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* **Corresponding author**.

parveenenv@gmail.com

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Pollution Load Reduction from Domestic Wastewater with Electrocoagulation Process for Agricultural Reuse

Sushila[1], Parveen Kumar[2]*

1 Research Scholar, Department of Basic and Applied Sciences, School of Engineering and Sciences, G D Goenka University, Sohna - Gurugram Road, Sohna, 122103, Haryana, India
2 Assistant Professor, Amity School of Earth and Environmental Sciences, Amity University Haryana, Amity Education Valley, Gurugram (Manesar), 122413, Haryana, India

Abstract

Objectives: The present study is aimed to investigate electrocoagulation of domestic wastewater and assessment of pollutants removal efficiency for potential reuse in agriculture. **Methods:** The electrocoagulation treatment of domestic wastewater with Fe – Fe electrodes was performed under optimal conditions of pH (8.0), current density (0.6 mA/cm^2), treatment time (45 minutes), and NaCl dose (2.8 g/L) in a slurry type of reactor. The primary clarified and biotreated domestic wastewaters were subjected to electrocoagulation with Direct Current (DC) as power source. **Findings:** There was observed higher pollutants removal efficiency from the biotreated wastewater as compared with the primary clarified wastewater after electrocoagulation. The treated wastewaters showed significant removal of pollutants in terms of BOD (79.5% – 87.9%), COD (86.8% – 89.5%), TDS (87.4% – 89.9%), TSS (66.7% – 75.3%), conductivity (77.8% – 78.4%), turbidity (74% – 81.2%), colour (77.7% – 86.2%), nitrates (44.1% – 51.7%), and phosphates (48.7% – 55.9%) after electrocoagulation treatment. Electrocoagulation considerably improved the biodegradability index of the primary clarified (0.59 to 0.92) and biotreated (0.69 to 0.8) wastewaters. This indicates easy removal of the pollutants further by biological processes in the aquatic ecosystems. Electrocoagulation demonstrated potential for removal of pollution from the domestic wastewater for productive reuse in agriculture and urban areas. **Novelty:** There exist few studies of use of electrochemical process for treatment and reuse of domestic wastewater. The treated waters complied with the regulatory standards and had satisfactory quality for reuse in agriculture and urban activities.

Keywords: Electrocoagulation; Domestic wastewater; Biodegradability index; Agricultural reuse; National Green Tribunal

1 Introduction

The fresh water is a key resource for steadfast economic growth, successful food production in agriculture, and sustenance of life. The agricultural sector is the largest consumer of fresh water (70%) followed by industrial (25%) and domestic (5%) sectors. Particularly, the people in the developing world suffer with water scarcity and poor hygiene because of uneven distribution and pollution of water resources. The discharge of untreated or partially treated wastewater is a prime factor for pollution of surface and ground water resources[1]. There is generated 72368 MLD of sewage at urban centers in India which is projected to increase further by 75% – 80% in the next 25 years. Merely, 13.5% sewage is treated efficiently out of 18.6% of the total treatment capacity in India[2]. There is reported slight improvement of water quality in Indian rivers as polluted stretches decreased from 351 in 2018 to 311 in 2022[3]. However, there is need to further develop wastewater management infrastructure and efficient processes for treatment of wastewater. This would help to safeguard public health and the environment along with generation of alternative source of water for reuse in industries, horticulture, and agriculture etc.

The domestic wastewater is used water generated from household activities like bathing, washing of clothes, water closets, cleaning of hands, and kitchen. It severely affects the water quality owing to decomposition of organic wastes[4]. It is characterized with wide variety of organic pollutants and pathogens. The plant nutrients are reported to alter species composition in the aquatic ecosystems. The pathogens pose risk of communicable disease spread. Hence, domestic wastewater treatment is essential to safeguard aquatic life and public health. The conventional processes are in-efficient for the removal of emerging contaminants from the domestic wastewater and have high cost owing to maintenance, sludge generation and disposal, and more treatment time. Whereas the electrocoagulation process is reported to be fast and energy efficient, economical with less sludge generation, and effective for removal of pathogens and toxic pollutants from the wastewater[5]. The application of electric current results in dissolution of the metallic cations (M^{n+}) by oxidation of sacrificial anode which leads to in-situ generation of coagulant species [M(OH)n]. The coagulant destabilizes pollutants in the wastewater to produce large flocs which precipitate to remove the pollutants[6]. The electrocoagulation process is reported to effectively remove pollutants from the wastewater originating from diverse sources[7,8].

There is need of efficient wastewater treatment processes to meet ever stringent norms for disposal and recycling of treated water. Limited studies are available on application of electrocoagulation and biological hybrid process for pollutants [Fe(OH)3] removal from the domestic wastewater and recycling potential in the agriculture[9]. The present study investigated efficiency of electrocoagulation process for pollutants removal from the primary clarified and biotreated domestic wastewaters with Fe – Fe electrodes under optimal conditions of pH (8.0), current density (0.6 mA/cm^2), reaction time (45 minutes), and NaCl dose (2.8 g/L). The treated water quality is compared with the regulatory standards for treated sewage discharge and reuse of treated water for landscaping, horticulture, and agriculture.

2 Methodology

2.1 Materials

The wastewater samples were obtained from a nearby Sewage Treatment Plant after the primary clarifier and secondary treatment. The wastewater samples were collected using grab sampling and stored below 4°C in the laboratory prior to further investigations and electrocoagulation studies. The iron electrodes were procured from a nearby workshop and utilized as anode and cathode. A digital multi-meter was used to read the current and voltage values of the circuit. Further, different materials utilized for the study were glass reactor, magnetic beads, electrical clips, and copper wires. The NaCl (Fisher Scientific, SQ grade) was used as electrolyte to ensure proper conductivity in the reaction mixture.

2.2 Electrocoagulation assembly

The electrocoagulation assembly comprised of a glass vessel fitted with iron electrodes as anode and cathode arranged parallel to each other with mono-polar configuration (Table 1). The parallel arrangement helps to minimize the energy consumption by lowering the potential difference between the electrodes[10]. The treatment assembly is shown in Figure 1. The primary clarified and biotreated domestic wastewaters were adjusted to the desired pH using 1 molar solution of H_2SO_4 and NaOH and subjected to electrocoagulation in batch mode. The magnetic stirrer was used to agitate reaction mixture (100 rpm) during electrocoagulation studies.

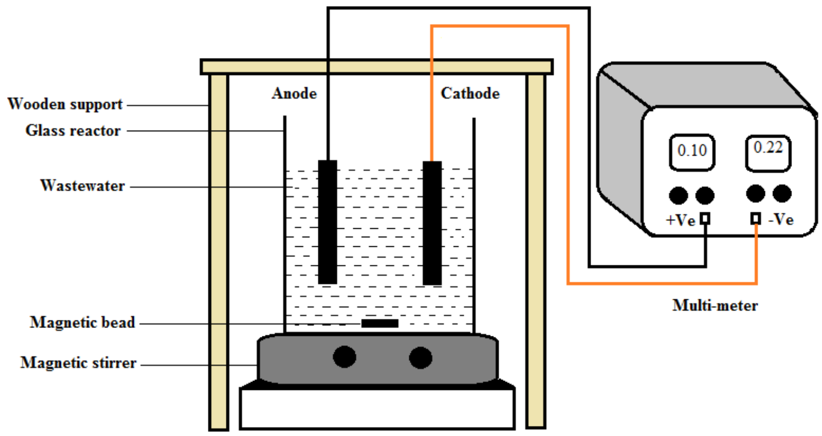

Fig 1. The electrocoagulation assembly for treatment of domestic wastewater

Table 1. The details of the electrocoagulation assembly

Electrocoagulation vessel		**Electrodes configuration**	
Mode	Batch	Anode	Iron
Material	Glass	Cathode	Iron
Capacity (mL)	1000	Dimensions	12cm × 6cm × 1.5mm
Wastewater used (mL)	700	Number	2
Electrodes spacing (mm)	10	Arrangement	Parallel
Power source	Direct current		
Voltage range (V)	10 to 16	Connection	Monopolar
Current density (mA/cm^2)	0.2 - 0.8		

2.3 Treatment studies

The primary clarified and biotreated domestic wastewaters were subjected to electrocoagulation under the optimal conditions of pH (8.0), treatment time (45 minutes), current density (0.6 mA/cm^2), and NaCl dose (2.8 g/L)[11]. The pollutants removal efficiency was evaluated in terms of the percentage removal of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total dissolved solids (TDS), conductivity, turbidity, colour, nitrates, and phosphates from the wastewater (Equation (1)).

$$Pollutants\ removal\ efficiency\ (\%) = \left[\frac{I_0 - F}{I_0}\right] \times 100 \tag{1}$$

Where,

I_0 = Initial pollutant concentration

F = Final pollutant concentration after treatment

The experiments were performed in triplicate under ambient environment and average results were recorded.

2.4 Analytical techniques

The wastewater samples were characterized before and after electrocoagulation in terms of BOD, COD, colour, TSS, TDS, conductivity, turbidity, pH, nitrates, and phosphates following the Standard Methods. BOD_5 was estimated by assessment of dissolved oxygen content before and after incubation at 20°C. COD was measured following closed reflux titrimetric method. The wastewater colour was estimated by measuring absorbance (465 nm) with a UV-VIS spectrophotometer (SPEKOL 2000, Analytic Jena). TSS and TDS were measured following gravimetric method. The conductivity and turbidity were estimated using laboratory scale digital Conductivity and Turbidity Meters. The wastewater pH was measured using a bench scale pH meter (TOSHNIWAL). All the analyses were carried out in triplicate and average results were recorded.

2.5 Statistical analysis

The statistical data analysis was carried out with SPSS software (version 23). The variance analysis (one way ANOVA) was carried out followed by post hoc Tukey's all pair wise multiple comparison test ($p < 0.05$) to compare the means of different parameters.

3 Result and Discussion

3.1 Wastewater characteristics

The average characteristics of the primary clarified and biotreated domestic wastewaters utilized for the present study are summarized in Table 2. The primary clarified wastewater presented high organic load in terms of BOD, COD, TDS, TSS, colour, turbidity, nitrates, and phosphates as compared to the biotreated wastewater. The optimum treatment conditions for electrocoagulation were explored using primary clarified domestic wastewater. The primary clarified and biotreated domestic wastewaters were subjected to the electrocoagulation under optimal conditions of pH (8.0), treatment time (45 minutes), current density (0.6 mA/cm^2), and NaCl dose (2.8 g/L)[11].

Table 2. General characteristics of the primary clarified and biotreated domestic wastewaters

Parameter	Primary Clarified Wastewater	Biotreated Wastewater
pH	7.1±0.02	7.2±0.01
BOD (mg/L)	200.4±4.1	90.6±3.8
COD (mg/L)	340.2±3.3	130.4±2.8
BOD/COD ratio	0.59	0.69
TSS (mg/L)	147.6±4.7	110.4±4.2
TDS (mg/L)	930.2±8.4	225.5±7.7
Conductivity (mS/m)	970±0.5	990.3±0.7
Turbidity (NTU)	135.1±3.5	60.2±3.1
Colour (Pt-Co. units)	200.6±4.2	80.2±3.5
Nitrate (mg/L)	0.84±0.01	0.58±0.01
Phosphate (mg/L)	0.74±0.1	0.34±0.02

3.2 BOD and COD removal

BOD and COD represent amount of organic matter in the wastewater. The excess of organic matter in wastewater depletes dissolved oxygen which is crucial for survival of organisms in the aquatic ecosystems. There was achieved 86.8% and 89.5% removal of COD for the primary clarified and biotreated wastewaters, respectively, after 45 minutes of treatment (Figure 2). A higher COD removal efficiency was obtained for biotreated wastewater as compared to the primary clarified wastewater. The biotreated wastewater was already characterized with a low COD load (90.6 mg/L) as compared with the primary clarified wastewater. Bote et al. (2021) also reported comparable COD removal (67% - 83%) efficiency from the domestic wastewater following 45 – 60 minutes of electrocoagulation with Fe-Fe electrodes[12].

The electrocoagulation resulted in 79.5% and 87.9% removal of BOD from the primary clarified and biotreated wastewaters, respectively (Figure 2). There was observed significant removal of BOD for both the wastewaters. This might be a result of degradation of the biodegradable organic pollutants. Koyuncu and Ariman (2020) also reported 69% – 81% removal of BOD from the domestic wastewater with real scale electrocoagulation[5]. There was also observed significant improvement in the biodegradability index (BOD/COD ratio) of the primary clarified (0.92) and biotreated (0.80) wastewaters after electrocoagulation. This indicates easy removal of the residual pollutants by biological processes in the aquatic ecosystems. COD and BOD are removed by adsorption of organic pollutants on in-situ generated coagulants, i.e. $[Fe(OH)_3]m$ or $[Fe(OH)_2]$.

3.3 TSS and TDS removal

TSS is a measure of suspended particles in the wastewater which in excess cause scattering of light to affect the rate of photosynthesis. This leads to depletion of oxygen in the aquatic ecosystems. The suspended particles absorb more heat to raise

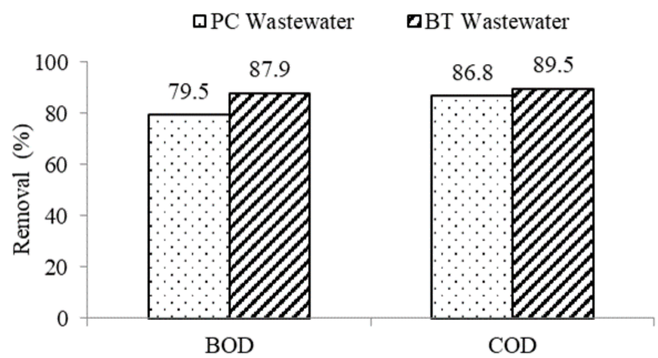

Fig 2. BOD and COD removal (%) from primary clarified (PC) and biotreated (BT) domestic wastewater after electrocoagulation treatment

water temperature which also reduces oxygen saturation to negatively harm the aquatic life. The sediments also cause fish death by clogging of gills, suffocation of fish eggs, and benthic organisms. The suspended matter is proportional to the microbial load in the water which interferes with treatment processes to negatively influence the water quality[13]. TDS is represented by dissolved organic and inorganic substances (minerals and ions etc.) in the wastewater which pass through filtration. The excess of salts produce salinity and sealing of soil in irrigated land. This influence microbial diversity and physicochemical properties of the soil and make it unfit for the plant growth[9]. TSS and TDS removal efficiency of the electrocoagulation process for primary clarified and biotreated wastewaters is presented in the Figure 3. There was achieved higher TSS removal for biotreated wastewater (75.3%) as compared with the primary clarified wastewater (66.7%). This may be because of already lower load of TSS in the biotreated wastewater following secondary treatment. Similarly, there was observed higher removal of TDS in case of the biotreated wastewater (89.9%) as compared with the primary clarified wastewater (87.4%). TDS in the wastewater is removed by the physical adsorption of dissolved species on to the surface of in-situ generated coagulants. On the other hand, TSS is trapped by a blanket of sludge produced simultaneously by coagulating particles. The liberated H_2 gas during electrolysis lifts the resultant sludge to the surface of water.

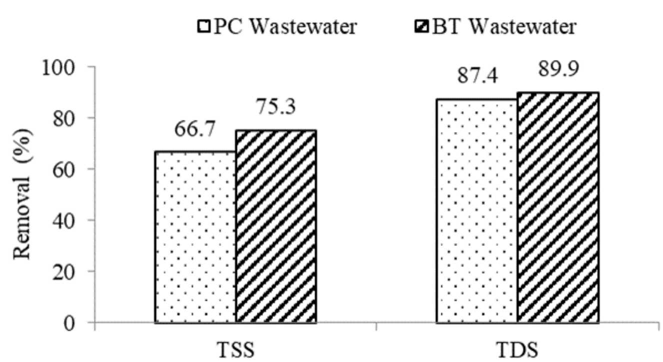

Fig 3. TSS and TDS removal (%) from primary clarified (PC) and biotreated (BT) domestic wastewater after electrocoagulation treatment

3.4 Conductivity and turbidity removal

The ability of a solution to conduct electric current is known as conductivity. It is an important indicator of water quality. The considerable variations in the conductivity of water can be detrimental to the aquatic organisms. The particles in wastewater are responsible for turbidity. The high turbidity can clog wastewater infrastructure and negatively influence the disinfection process[13]. There was observed significant removal of conductivity and turbidity from primary clarified and biotreated domestic wastewaters after electrocoagulation (Figure 4). The conductivity was removed by 77.8% and 78.4% from the primary clarified and biotreated wastewaters, respectively. Whereas, turbidity removal followed the order of 74% and 81.2% in case of primary clarified and biotreated wastewaters, respectively. This is correlated with the proportionate removal of TDS and TSS from the primary clarified and biotreated wastewaters following the electrocoagulation. Bote and Desta (2022) achieved 91.23% and 96% of turbidity removal from the domestic wastewater after electrocoagulation with Al–Fe and Fe–Al electrodes, respectively, at a pH of 9, current of 0.09 A, and reaction time of 45 minutes (14). There were achieved comparable results in the present study also.

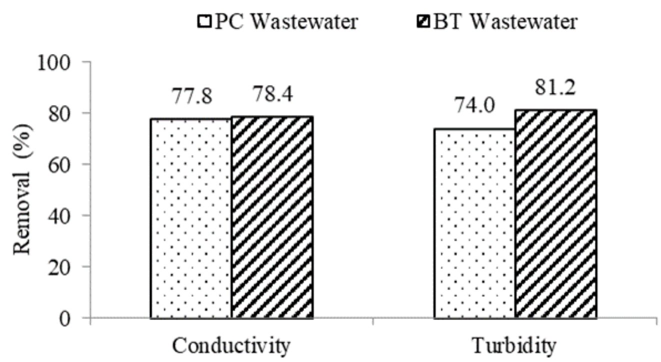

Fig 4. Conductivity and Turbidity removal (%) from primary clarified (PC) and biotreated (BT) domestic wastewater after electrocoagulation treatment

3.5 Colour removal

The dissolved and suspended solids impart colour to the wastewater. Colour indicates the state of the wastewater. The colour removal efficiency of the electrocoagulation process for primary clarified and biotreated wastewaters is depicted in Figure 5. The colour of the biotreated wastewater was already very low as compared to the primary clarified wastewater. There is observed higher colour removal from the biotreated wastewater (86.2%) as compared with the primary clarified wastewater (77.7%). Ebba et al. (2021) reported 94.40% removal of colour from hospital wastewater with Fe–Fe electrode combination at a pH of 7, current of 0.09 A, and 3 g/L of electrolyte (6). The results obtained in the present study are comparable with the above work performed under analogous operating conditions.

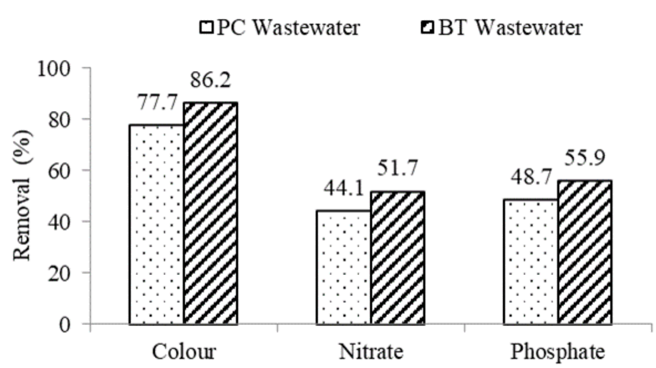

Fig 5. Colour, Nitrate, and Phosphate removal (%) from primary clarified (PC) and biotreated (BT) domestic wastewater after electrocoagulation treatment

3.6 Nutrients removal

The wastewater is generally characterized with high concentration of nutrients (nitrates and phosphates) which may be utilized for supporting plant growth in agriculture. However, the excess of nutrients may produce negative effect on the aquatic ecosystems by producing eutrophication (9). The wastewater usually contains organic and ammonium nitrogen along with negligible amount of nitrate and nitrite nitrogen. The nitrate and phosphate were removed to the moderate efficiency from the primary clarified and biotreated wastewaters following electrocoagulation (Figure 5). There was achieved 44.1% and 51.7% removal of nitrate from the primary clarified and biotreated wastewaters, respectively. The ammonium nitrogen is removed by anodic oxidation[15] whereas organic nitrogen compounds are removed by the sweep flocculation after adsorption on the surface of generated coagulants[16]. The raw wastewater contains inorganic phosphate ions and organic phosphorus compounds. Phosphate was removed by 55.9% for the biotreated wastewater which is significantly higher as compared with the primary clarified wastewater (48.7%). Phosphate compounds are removed from the wastewater by co-precipitation with electrode generated metal ions and adsorption on the metal hydroxides[17].

Sharma et al. (2021) reported 91.8%, 94.3%, and 96.5% removal of COD, BOD, and turbidity, respectively, from the domestic wastewater after 30 minutes of treatment using Al – Fe mono-polar electrode combination at a current density of 1.25 mA/cm^2 [18]. The present study involved electrocoagulation of domestic wastewater at a lower current density (0.6 mA/cm^2) and obtained comparable results, i.e., 86.8% and 89.5% of COD, 79.5% and 87.9% of BOD, 74%, and 81.2% of turbidity removal from primary clarified and biotreated wastewaters, respectively, following 45 minutes of electrocoagulation.

3.7 Agricultural reuse potential of treated water

The fresh water is a valuable and vital resource for existence of life. There exists huge variability in temporal and spatial distribution of water which is being threatened further by the current trends of climate change. Hence, the reuse of treated water for specific productive applications, like flushing waste, car washing, fire fighting, fountains, cooling tower in industry, fish culture, horticulture, forestry, and irrigation in agriculture etc., is the need of the hour. It can potentially reduce the consumption of the freshwater[1].

The reuse of the treated water is an important aspect of government vision for water resources management during 'Amrit Kaal'. Only 3% of the treated water and 1% of generated wastewater is being reused for productive purposes as per Central Pollution Control Board (CPCB). Hence, there exists huge scope for reuse of treated water as a valuable resource[1]. The agricultural sector is the largest user of fresh water consuming around 90% and 70% of the total water withdrawals at national and global scale, respectively. The domestic wastewater is characterized with presence of essential plant nutrients, i.e., nitrates and phosphates, which are potential resource for energy recovery. Hence, the domestic wastewater is a lucrative resource to restore the soil fertility in the degraded land and water conservation for ensuring food security. Hence, the treated water can effectively supplement the freshwater for irrigational use in the agriculture. The safe reuse of the treated water prevents soil degradation, contamination of water resources, and decreases public health hazards[19].

The pollution has severely affected water quality in 323 out of 351 rivers flowing in the country. The relaxed wastewater discharge standards will degrade the quality of water resources and the environment. Hence, National Green Tribunal (NGT) made stricter standards for discharge of wastewater from the sewage treatment plants (STPs) in 2019. The Ministry of Environment, Forest and Climate Change (MoEFCC) is directed to ensure implementation of revised standards to entire country[20]. The treated water quality was compared with the regulatory standards for treated water discharge as per NGT order (2019) and irrigational reuse of treated water for landscaping, horticulture, and agriculture, i.e., Central Public Health and Environmental Engineering Organization (CPHEEO) and Food and Agricultural Organization (FAO) standards (Table 3).

Table 3. Electrocoagulated wastewater quality comparison with regulatory standards for wastewater discharge and reuse in landscaping, horticulture, and agriculture[21,22].

Parametres	Electrocoagulated wastewaters		Sewage treatment plants (NGT 2019)**		Landscaping, horticulture and agriculture (CPHEEO, 2023)				FAO
							Crops		
							Edible crops		
	Primary clarified wastewater	Biotreated wastewater	Mega and Metropolitan Cities	Class I Cities	Horticulture, golf courses	Non-edible crops	Raw	Cooked	
pH	8	8.2	5.5–9		6.5 – 8.5				NA
BOD	41.13	11	10	20	≤6-10 (≤6 preferred)				NA
COD	44.8	13.7	50	100	AA	AA	AA	AA	NA
TSS	49.2	27.3	20	30	AA	AA	AA	AA	NA
TDS	117.6	22.7	NA	NA	2100				None: <450 Slight to moderate: 450-2000 Severe: >2000

Continued on next page

Table 3 continued

Conductivity	215.2	213.8	NA	NA	NA	NA	NA	NA	None: <700 Slight to moderate: 700-3000 Severe: >3000
Turbidity	35.2	11.3	NA	NA	AA	AA	AA	AA	NA
Colour (Pt Co Units)	44.71	11.1	NA	NA	Colourless	AA	Colourless	Colourless	NA
Nitrate	0.47	0.28	NA	NA	NA	NA	NA	NA	5 (without restriction) 30 (with slight to moderate restrictions)
Phosphorus	0.38	0.15	1	1	AA	AA	AA	AA	NA

All values are in mg/L except for pH, turbidity (NTU), and conductivity (mS/m); **Standards applicable for discharge into water bodies and land disposal/application, while reuse is encouraged; AA - as arising when other parameters are satisfied.

A suitable range of pH is required for the successful plant production and maintenance of soil quality. The pH influences availability of nutrients for absorption by plants [23]. The pH of the primary clarified (8) and biotreated (8.2) wastewaters after electrolysis lied within the permissible limits. The excess organic matter can produce troubles for the irrigation infrastructure. CPHEEO recommended 11 - 28 kg/ha/day of organic loading (BOD_5) in the soil to ensure suitable amount of organic matter for microbial growth and prevention of clogging. The residual BOD in primary clarified wastewater after electrocoagulation exceeded regulatory standards. The residual BOD for biotreated wastewater after electrocoagulation was successfully reduced below NGT regulatory standard for discharge of treated sewage, i.e., 10 and 20 mg/L for Mega-Metropolitan and Class – I cities, respectively. Electrocoagulation successfully reduced COD for primary clarified and biotreated wastewaters below the NGT (2019) regulatory standard of 50 and 100 mg/L for Mega-Metropolitan and Class – I cities, respectively.

The excess of particulate matter in wastewater clog soil and irrigation infrastructure owing to sludge deposition. This can lead to interference with aeration and development of anaerobic conditions in soil. The residual TSS for primary clarified (49.2 mg/L) and biotreated (27.3 mg/L) wastewaters slightly exceeded the set regulatory standard (20 mg/L). Similarly, there is observed proportionate reduction in the turbidity of the wastewaters after electrocoagulation. The excess of dissolved solids in water can produce ion toxicity and interfere with nutrients uptake to influence the plant growth [24]. There were achieved 117.6 and 22.7 mg/L of TDS for primary clarified and biotreated wastewaters after electrocoagulation. It was well below the regulatory standards of CPHEEO (2100 mg/L) and FAO (<450 mg/L). The residual conductivity values were also within standard limits of FAO (<700 mS/m). The domestic wastewaters were characterized with low level of nitrates and phosphates. They are beneficial for plant growth, but excess quantity can pollute the ground water. The excess quantity of nutrients can also clog the irrigation channels because of luxuriant growth of algae and weeds. The nitrate content for primary clarified and biotreated wastewaters was reduced to 0.47 and 0.28 mg/L, respectively, after electrocoagulation which was under the permissible limit of 5 mg/L (FAO). Whereas the phosphorus content was reduced to 0.38 and 0.15 mg/L for primary clarified and biotreated wastewater, respectively, after electrocoagulation which was also well below NGT (2019) regulatory standard of 1 mg/L. The colour of the wastewaters was also reduced to nearly colourless after electrocoagulation.

3.8 Sludge generation

Electrocoagulation generates a small amount of good quality sludge with better stability and dewatering potential as compared with the sludge generated with chemical coagulation [25]. There was generated 1.3 and 0.4 kg of sludge/m^3 of primary clarified and biotreated wastewater, respectively, following electrocoagulation treatment. There was found 19% and 14% of solid matter in the sludge produced during electrocoagulation of primary clarified and biotreated wastewaters, respectively.

4 Conclusion

The freshwater availability and safe disposal of wastewater influence human society and environment. The wastewater treatment and reclamation are potential solution to above challenges. The following conclusions are drawn based on the present study:

- Electrocoagulation removed pollutants with better efficiency for the biotreated wastewater as compared to the primary clarified wastewater.
- Biodegradability of wastewaters improved significantly following electrocoagulation. This indicates easy removal of the residual pollutants in nature.
- The residual parameters (except BOD and TSS) for electrocoagulated primary clarified wastewater complied with the treated sewage discharge standards of NGT (2019). The further treatment with adsorbants/ oxidation pond is needed before discharge in aquatic ecosystems and/ or productive reuse to fully comply with regulatory norms. Whereas the residual parameters for electrocoagulated biotreated wastewater complied fully with discharge standards (Class – I cities) with satisfactory quality for productive reuse in landscaping, horticulture, and agriculture.
- Electrocoagulation can be potentially adopted in combination with biological and/ or physicochemical processes to produce treated water of satisfactory quality. The potential benefits observed in laboratory studies should be confirmed with pilot scale investigations involving continuous operation. The future studies should explore development of stable electrodes with large surface area, process optimization, and efficient application of solar energy as a sustainable source of energy for economical operation.

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