Barrage	224
2	Delhi Segment	Wazirabad Barrage to Okhla Barrage	22
4	Eutriphicated Segment	Okhla Barrage to Chambal Confluence	490
5	Diluted Segment	Chambal Confluence to Ganga Confluence	468

Table 2. Analytical methods used for measurement of various parameters of pollutedYamuna river water

S. No	Parameters	Abbreviation	Units	Analytical methods	Instruments
1	pH	pH	-	Instrumental	pH meter
2	Electrical Conductivity	EC	mS	Instrumental	Conductivity meter
3	Biological Oxygen Demand	BOD	mgl^{-1}	5-days incubation, 20^0C	BOD incubator and titration assembly
4	Chemical Oxygen Dmand	COD	mgl^{-1}	Potassium dichromate oxidation	Refluxing assemble
5	Dissolved Oxygen	DO	mgl^{-1}	Titrimetric	Titration assembly
6	Total Dissolved Solids	TDS	mgl^{-1}	Filtration and gravimetric	Temperature controlled oven
7	Total Suspended Solids	TSS	mgl^{-1}	Filtration	Filtration assembly
8	Total Hardness	TH	mgl^{-1}	Titrimetric	Titration assembly
9	Total Alkalinity	TA	mgl^{-1}	Titrimetric	Titration assembly
10	Microbial population	MP	No/100 ml	Plate count method	Microbial culture assembly
11	Metal concentration		mg^{-1}	Analytical technique	Atomic absorption spectroscopy.

Table 3. Physicochemical characteristics of the Yamuna river in Delhi segment

Parameters	WS-1	SW-2	WS-3	WS-4	WS-5
pH	8.5	10.6	8.9	10.2	8.9
EC	8.18	8.92	9.86	7.43	7.24
TSS	2350	2660	2378	2360	2342
TDS	2870	2989	2930	2890	2882
TH	548	578	554	556	548
TA	678	723	718	704	697
BOD	38	42	41	40	39
COD	468	518	496	408	407
DO	0.0	00	0.0	0.0	0.0
MP	$9.4x10^7$	$10x10^7$	$9.8x10^7$	$9.2x10^7$	$9.1x10^7$
SO_4^{2-}	223	320	286	276	263
$NO3^-$	289	298	290	280	276
Cl^-	1438	1504	1470	1400	1398

Table 4. Physicochemical characteristics of the Yamuna River in Delhi segment

Parameters	WS-1	SW-2	WS-3	WS-4	WS-5
pH	6.8	6.7	6.8	6.8	6.8
EC	1.2 (85.3)	1.6 (81.7)	0.92 (88.2)	0.64 (91.3)	0.73 (89.9)
TSS	543 (76.8)	487 (81.6)	456 (80.8)	463 (80.3)	563 (75.9)
TDS	387 (86.5)	378 (87.2)	341 (88.3)	307 (89.3)	289 (89.9)
TH	68 (86.1)	58 (89.9)	52 (90.6)	54 (90.2)	62 (88.6)
TA	65 (90.4)	57 (92.1)	68 (90.5)	53 (92.4)	57 (91.8)
BOD	8 (78.9)	9 (78.5)	8 (40.4)	7 (82.5)	7 (82.0)
COD	73 (84.4)	68 (86.8)	62 (87.5)	48 (88.2)	57 (85.9)
DO	6 (450)	5.6 (456)	5.8 (982)	5.8 (925)	5.7 (900)
MP	$2.2x10^3$(76.5)	2.8 $x10^3$(72.0)	1.7 $x10^3$(82.6)	$1.9x10^3$(79.3)	$2.0x10^3$(78.0)
SO_4^{2-}	64 (71.3)	78 (75.6)	57 (80.0)	70 (74.6)	62 (76.4)
$NO3^-$	38 (86.8)	47 (84.2)	51 (82.4)	49 (82.5)	42 (84.7)
Cl^-	212 (85.2)	207 (86.2)	196 (86.6)	230 (83.5)	210 (85.1)

Table 5. Heavy metal concentration of the Yamuna River in Delhi segment

Metals	WS-1	SW-2	WS-3	WS-4	WS-5
Chromium	96.6	106.2	105.9	99.8	98.6
Cadmium	29.3	32.3	32.5	34.2	32.9
Cobalt	68.7	76.5	72.7	64.4	61.5
Nickel	97.2	88.7	78.3	63.3	62.3
Manganese	963.4	1063.3	1007.7	998.7	984.2
Lead	176.4	213.3	206.4	197.8	181.6
Zink	2728.8	3360.2	3270.6	3230.2	3220.6
Copper	238.3	276.4	270.2	263.5	259.3

Table 6. Removal of heavy metals fromYamuna river water by electrochemical treatment process

Metals	WS-1	SW-2	WS-3	WS-4	WS-5
Chromium	5.2 (94.6)	6.3 (94.0)	4.3 (95.9)	5.2 (94.7)	4.8 (95.1)
Cadmium	2.1 (92.8)	2.4 (92.5)	2.8 (91.3)	3.7 (89.1)	3.6 (89.0)
Cobalt	4.2 (93.8)	4.7 (93.8)	5.2 (92.8)	5.3 (91.7)	6.4 (89.5)
Nickel	4.3 (95.5)	3.9 (95.6)	4.6 (94.1)	5.2 (91.7)	5.8 (90.6)
Manganese	3.4 (99.6)	6.2 (99.4)	7.4 (99.2)	8.2 (99.1)	9.3 (99.0)
Lead	23.1 (86.9)	23.6 (88.9)	19.8 (90.4)	20.9 (89.4)	28.7 (84.1)
Zinc	27.9 (98.9)	22.9 (99.3)	26.9 (99.1)	29.9 (99.0)	30.7 (99.0)
Copper	34.7 (85.4)	28.7 (89.6)	30.2 (88.8)	22.7 (91.3)	26.2 (89.8)

It was also assumed that mixing of sewage particles, detergents dentifrices materials, and dumped garbage microbial extract which directly affected by common activities at the both sites of drainage and riverbank in urban areas. Higher TDS level in rivers increases the chemical and biological oxygen demand which directly based the dissolved oxygen level in water. Generally 86 to 89 percent TDS was removed from test solution by electrochemical treatment process. The experimental values of TA were in the various ranges as reported in Table 3. The experimental results clearly indicated that the large amount of carbonates, bicarbonates and hydroxyl ions are present in all sample water. A reduction in TA was observed after treatment of each sample by electrochemical method (Table 4). TH is also very important parameters of water quality from its domestic and industrial use point of view. Hard water causes serious problem in many industries. Present observations clearly reported that the TH values of all samples are approximately same, it means pollution level of Yamuna water is same as per drainage water (Table 3). There was no variation in TH contents among all sampling points due to direct mixing of domestic and industrial effluents in the Yamuna river. Some investigators clearly support the hypothesis that urban runoff and industrial effluents has been contributing effectively to deteriorate Yamuna river water quality at Delhi segment. By electrochemical process 52 to 68 percent TH reduced (Table 4).

Limited chloride concentration in water isuse full, while higher concentration of chloride in freshwater act as a pollutants. Chloride concentration in all studied water samples was very high (Table 3), but 83 to 86 percent usually is reduced during treatment (Table 4). Sulphate and nitrate are important parameters of river water showing the pollution status and anthropogenic load in river water. Concentration of sulphate and nitrate in all samples are shown in Table 3. Higher sulphate and nitrate in all water samples are due to the mixing of municipal runoff in Yamuna river water. The high concentrations of chloride, nitrate and sulphate in all water samples also indicated that urban runoff is direct responsible to damaging Yamuna water quality. Biochemical oxygen demand is a measure of the quantity of oxygen used by microorganisms in the oxidation of organic matter in aqueous system. BOD values represent organic pollution in the aqueous environments. BOD values of all studied samples are show in Table 3. It is clear from experimental results the BOD of all samples are higher than permissible range. The BOD value of WS-1, WS-2, WS-3, WS-4 and WS-5 are approximately equal which evident that the no difference between water quality of Yamuna river and drain effluents because several drains are directly discharge huge amount of untreated domestic and industrial effluents. Similar BOD level from Wazirabad barrages to Okhala barrage further indicates the self-purification capacity of Yamuna river had lost. When BOD levels are high, dissolved oxygen (DO) levels decrease because the oxygen that is available in the water is being consumed by the bacteria. Since less dissolved oxygen is available in the water. An experimental observation clearly indicates the value DO is zero (Table 3). The category of water of Delhi segment is “dead Water quality”, which not fit for irrigation or any other purposes like domestic, industrial construction point of view.

COD is also an important parameter of water indicating the health scenario of freshwater bodies. COD varied from 468.0 to 407.0 mg ^{1} at different sampling points. A trend of decreasing COD level was at downstream sites. There was a negative relationship between COD and DO. DO may be a potential indicator of river quality in assessing urban impacts on river ecosystem. The water quality in terms of DO is always of important factor because at the waste discharge points in river, the DO is required for aerobic oxidation of the organic matters. DO levels are also most important in the self-purification of the river.

Toxic metals

The toxic metals discharged by drains into the Yamuna River are shown in Table 5. It is evident from the results that large amount of toxic metal are released from various drains, which is highly dangerous to the public health. It is further conclude from the Table 3 that the maximum load of metal ions was transported from Najafgarh, Barapullah and Shahdara drains. The metal ions show different trends which depend upon the discharge of different qualities of effluent of drains. This may be concluded that effluent discharge from various industrial sources through urban runoff. The metal ions concentration in Yamuna water was found too much higher than the permissible limits. Therefore, the use of the Yamuna river water for agricultural, domestic and industrial supply is not good without the proper treatment of water. In is also found that the very bad impact of Yamuna river water on ground water quality. The vicinity areas of Yamuna river are recharging through seepage from main stream of Yamuna river. The most of the metals were found in the underground water because surface water qualities play a significant role in the groundwater (Sharma, and Pande, 1998; C. K. and Sharma, 2006).

Removal of toxic metals

In the present investigation, electro-coagulation process has been evaluated as a treatment technique for toxic metals removal from sample waters. The electrochemical process is affected by many operating parameters, such as pH of test solution, concentrations of toxic metals, current density, physicochemical parameters and treatment period. In the present studies all these parameters have been explored in order to evaluate to removal of Chromium, cadmium, cobalt, nickel, manganese, lead, zinc and copper from test samples. Experimental results (Table 6) reported that maximum removals of all toxic metals from each test solution were obtained at 6.8 pH. In addition, pH changes during the treatment process dependent on the redox reactions which influence the pH of test solution. The removal efficiency of all studied metals after 150 minutes of electrolysis period at the constant current density of 25 mA/cm^2 reached maximum values as represented in table 6 at pH 6.8. The removal percent for all studied metals is very low at pH 4. The removal efficiency increased with increasing the pH up to 6.8. The decrease in removal efficiency of heavy metals from aqueous medium was also described by other investigators at strong acidic and alkaline pH.

The physicochemical parameters such as pH, total suspended solids (TSS), total dissolved solids (TDS), total hardness (TH), total alkalinity (TA), biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), electrical conductivity (EC) chloride, sulphate, nitrate, toxic metals and microbial population (MP) are play key role for monitoring of water quality of rivers. In order to study the possible impact of Yamuna river water on ground water quality the concentrations of most of the metals analyzed were found out of the permissible limits. The presence of various metals in the groundwater indicates the possibility of groundwater contamination due to seepage from the Yamuna River. It is observed that the surface water bodies play a significant role in the groundwater flow system. The hydraulic gradient imparts significant role in lateral and vertical migration of contaminants in groundwater aquifers. However, further detailed studies are needed to confirm this observation.

Conclusion

On the basis of results, it is also concluded that the pH, total suspended solids (TSS), total dissolved solids (TDS), Total Hardness (TH), total alkalinity (TA), biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), electrical conductivity (EC) chloride, sulphate, nitrate, toxic metals and microbial population (MP) are very high in comparison to the permissible limit thus making Yamuna water unfit for any purpose. Experimental results reported that drastic variations were found in each water samples after treatment by electrochemical process. Indicating water pollution levels was manifold higher than the prescribe limit by the pollution control authorities for irrigation.

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