An electrochemical analysis of acute contamination of environmental water and restoring of water quality using taro carbon

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Abstract

Electrochemical techniques were successfully employed to estimate contamination of water of river Buriganga, Bangladesh. A Pt–Cu electrode has been exploited to measure selective nitrate concentration, and corrosion rate of iron has been proposed to indicate relative abundance of dissolved contaminants. In order to evaluate the pollution level, water parameters of river Buriganga have been compared with those obtained from two freshwater streams named Surma and Dawki of the country. An iron strip in contact with Buriganga river water is corroded three times rapidly compared to its contact with Dawki or Surma river water indicates acute contamination of Buriganga river water. The River Buriganga is facing acute pollution from the point of high TDS (0.664–0.694 g/L), low DO (1.47–4.4 mg/L), high COD (197–218 mg/L), high ammonia (270–420 mg/L) and high nitrate concentration (107–157 mg/L). Negative ORP value (–292 to –310 mV) of Buriganga river water indicates that the stream contains high level reducing species. Meanwhile, positive ORP value indicates that Dawki (+203 to +209 mV) and Surma (+184 to +205 mV) river water contain oxidizing species. Sediment analysis shows the deposition of disintegrated organic pollutants on the bottom of the River Buriganga. Cost-effective carbon material synthesized from taro stems has been proposed to restore water parameters of filthy water system like Buriganga river.

Keywords Nitrate · Ammonia · TDS · DO · Sediment · Taro carbon

Introduction

Owing to various reasons water quality, especially surface water of our beloved planet is being polluted repeatedly. The reasons include natural processes (e.g., heavy rain, flood, precipitation, soil erosion, reduction of flow, etc.), anthropogenic activities (e.g., deforestation, urbanization, industrialization, inadvertent agricultural practices, etc.) and the immense applications of water resources (Dwivedi et al. 2018). The increasing pollution by various contaminants

has a significant adverse health effects for marine lives and humans (Wang and Yang 2016; Kubicz et al. 2018; Falkenberg et al. 2018). Due to increased pollution, fresh water has now become important commodity worldwide. According to latest report, approximately 2.1 billion people over the world do not have admittance to adequate sources of drinking water (WHO 2017). Note that the Buriganga is one of the important rivers in Bangladesh. The city of Dhaka is known as one of the most densely populated (density over 40,000/km²) cities over the globe (Kabir et al. 2018). Because of rapid and unplanned urbanization, the dwellers of this city are experiencing lack of planned waste disposal maintenance. Consequently, once mighty river Buriganga is now become filthy water stream in this country because of rampant dumping of human and industrial waste (Kamal et al. 1999). There are so many chemicals that may contaminate a water system. The total dissolved solids (TDS) vary typically in lakes and streams within the range of 50–250 mg/L. In the areas of hard water or high salinity or sea water intrusion, TDS values may be as high as 500 mg/L. According to United States Environmental Protection Agency,

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acceptable level of TDS in drinking should be 500 mg/L or less than 500 mg/L. While organic wastes are dumped, they are decomposed by bacterial activities. In marine waters, nitrogenous compounds are converted into ammonia by consuming dissolved oxygen (DO) and then ammonia is converted into nitrites and nitrates. According to world health organization (WHO), normal level of ammonia in ground waters exist below 0.2 mg/L, whereas surface waters may contain as high as 12 mg/L (WHO 2003). Meanwhile, tolerable threshold of nitrate ion concentration in groundwater is 50 mg/L (Wick et al. 2012). Electrochemical sensors are one of the green techniques and thereby playing a vital role to detect and quantify environmental hazards from water (Khan and Khan 2010; Khan et al. 2013, 2016; Rahman et al. 2015; Deng and Li 2018; Farzbod and Moon 2018). These sensors are extremely popular because of their remarkable experimental simplicity, sensitivity, and low cost. The chemical sensors have drawn the top attention among the currently available sensors satisfying the curtail requirements to be used in the commercial stage. Concurrently, these sensors have shown efficiency in a wide range of important applications such as in the fields of industrial, environmental, clinical, and agricultural analyses (Moya et al. 2017; Su et al. 2018). As a result, electrochemical sensors are accounted for approximately 58% of all chemical sensors. Several sensors and methods have been reported in the literature based on the application and selectivity. For example, a copper-based electrode can be applied for measuring nitrates from water (Alam et al. 2015). Electrochemical impedance spectra can be used for quantifying solution conductivity and charge carriers (Tanjila et al. 2016). Meanwhile, by measuring open circuit potential (OCP) and evaluating corrosion current of a metal, it may be possible to speculate the types of species present in an aquatic system (Sander et al. 1996; McCafferty 2005; Jegdić et al. 2008). Here, we have proposed iron corrosion rate as an indicator of water quality. However, in the past years, the river Buriganga supplied major fraction of water for the dwellers of Dhaka city for domestic, industrial, and irrigational purposes. Because of acute contamination, nowadays, water of this river is not useable. After Kamal et al., no significant studies have been documented pertaining to determination of contaminants in the Buriganga river (Kamal et al. 1999). In order to treat wastewater like Buriganga, several processes such as chemical, Fenton oxidation, chemical coagulation, electro-coagulation, biological degradation(aerobic and anaerobic), adsorption and membrane separation process (Rezazakemi et al. 2018; Sheikh et al. 2019; Mirqasemi et al. 2020; Tavangar et al. 2020) are available but unfortunately no report has yet been published which recommends how the water parameters of Buriganga river water may be restored. Thus, the aim of this study is to report contamination level of Buriganga river and propose

a cost-effective method so that water parameters can be restored.

In the present work, we have employed different electrodes to detect and quantify the pollutants in terms of dissolved solid, dissolved oxygen, nitrate contamination, ammonia, etc. Later the results were cross-checked with the data obtained using commercial membrane-based electrodes. In order to understand the level of pollution of Buriganga river, the obtained data have been compared with respect to data received for fresh water samples collected from the rivers Surma and Dawki which are located in the north-east region of Bangladesh down to the topmost rainy region (The Meghalaya State, India) on the globe (World Atlas; Soja and Starkel 2007). It is well known that carbon materials are often used to treat wastewater which can be synthesized from different plants. In the present case, we selected taro stem (*Colocasia esculenta*), which is extensively available everywhere over the planet, as a potential carbon source. In this article, we have shown how the water parameters of Buriganga river water could be improved followed by treating with taro carbon.

Experimental

Study area

The river Buriganga is situated at the southern part Dhaka City, the capital of Bangladesh. Geographically, it is located altitude between 23° 36' E and 23° 46' E, with longitude between 90° 14' N and 90° 36' N (see Fig. 1). This river is originated as a result of confluence of the river Padma (Ganges) and the river Dhaleswari, which, is a distributary, 160 km long of the Jamuna River in central Bangladesh. The Lakhya River is combined to the Dhaleswari, approximately 11 km downstream of the Buriganga confluence, which is then merged into the Meghna River, just upstream of the Padma confluence near Chandpur. The Buriganga takes stream mainly from the river Turag, which receives spill flows from the river Jamuna and local rain fall. The lower reaches of the Buriganga–Dhaleswari–Lakhya river system are tidal during the dry season (November–March) when upstream inflows are nominal (Kamal et al. 1999). The average width and depth of the river Buriganga are 400 m and 10 m, respectively. This river is only 27 km long. The sampling was performed from 10 major points of the river. The samples were also collected from two rivers named Surma and Dawki. Both of these rivers are located in the north-eastern region of Bangladesh which carry flows due to rain fall in the Meghalaya, India, which is known as the most rainy region over the globe where the annual rainfall is even up to 23,000 mm (Soja and Starkel 2007). Therefore, the

Fig. 1 The study area: River Buriganga, Dhaka, Bangladesh

waters of these rivers are fresh and clean, which are ideal for any reference of study in terms of purity.

Electrochemical investigations

The electrochemical investigations such as cyclic voltammetric (CV), open circuit potential (OCP) and electrochemical impedance spectroscopic (EIS) measurements were carried out using an Autolab potentiostat (PGSTST 128 N, The Netherlands) in a conventional three-electrode cell. A Teflon-coated Pt electrode (2 mm in diameter) functioned as a working electrode, where an Ag/AgCl (sat. KCl) and a Pt wire acted as reference and counter electrodes, respectively. Before the experiments, a bare Pt electrode was mechanically polished with alumina (0.3 μm) slurry on a soft lapping pad until a mirror-like shiny surface was attained. A Pt electrode was employed to predict the presence of relative abundance of dissolved oxygen. Meanwhile, a Pt–Cu electrode was employed to infer the presence of reducible substances in the river waters. In order to prepare a Pt–Cu electrode, a Pt disk electrode (2 mm diameter) was cycled between 0 and -0.8 V in 0.01 M CuSO_4 solution for five times at scan rate

of 100 mV/s. This approach yielded a thin over layer of Cu metal particles on Pt surface. Then, the Pt–Cu electrode was washed with distilled water and dried at 60 $^{\circ}\text{C}$ for several minutes before use. All the electrochemical measurements were performed under aerated condition. The open circuit potential and Tafel slope was evaluated by using a cylindrical (r : 2 mm and h : 3 mm) iron electrode.

In situ determination of pH, TDS, ORP, DO, Nitrate and ammonia

Temperature, pH, TDS and ORP were measured on site using LAQUAact PD110 m (Horiba, Japan). The NO_3^- detection was performed using Horiba LAQUAtwin Nitrate NO_3^- Meter (NO_3^-11). For this purpose, the research group collected samples from 10 different locations within 27 km length of the river Buriganga from where 17 different samples were collected for analysis. In order to obtain data, the sensor was immersed 50 cm depth down to the surface of the water level. In situ ammonia was measured colorimetrically using an ammonia meter (Mi405 Photometer) supplied by Milwaukee (Hungary). In this case, Nessler

reagent was added to the 5 mL samples containing ammonia, which made the samples to turn into a yellowish hue. The associated color change was then colorimetrically analyzed by exploiting the principle of Beer–Lambert Law. According to this law, light is absorbed under an ambient environment and the complimentary color intensity of the emitted radiation determines the concentration. In the presence of $\text{N}(-\text{NH}_3)$, a narrow band interference filter at 420 nm allows only the violet light to be detected by the silicon photodetector and omits all other visible light emitted from the tungsten lamp. The emitted light intensity is automatically converted into ammonia concentration. Additionally, chemical oxygen demand (COD) was also checked. All the analytical measurements were performed three times. The detailed experimental procedure is described in elsewhere in the literature (Maria Rahman et al. 2014).

Sediment analysis

Sediments were collected from different locations of the rivers (approximately 1–2 m deep from the level of water). Next, the as-collected samples were dried at 110 °C and meshed properly. Then, the materials were evaluated by FESEM instrument (FESEM; JSM-7600F, Japan). At the same time, energy dispersive X-ray analysis (EDS) was performed by using FESEM–coupled XEDS from JEOL, Japan.

Recovery of water parameters

The restoration studies of water parameters of Buriganga river water was performed using carbonous adsorbent derived from the taro stems. For this purpose, taro stem collected from local area were cut into 3 cm × 2 cm sizes and then dried at open air at 40 °C for several hours to remove water content. Next, the dried material was pulverized using a commercial blender and screened using 80-micron sieves. In a 500-mL beaker, 25 g of sieved material was taken along with 50 mL of concentrated HCl. This mixture was then sonicated for 90 min such that a dispersion carbon material is prepared, followed by addition of 200 ml DI water. The mixture was then blended for an hour and kept rest for another 1 h such that a distinct layer of solid phase and aqueous phase are seen. The carbon materials were collected carefully by filtration method and washed repeatedly. After drying at 110 °C, the resulting mass was then transferred to alumina crucible and placed in N_2 saturated furnace. Finally, the crucible was heated to 500 °C gradually and kept at this temperature for 6 h, which yielded black colored mass. In this way, activated carbon was prepared from taro stem. Batch experiments were performed using this taro carbon where the volume of wastewater was 500 mL in each case with variable amounts of taro carbon. The detailed experimental procedure is given in Scheme 1.

Results and discussion

Relative conductivity and oxygen abundance

Figure 2 shows the EIS spectra recorded using a Pt disk electrode at 0 V. An EIS spectrum is typically presented in the form of a complex plane plot, where Z' and Z'' represent the imaginary parts of impedance, respectively. For a classical non-polarizable system, the circuit comprises a series junction of solution resistance (R_s) along with a parallel combination of a double-layer capacitance (C_{dl}) and charge transfer resistance (R_{ct}). Note that irrespective of river water, semicircles appeared in each case with different radius indicating some charge transfer process occurring at the electrode–river water systems. At the higher frequency region of the EIS spectra, the capacitive impedance is short-circuited, which in fact eliminates the R_{ct} .

Consequently, only R_s remains at the high frequency intercept of the spectra. Meanwhile, the low frequency intercepts denote the sum of the values of R_s and R_{ct} . As a result, in the present case, it can be said that the diameters of the semicircles shown in Fig. 2 define the value of R_{ct} for the respective river water systems. From the close view of the EIS spectra (see inset of Fig. 2), order of resistivity of the river water was as follows:

$$R_s(\text{Dawki}) > R_s(\text{Surma}) > R_s(\text{Buriganga})$$

This observation suggests that Buriganga river water is highly conductive in comparison with other river waters. Correspondingly, this measurement ensures that the Buriganga river water contains huge TDS (0.664–0.694 g/L, see Table 1), whereas Dawki and Surma river contains 0.043–0.12 g/L and 0.063–0.083 g/L TDS, respectively. In majority cases, high levels of TDS are originated due to the presence of chlorides of potassium and sodium. These ions have light or no short-term health risks, but toxic ions such as arsenic, nitrate, cadmium, etc., are also dissolved in the water which causes increase in TDS. The disposal of electrolytes from various industries installed over the banks of the river Buriganga and/or nitrate/nitrite ions generated due to biological conversion of nitrogenous pollutants perhaps made the Buriganga river to show high level TDS.

Conversely, the radius of the EIS spectra represents the charge transfer resistance, which varies with the concentration of the charge carrier species. From the fitted EIS curves, the charge transfer (R_{ct}) was found to be 132 ± 4 , 217 ± 3 and 1120 ± 8 kΩ for Surma, Dawki and Buriganga river waters, respectively, at 0 V. Here, it is to note that the pH of the river water streams was found slightly basic ($8.0 > \text{pH} > 7.0$). In such a medium, a platinum electrode can reduce oxygen as per following reactions (Geniès et al. 1998; Strbac 2011)

Scheme 1 A schematic representation of experimental setup

Under the experimental conditions and as per above reactions, the charge transfer should be quite difficult if the medium does not contain enough charge carrier like

dissolved oxygen (DO). In the case of Buriganga water, the Pt electrode experienced highest charge transfer resistance implying that this river water contained least DO. From field analysis, the DO level of Dawki and Surma river was to be in the range of 5.6–6.8 mg/L and 5.2–6.9 mg/L, respectively, while the Buriganga river contained alarmingly low level of DO (1.47–4.4 mg/L, see Table 1).

According to a recent report, the DO level of river water systems even downs to zero in the dry seasons (Whitehead et al. 2018). Note that a typical air saturated fresh water

Fig. 2 EIS spectra of different river waters recorded using a Pt disk electrode at 0 V versus Ag/AgCl (sat. KCl). Inset shows enlarged view of solution resistance

contains DO of ca. 7.56 mg/L at 30 °C (Peterson and Risberg 2009). The lower DO is resulted in the marine systems for two main reasons: firstly, water with high concentrations of dissolved solids such as salt decreases DO level, and secondly, excessive growth of algae is promoted by phosphorus and/or nitrogen. While algae die and decompose, the process consumes dissolved oxygen (Peterson and Risberg 2009). Thus, the direct discharge of organic and/or inorganic pollutants from point sources and nonpoint sources into the Buriganga river increased the concentration of dissolved solids and caused lowering of DO level.

ORP and metallic corrosion

Figure 3 shows the polarization curves of an iron electrode recorded using different river waters. Note that open circuit potential (OCP) of Buriganga, Dawki and Surma river waters lie at -0.68 V, -0.48 V and -0.36 V, respectively. The most negative OCP exhibited by the Buriganga river indicates that its water contains enough reductants, perhaps due to presence of organic wastes (which was confirmed by the estimation of large COD value 196–218 mg/L). Later the results were verified by means of in situ evaluation of ORP values as reported in Table 1. The Buriganga river water showed negative ORP values (-292 to -300 mV) while the other river water showed positive values (ca. $+200$ mV). The negative ORP values of Buriganga river water indicate that high level reductant/antioxidants are present in the water

system. However, the evaluation of corrosion rate of a metal such as iron may be an indicator of water quality of a certain system. The corrosion rate of a metal under test can be calculated from the slopes of $\log(i)$ versus E plots as shown in Fig. 3.

The corrosion rate of a metal is often evaluated by measuring the equilibrium currents between opposing (anodic and cathodic) reactions. In the anode surface, metal particles are oxidized by releasing electrons into the metal strip. Meanwhile, in the cathode compartment, the species (often O_2 or H^+) in solution is reduced by receiving electrons from the metal. While the rates of these two opposing processes are balanced, then no virtual electrical current is observed. These two processes may take place on similar metals or on different two metals which are electrically connected. In conjunction with the principle, the corrosion process assumes that the rates of both processes (anodic and cathodic) are controlled by the kinetics of the electron-transfer reaction at the surface of the test metal. Note that an electrochemical process under kinetic control satisfy the Tafel Eq. (4) (Gileadi and Kirowa-Eisner 2005; Alam et al. 2018)

$$\ln I = \ln I_0 + \ln \frac{\eta F \beta}{RT} \quad (4)$$

Here, net current (I) is related to corrosion current (I_0) and over potential ($\eta = E - E^0$). Using the above approximation, the value I_0 was evaluated as $31.6 \pm 2.1 \mu\text{A}$, $10.1 \pm 1.5 \mu\text{A}$ and $9.5 \pm 1.1 \mu\text{A}$ for Buriganga, Dawki and Surma river,

Fig. 3 The Tafel plots of Fe electrode recorded for different river waters under room condition

Table 1 In situ determined physical and chemical parameters of river waters

Rivers	T (°C)	pH	ORP (mV)	TDS (g/L)	DO (mg/L)	NO_3^- (mg/L)	NH_3 (mg/L)	COD (mg/L)
Dawki	28.1–28.5	7.01–7.03	+203 to +209	0.043–0.12	5.6–6.8	<0.1	<0.1	–
Surma	28.0–28.3	6.93–7.01	+184 to +205	0.063–0.083	5.2–6.9	<0.1	<0.1	–
Buriganga	28.8–29.04	6.50–7.50	–292 to –310	0.664–0.694	1.47–4.40	107–157	270–420	197–218

respectively. Since current intensity corresponds to the rate of an electrochemical process, thus it can be assumed that the Buriganga river water could corrode iron three times faster than Surma or Dawki river water. The corrosion current is highly related to water quality such as salinity (Melchers 2015). High level dissolved solids, such as chlorides, nitrates and sulfates can induce chemical or bio-chemical corrosion of metal. The above observation, thus, ensures that Buriganga water contains excessive dissolved solids.

Evaluation of ammonia and nitrate

In the previous section, it has been reported that Buriganga river water has TDS above the acceptable level. According to geographical position of river Buriganga, saline water intrusion from the nearest Bay of Bengal is not possible. However, increased nitrate concentration may contribute to the TDS of the water stream. In the marine waters nitrate ions often coexists with ammonia as they are inter convertible (Jensen et al. 1985).

Ammonia may enter into the water stream via municipal effluents and/or the biological disintegration of nitrogenous wastes from animals (Chen et al. 2016). Several secondary means such as runoff from crop lands, air deposition, nitrogen fixation, etc., can also introduce ammonia to the natural water systems. Ammonia exists in water having an equilibrium between molecular (NH_3) and its ionized form (NH_4^+). Toxicity to marine lives arises mainly from molecular NH_3 , with minor contribution from NH_4^+ (Miller et al. 1990). Due to low DO and high level of COD values, we assumed that Buriganga river stream must contain considerable ammonia concentration. We, therefore, evaluated in situ ammonia from the river waters using spectrometric method. The data are reported in Table 1. Note that concentration of ammonia was 270–420 mg/L in the case of Buriganga river water, while it was bellow detection level for Surma and Dawki river waters. In the biologically contaminated waste water systems under aerobic condition, nitrifying bacteria consumes oxygen by converting ammonia into nitrite (NO_2^-), consecutively Nitrobacter transforms nitrite into nitrate ions (NO_3^-) as per following reaction mechanism (Schmidt et al. 2002).

Nitrate ions in groundwater also may be introduced from the point sources such as sewage disposal systems and livestock facilities, inadvertent application of fertilizer in the cropland, parks, gardens, etc. As the Buriganga river water contains significant concentration of ammonia originated

from biological waste, the environment is ideal for bacterial conversion of ammonia into nitrite/nitrate ions. Thus, we took attempts to detect the presence of nitrate ions in river waters using a Pt–Cu disk as working electrode.

Figure 4A shows the CVs of river waters recorded at a scan rate of 50 mV/s using a Pt–Cu working electrode within the potential window between 0 and -1.4 V. At the surface of a Pt–Cu electrode, nitrate ions are converted into ammonia ions under reduction condition as per following reactions (Hasnat et al. 2014).

Thus, a broad reduction wave could be obtained (shown in Fig. 4B) if nitrate/nitrite ions are present in the water sample. Note that the CVs obtained for Surma and Dawki Rivers do not show any reduction wave while the Buriganga water shows sharp reduction peak between -0.83 V and -1.2 V whose profile almost superimposes that obtained for 150 ± 3 ppm NaNO_3 in 0.1 M KCl solution prepared by deionized water. Consequently, it is experimentally evident that Buriganga river water contains N-nitrate/nitrite. However, the field data measured with ion-selective membrane electrode showed that Buriganga river water contained 107–157 mg/L nitrate/nitrite ions, which ensures acute anthropogenic contamination in the river Buriganga. Consequently, it can be said that the River Buriganga one of the World's most endangered rivers which is facing increased TDS, acute ammonia concentration and lowered DO.

Sediment analysis

As the water flow of Buriganga river contains huge inorganic and organic contaminants, thus there is a high potentiality of deposition of insoluble contaminants on the bottom of the river. In order to determine the contaminants in the sediments, steps were taken in terms of X-ray analysis. Scanning electron microscopic (SEM) image can explain the surface morphology of a material, while coupled EDS can detect even trace quantities of elements within a material. Hence, in order to examine the texture and composition, the collected sediment specimens were dried first at 110°C to remove all of water constituents and then meshed properly.

Next, FE-SEM images were taken along with recording of EDS spectra. It can be seen from Fig. 5 that the mineral composition of the soils of all of the river soils is almost similar and comprise mainly Ca, Si, K, Fe, Mg and Al with traces of Zn and S. The presence of oxygen indicates that these elements exist in the form of oxides. The SEM images of Dawki (panel A of Fig. 5) and Surma (panel B of Fig. 5) indicate that their sediments are comprised of coarse particles with

Fig. 4 Cyclic voltammograms of river waters recorded at a scan rate of 50 mV/s using a Pt–Cu working electrode in 0.1 M KCl. **A** Black line: Surma river water, Blue line: Dawki river water, Red line: Buriganga river water; **B** Responses of Pt–Cu electrode toward nitrate reduction reactions under ideal condition; Dotted line: 0.1 M KCl, Pink line: 150 ppm NaNO_3

sharp edges. Meanwhile, the texture of Buriganga (panel C of Fig. 5) soil particles are rather smooth with irregular shapes. Such different texture of specimen indicates that insoluble organic particles originated from the disintegration of municipal and industrial wastages have been deposited at the bottom and bank of the Buriganga River.

Restoration of water quality

Carbon materials derived from various sources have excellent efficiency to remove different pollutants from water (Gaikwad and Balomajumder 2017; Rashidi and Yusup 2017; Tchikuala et al. 2017; Ratan et al. 2018; Menya et al. 2018; Chen et al. 2018). Thus, batch experiments were performed to restore water parameters of Buriganga river water using carbonous materials synthesized from taro stems (in this article synthesized carbon is designated as taro carbon). Figure 6 shows the image of taro stems and corresponding SEM image of taro carbon.

Here, to perform the batch experiment, at first water samples were collected in a tank from the river and removed all suspended particles. Next, water tank was allowed to stay under open air for 48 h, where the temperature varied between 24 °C and 36 °C. From the water tank, 500 mL was then taken in a batch reactor along with 5 g taro carbon.

At this stage, the batch reactor was shaken using an orbital shaker for 120 min (see Scheme 1). After completion of shaking, the batch was allowed to rest for another 60 min. Then, the clear aqueous phase was separated for chemical analysis.

Figure 7 shows analytical results, which compares some water parameters before and after treatment with taro carbon. It is seen from this figure that after treatment, COD decreased by ca. $90 \pm 2\%$, ammonia concentration decreased by $85 \pm 3\%$, nitrate concentration decreased by $52 \pm 2\%$, and

TDS decreased by $63 \pm 3\%$. Additionally, after the treatment, ORP value of the water treated water sample was found change to +160 mV from −310 mV and DO level raised to 5.1 mg/L from 2.3 mg/L. This observation suggests that taro carbon is an efficient adsorbent to remove undesired dissolved particles from the wastewater system. It is worthwhile, to note that because of high absorbability carbonous materials can remove organic materials very easily from water (Hami et al. 2007).

As a result, COD value decreased significantly in the present case. However, a drastic removal of ammonia using a carbonous materials is difficult (Park and Jin 2005). In the present case, removal of ammonia not only occurred by absorbability of taro carbon but also ammonia generation was inhibited as the suspended particles and TOC were removed, which perhaps indirectly contributed to decrease ammonia level in the wastewater at pH ~7.0.

Consequently, electrochemical analysis reveals that river Buriganga is extremely polluted river in Bangladesh due to industrial and human waste disposal, and the contamination can be minimized by treating with activated carbon synthesized from taro stems.

Conclusion

In this research, laboratory-based electrochemical experiments in terms of EIS, CV and OCP were performed to detect and quantify pollutants in Buriganga river water and then compared with two other sources of fresh water from Surma and Dawki river to perceive the pollution level of Buriganga river. In EIS study, low water resistance (R_s) of Buriganga river compared with Surma and Dawki rivers revealed the presence of highly conducting materials which stands for high TDS value. Additionally, the higher value

Fig. 5 FE-SEM images and associated EDS spectra of soil specimen collected from different rivers. **A** Dawki, **B** Surma and **C** Burigana soil

Fig. 6 Image of taro stem (**A**) and SEM image of taro carbon (**B**)

Fig. 7 Batch treatment of Buriganga river water with standard errors on average. Volume: 500 mL, adsorbent (taro carbon) dosage: 5 g [red mark: untreated water; blue mark: treated water]

of charge transfer resistance (R_{ct}) of Pt electrode showed the lack of charge carriers like dissolved oxygen in Buriganga river water. Most surface water has a positive ORP values (+200 to +600 mV) which was observed in the case of Surma and Dawki river waters. Water with negative ORP values has a higher amount of reducing agents as it was found in the case of Buriganga river water (−292 to −300 mV). The Buriganga river water corrodes iron three times rapidly than Surma or Dawki river water. A COD analysis can easily measure the number of organics contaminants in water. Due to dumping of huge municipal wastage, the Buriganga river water exhibited high COD (197–218 mg/L). Ammonia is toxic to fish while its concentration reaches >0.03 mg/L. WHO recommends maximum ammonia level as 0.2 mg/L and 50 mg/L nitrate in drinking water. However, Buriganga water contains alarmingly high level of ammonia (270–420 mg/L) and nitrate ions (107–157 mg/L). The DO level in Buriganga was found in the range 1.47–4.40 mg/L. Fishes and crustaceans receive oxygen for respiration through their gills, while plant lives and phytoplankton need dissolved oxygen for respiration. If DO level in water drops below 5.0 mg/L, aquatic lives are put under stress. These indicators are enough to conclude the death of fishes and other aquatic creatures in the river Buriganga. Lastly, the presence of insoluble organic particles originated from the disintegration municipal and industrial wastages was confirmed by the sediment analysis of Buriganga River. In conclusion, it can be said that the water of the Buriganga is now acutely polluted and cumulative municipal filth and human waste have turned it like a stream of black gel. Sustainable actions are highly recommended to revert the water parameters to the acceptable standards. However, treatment using taro carbon may be a cost-effective means to treat wastewater like Buriganga river water, and it was found that COD value and ammonia concentration decreased drastically and the TDS value, nitrate concentration also decreased.

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Compliance with ethical standards

Conflict of interest We do not have any conflict of interest.

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