Natural Banana (*Musa acuminata*) Peel: an Unconventional Adsorbent for Removal of Fluoride from Aqueous Solution through Batch Study

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Abstract Higher level of fluoride in underground water is a burning problem in many parts of the world. Continuous ingestion of fluoride containing water leads to fluorosis. In the present work, natural banana (*Musa acuminata*) peel (NBP), an unconventional adsorbent, has been explored for removal of fluoride from aqueous system. The NBP was characterized by using SEM, FTIR, and point of zero charge. In the batch study, maximum fluoride removal was achieved at the pH 4.0 (pH_{ZPC} 5.63), taking about 60 min to attain equilibrium. Kinetics data were fitted with a pseudo-second-order ($R^2 = 0.99$) and Bahangam models ($R^2 = 1.00$). The experimental data fitted well to a D-R adsorption isotherm ($R^2 = 0.995$). Thermodynamic data suggests that the adsorption of fluoride on NBP is an exothermic reaction. Therefore, the results suggest that natural banana peel dust could be a cost-effective, eco-friendly adsorbent for removal of fluoride from aqueous medium.

Keywords Banana peel · Fluoride · Batch study · Regeneration

Introduction

Due to rapid industrialization, huge quantity of pollutants discharges in to the environment. Fluorine is one such pollutant

that threatens living organisms, in particular, humans [1]. Fluorine is the strongest electronegative element and belongs to group 17 in modern periodic table. Its atomic number and molecular weight is 9 and 19, respectively [2]. Very small quantity of fluorine is required for hardening of enamel and protection against dental caries. The excessive intake of fluoride leads to dental as well as skeletal fluorosis [3]. Apart from dental and skeletal fluorosis, fluoride can bind to the functional amino acid groups located around the active center of an enzyme to cause an inhibitory effect which leads to decrease enzyme activity [4]. The main source of fluoride in the environment is entirely geogenic in nature [5]. However, recently, literature cited that it enters through anthropogenic activities such as industrial drains [1]. Very recently, Das et al. [6] and Maitra et al. [7] highlighted that fluoride can interfere in the plant system also. Due to its strong negative impact on both animal and plant kingdom, the World Health Organization (WHO) has set a stringent guideline value of fluoride in drinking water at 1.5 mg/L. [8]. The problem with high fluoride in drinking water is a major problem in several tropical countries like India [9]. The only possible remedy of this problem is defluoridation [10].

Many techniques are available to remove fluoride from contaminated water such as reverse osmosis, electrodialysis, Donan dialysis, nanofiltration, and ion exchange [11]. But very recently, attention of scientists has been focused to use very low-cost, easily available materials [12]. A good number of low cost materials have been tested such as sugarcane ash [13], Tea ash [14], coconut fiber dust [15], lemon leaf dust [16], egg shell dust [17], calcareous soil [18], and rice husk ash [19]. However, most of the adsorbents are suitable at lower concentration and showed excellent performance at an extreme pH value, such as activated coal showed good fluoride uptake capacity at pH less than 3 [20]. Therefore, it is a great challenge among the scientists to explore low-cost, easily

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available, and eco-friendly adsorbents which remove fluoride from contaminated water under neutral pH [21].

Fruits peels have attracted considerable interest as potential candidates for removal of pollutants from aqueous solution due to their inexpensiveness, availability, environmental stability, and high surface area/sorption capacity [15]. Among the various fruits peel, banana peel is a major waste in many countries including India. Previous literature highlighted that banana peel extensively used for removal of heavy metals [22, 23]. But very handful of researcher tried to use banana peel as an adsorbent for removal of fluoride. From this viewpoint, present research has been formulated with the following objectives: (i) to prepare banana peel dust, (ii) to characterization of adsorbent through SEM, FTIR, and pH_{ZPC} study; (iii) the experimental data will fitted in various isotherm, kinetic, and thermodynamics equations; (iv) comparative study with previously published adsorbents; and (v) application of banana peel dust for defluoridation from filed samples.

Materials and Methods

Preparation of Natural Banana Peel Dust

The raw waste banana peels (*Musa acuminata*) were collected from nearby fruits stall of Burdwan town, West Bengal. After collection, peels were thoroughly washed with tap water followed by washing with de-ionized water and dried in hot air oven at 50 °C for 12 h. The dried peels were cut into small pieces and again dried in hot air oven for 24 h, maintaining 60 °C temperature. The dried banana peels were grinded in kitchen grinder to get the desired particle size (200 μm) using suitable the powder form of banana peel was stored in air light container (Table 1).

Table 1 Physical characteristics of banana peel

Parameter	Values
pH	6.59 $\pm$ 0.41
Conductivity(mS/cm)	190 $\pm$ 3.89
Specific gravity	2.66 $\pm$ 0.31
Bulk density(g/cm ³)	0.384 $\pm$ 0.11
Particle density(g/cm ³)	0.138 $\pm$ 0.01
Porosity (%)	178.26 $\pm$ 11.65
Moisture content (%)	2.98 $\pm$ 0.02
pH_{zpc}	5.63 $\pm$ 0.05
Dry matter	89.73 $\pm$ 2.34
Crude fiber	10.33 $\pm$ 1.01
Ash	17.94 $\pm$ 0.04
Mean $\pm$ SD	

Point of Zero Charge (pH_{ZPC})

Zero point charge of the NBP was determined by following the solid addition method [24]. Initially, a series of conical flasks were taken with 50 mL of 0.1 (M) KNO_3 solutions in each flask along with 0.1 g NBP. The pH of the 0.1 (M) KNO_3 solutions was adjusted by using 0.05 (N) HNO_3 and 0.1 (N) KOH solution. After thoroughly shaking (24 h), the pH of the final solutions was recorded and a graph was constructed by pH vs ΔpH .

Adsorption Experiments

The entire adsorption experiment was carried out by varying the operating variables such as pH, initial adsorbate concentration (ppm), dose (g), adsorbent particle size, contact time (min), shaking speed, and temperature (K). Batch experiments were carried out in a 250-ml conical flask containing fluoride solution (2.0–20.0 ppm) with varying adsorbent dose (0.1–10 g L^{-1}). The pH of the respective solutions was maintained by using 0.1(N) HCl and/or 0.1(N) NaOH . The contact time was (5–80 min) and temperature (300–333 K). After adsorption, the residual fluoride concentration was measured by ion selective electrode (Orion 4 star). The fluoride sample solution and fluoride standard solutions were diluted 1:1 with a TISAB solution [25]. The percentage of fluoride adsorption was calculated by using the following Eq. (1):

$$\text{Removal}(\%) = \frac{(C_0 - C_e)}{C_0} \times 100 \quad (1)$$

The adsorption capacity (mg/g) of the experimental adsorbent was calculated by using the following Eq. (2):

$$q_e = \frac{(C_0 - C_e)V}{m} \quad (2)$$

where C_0 and C_e denoted the initial and equilibrium fluoride ion concentrations (mg/L), respectively. V is the volume of the solution in liters, and m is the mass of the adsorbent used (g).

Instrumentation

A number of instruments were used for characterization of adsorbent and estimation of fluoride from aqueous medium such as scanning electron microscop (SEM) (HITACHI-S-530, Scanning Electron Microscope and ELKO Engineering) at an accelerating voltage of 20.0 kV, Fourier transform infrared spectroscopy (FTIR) (BRUKER, Tensor 27), and ion selective electrode (Orion 4 star).

Results and Discussion

Zero Point Charge of NBP

From Fig. 1, it is clear that the pH_{ZPC} of NBP is 5.63. That means, at this pH, the surface of NBP has no charge. However, below the pH (5.63), surface of NBP changes to positive and above the pH (5.63), the surface is negatively charged.

FTIR Analysis

FTIR is a valuable technique to identify the function groups present on the surface of the adsorbents. Present adsorbent exhibit various sharp peaks such as $3905\text{--}3258\text{ cm}^{-1}$ which is attributed to the alcoholic -OH stretching; 1631 , 1269 and $1116\text{--}624\text{ cm}^{-1}$, respectively, assigned to $\text{C}=\text{O}$ stretching of carboxylic acid or ester or ether and N-H deformation of amines, respectively (Figure Supply 1). After adsorption, the shifting of -OH and the slight decrease in intensity indicate the involvement of OH in the fluoride adsorption (Figure not supplied). Almost similar observation was reported by Mondal et al. [14] for removal of fluoride by using low-cost waste tea ash as adsorbent.

SEM Analysis

Scanning electron micrograph has immense potentiality for understanding the surface morphology of the adsorbents. SEM photograph of NBP before and after loading of fluoride was presented in the Fig. 2a, b. From Fig. 2a, it is clearly revealed that the surface of NBP has numerous micro-rough, porous structures which might be the area of fluoride loading. However, after fluoride removal, the surface of NBP does not exhibit such rough areas as before (Fig. 2b). Almost similar peel SEM structure of banana and orange has been demonstrated by previous researchers for removal of heavy metals from aqueous solution [26]. This observation clearly indicates

Fig. 1 ZPC of Banana peel dust

Fig. 2 Scanning electron microscopy of Banana peel. **a** Before passing fluoride solution (1500 $\times$ magnification). **b** After passing fluoride solution ($\times 1500$ magnification)

that NBP has tremendous role towards the affinity of fluoride binding.

Effect of pH

pH of the solution has remarkable role in both metal and nonmetal adsorption process [26]. Figure 3 clearly revealed that F removal remarkable elevated with changing pH from 2.0 to 4.0. However, after pH 4, the removal of F adsorption sharply declines with increasing alkalinity of the fluoride

Fig. 3 Effect of pH

solution. This phenomenon nicely interpreted with the help of ZPC of NBP. From the Fig. 1, it is clear that the ZPC of NBP is 5.63 and maximum F adsorption occurs at pH 4 which is below the pH zpc of NBP. That means the main driving force of F adsorption is purely electrostatic in nature [20] as per the Eqs. (4) and (3):

The removal of fluoride at lower pH is also reported by the earlier researchers [14, 18, 20]. Almost similar observation was reported by yadav et al. [27] in their earlier work where they argued that under acidic condition, the surface of the adsorbent changes to positive change which facilitate the fluoride adsorption through anion exchange.

Effect of Initial Concentration

The effect of initial concentration of fluoride is depicted in the Fig. 4. From the Fig. 4, it is clear that fluoride removal increased with increasing influent concentration from 2.0 to 20.0 mg/L. and maximum fluoride uptake of 0.96 mg/g was recorded at 30.08 mg/L. This could be attributed to the possible higher interaction between F ions and the binding sites on the NBP surface and saturation of all binding sites with F ions. Therefore, it was inferred that higher concentration of F in the solution is responsible for the increase in the percentage of F removal until the saturation of the NBP biomass is attained. Almost similar uptake pattern of fluoride was reported by Koilraj and Kannan [1].

Fig. 4 Effect of initial conc. (mg/L)

Effects of Adsorbent Dose

The fluoride removal increases with the amount of NBP used (Fig. 5). From the Fig. 5, it is clear that, when the adsorbent amount increased from 0.1 to 0.15 g/100 ml, the fluoride removal increased from 89 to 96.7%, respectively. This gradual increment is due to the enhancement of the surface area which promoted the sorption of fluoride [12]. On the other hand, the adsorption capacity (q_e mg/g) value decreased for a fixed influent (fluoride) concentration (16 mg/L) with the increase of adsorbent dose. This finding nicely fitted with the increase of adsorbent dose for a fixed solute load, and surface sites heterogeneity of the adsorbent [28]. According to surface site heterogeneity model, the surface is composed of sites with a spectrum of binding energies at the high adsorbent dose, the availability of higher energy sites decreases with a large fraction of lower energy sites occupied, resulting in a low q_e value. However, at lower adsorbent dose, all types of sites entirely exposed and the adsorption on the surface is saturated faster showing a higher q_e value [29, 30].

Effect of Contact Time

Figure 6 shows fluoride removal at different contact times using NBP as biosorbent. With increasing contact time, fluoride removal increased rapidly. However, after reaching maximum value (94%), removal gradually approached a more or less constant value indicating attainment of equilibrium. The adsorption nature of fluoride on NBP may be considered to be occurring in three distinct phases. In the first phase, rapid adsorption occurs. This may be the results of instantaneous sorption of fluoride on the surface of NBP. In the second phase, sorption of fluoride decrease. This is perhaps due to migration of fluoride from boundary layer to the interior pore [12]. In the third phase, the entire adsorption process attained equilibrium at 60 min due to non-availability of active sites.

Fig. 5 Effect of adsorbent dose (g)

Fig. 6 Effect of contact time (min)

Almost similar observation reported by Nasr et al. [12] and Fan et al. [31]. As after 60 min there is no further improvement in fluoride adsorption, an equilibrium time of 60 min was chosen for all subsequent experiments.

Effect of Temperature

Temperature is a crucial parameter in adsorption process. The effect of temperature on fluoride removal was studied in the solution temperature range from 300 to 333 K and it is presented in Fig. 7. It reveals that fluoride removal decreased with the increase in temperature. This result suggests higher temperature did not favor adsorption of F ions. The removal efficiency of fluoride at higher temperature can be attributed by the fact that the molecules get excitation at higher temperature and ultimately breakdown the attractive force between surface atom of the adsorbent and fluoride [32].

Fig. 7 Effect of temperature (g)

Effect of Co-ions on Fluoride Uptake

In general, field samples contain many anions besides the anion of interest. Therefore, the study of fluoride uptake in presence of other co-ions is highly desirable with respect to environmental contamination point of view. Present study was conducted with the anions such as carbonate, nitrate, sulfate, chloride, and phosphate and the results are presented in Fig. 8. The concentration of fluoride was taken as 30 mg/L along with 50 mg/L concentration other co-ions. Results revealed that fluoride uptake strongly influenced by carbonate followed by phosphate and sulfate. The strong interference of fluoride uptake by carbonate is due to the preferential binding of carbonate on the surface of adsorbent [33]. The interference of phosphate is also reported by earlier researcher [34]. The relative interference of fluoride uptake by co-ions is in the order of $\text{CO}_3^{2-} > \text{PO}_4^{3-} > \text{SO}_4^{2-} > \text{NO}_3^- > \text{Cl}^-$.

Isotherm Study on Fluoride Adsorption

The entire biosorption of fluoride on NBP was assessed by using widely used four isotherms namely Langmuir, Freundlich, and D-R, and Temkin. Results revealed that among the four isotherms, Freundlich isotherm [35] nicely fitted with high correlation coefficient, suggesting multilayer adsorption of fluoride on NBP. The dimensionless separation factors (R_L) suggested that the fluoride adsorption is favorable as the values of R_L less than 1 and greater than zero for all studied initial concentration of fluoride [36]. All the isotherms constant along with the regression coefficients (R_L) are provided in the Table 2. From Table 2, it is clear that the maximum adsorption capacity was recorded as 16.14 mg/g from D-R equation and the value is higher than Langmuir isotherm [37]. K_L (L/g) is the adsorption constant related to the affinity

Fig. 8 Effect of interfering ions for fluoride removal on NBP

Table 2 Parameters of isotherm models on adsorption of fluoride by NBP

Isotherm model	Equation	Parameters
Langmuir	$\frac{1}{q_e} = \frac{1}{K_L q_m} \frac{1}{C_e} + \frac{1}{q_m}$	$K_L = 0.13$ $R_L = 0.842$ $q_m = 1.212$ $R^2 = 0.246$
Freundlich	$\log q_e = \log K_f + \frac{1}{n} \log C_e$	$K_f = 1.321$ $n = 8.26$ $R^2 = 0.314$
D-R	$\ln q_e = \ln q_{DR} - K_{DR} R^2 T^2 \ln \left(1 + \frac{1}{C_e} \right)$	$q_{max} = 16.4$ $\beta = 6 \times 10^7$ $E_S = 9.12 \times 10^{-6}$ $R^2 = 0.995$
Temkin	$q_e = B_T \ln K_T + B_T \ln C_e$	$B_T = 0.007$ $K_T = 3.036 \times 10^{-15}$ $R^2 = 0.110$

of binding sites (L/g) and lower values of K_L (0.13) indicate that the particles radius of adsorbent was small towards adsorption [38]. Moreover, the adsorption energy (E) was also calculated from D-R equation and it clearly revealed that fluoride adsorption onto the NBP is absolutely physisorption in nature (as the value of $E < 8$). Table 2 also provides the valuable information regarding heat of adsorption (B_T) and Temkin isotherm binding constant, K_T (L/min). Results indicate that the value of $B_T < 8$, therefore, interaction between F and NBP is purely physisorption in nature.

Kinetic Study in Adsorption of Fluoride

The kinetics of fluoride adsorption by NBP was assessed by the use of pseudo-first-order, pseudo-second-order,

intraparticles diffusion and Bahangam kinetic models. The adsorption kinetics not only describes the adsorption mechanism of adsorbates on the adsorbents but also describes the adsorption rate which controls the contact time of adsorbates at the solid-liquid interface [39]. The linearized forms of all the four kinetics models along with different constant terms and regression coefficient values are presented in Table 3. From the Table 3, it is clear that biosorption kinetics nicely fitted with Bahangam equation and pseudo-second-order kinetics. However, pseudo-first-order and intraparticles models showed moderate agreement with the studied results. The kinetics of adsorbate-adsorbent interaction depends on many factors such as nature of adsorbate and adsorbent, pH of the aqueous medium, temperature of the adsorption reaction, average time of contact between adsorbate and adsorbent and mass transport process [40]. The data were further used to investigate the slow step occurring in the present adsorption system. The applicability of Bahangam's equation was given by Aharoni and Ungarish [41]. As such $\log \log [C_0/(C_0 - q_m)]$ was plotted against $\log t$ (Figure not shown) and the constant values presented in Table 3. The plot was found liner indicating that kinetics confirmed to Bahangam's equation and therefore the adsorption of fluoride on NBP was pore diffusion control [42].

Thermodynamic Parameters

The entire biosorption of fluoride by NBP were calculated by the following Eqs. (5–6):

$$\Delta G^0 = -RT \ln k \quad (5)$$

$$\Delta G^0 = \frac{\Delta S^0}{R} - \frac{\Delta H^0}{RT} \quad (6)$$

where ΔG^0 , ΔS^0 , and ΔH^0 are the thermodynamics parameters free energy, entropy and enthalpy, respectively, and

Table 3 Parameters of kinetic models on adsorption of fluoride by NBP

Kinetic model	Equation	NBP
Pseudo-first-order	$\log(q_e - q_t) = \log q_e - \frac{k_1 t}{2.303}$	$q_{e1} = 1.94$ $K_1 = 1.08 \times 10^2$ $R^2 = 0.982$
Pseudo-second-order	$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e}$	$q_{e2} = 37.6$ $K_2 = 5.78 \times 10^{-4}$ $R^2 = 0.991$
Intra-particle diffusion	$q_e = k_{it} t^{0.5} + C$	$K_{it} = 0.262$ $I = 0.643$ $R^2 = 0.977$
Bahangam equation	$\log \log \left[\frac{C_0}{(C_0 - q_m)} \right] = \log \left(\frac{K_0 m}{2.303} \right) + \alpha \log t$	$\alpha = 0.974$ $K_0 = 7.664$ $R_2 = 1.00$

Table 4 Thermodynamic parameters on adsorption of fluoride by NBP

Thermodynamic parameters	Temperature (K)	NBP
ΔG^0	300	−5831.44
	303	−7524.68
	313	−7400.89
	323	−7073.40
	333	−7162.27
ΔH^0		-8.86×10^2
ΔS^0		0.84×10^2

other two constants are K (is the distribution co-efficient ($K = \frac{q_e}{C_e}$)) and R (is the universal gas constant). The Van't Hoff plot of $\ln K_c$ against $1/T$ (plot not shown) was used to calculate the free energy (ΔG^0), entropy (ΔS^0), and enthalpy (ΔH^0) by varying temperature from 313 to 343 K, and the calculated value is depicted in Table 4. The results suggest that the F adsorption is not favorable at higher temperature. Moreover, the negative value of enthalpy change indicated that fluoride biosorption on NBP was exothermic [43]. The positive entropy change during adsorption was due to gain of translational degree of freedom [44]. The negative free

Table 5 Comparison of the defluoridation capacities of different biomass

Name of adsorbent	Adsorption capacity (mg/g)	Reference
Used tea leaves	0.51	[46]
Cynodon dactylon-based activated carbon	4.617	[47]
Fungal biomass (<i>Pleurotus ostreatus</i> 1804)	1.272	[48]
Treated banana peel	0.395	[49]
Treated coffee husk	0.416	[49]
Activated rice husk	0.426	[19]
Tea ash	8.55	[14]
Eggshell dust	1.09	[17]
Lemon leaf dust		
LLD-1	7.63	[16]
LLD-2	27.03	
LLD-3	38.46	
Coconut fiber dust (CFD)		
CFD-1	12.66	[15]
CFD-2	25.64	
CFD-3	38.46	
<i>Aspergillus</i>	8.09	[50]
Ca-pretreated <i>Aspergillus</i> tea ash	4.8	[50]
Rice husk ash (RHA) by coating $Al(OH)_3$	9–10	[51]
Zirconium impregnated cashew nut (<i>Anacardium occidentale</i>) shell carbon	1.83	[52]
<i>Eichhornia crassipes</i> biomass carbon at 300 °C	0.52	[53]
Aluminum impregnated coconut fiber ash	3.192	[33]
Aluminum impregnated	34.48	[24]
Potato plant ash		
Lichen	0.81	[54]
Ca-pretreated lichen	1.72	[54]
Activated silica gel	0.308	[19]
Calcium carbonate	12.5	[55]
Activated alumina	1.2	[55]
Activated sugarcane ash	10.99	[55]
Saw dust raw	1.73	[20]
Wheat straw raw	1.93	[20]
Activated bagasse carbon	1.15	[20]
Natural banana (<i>Musa acuminata</i>) peel	1.212	Present study

Table 6 Variation of water quality parameters of field samples

Parameters	Alampur	Saldha	Nasipur
pH	7.56	7.81	7.63
EC ($\mu\text{S}/\text{cm}$)	2041	3011	2716
Cl (mg/L)	41.75	35.71	157.7
SO_4^{2-} (mg/L)	130.4	95.3	120.1
PO_4^{3-} (mg/L)	13.5	7.1	0.51
Fe^{3+}	0.211	0.52	0.64
TDS (mg/L)	633.1	548.8	600.9
TH (mg/L)	175.5	160.0	184.6
F (mg/L)	3.12	14.22	2.51

energy change with increasing temperature suggests the feasibility of the process and its spontaneous nature [45].

Comparison with Other Adsorbents

In order to compare the adsorption capacity of the studied adsorbent with previously reported adsorbents, a comprehensive table has been provided (Table 5). From the Table 5, it is clear that the adsorbents such as *Cynodon dactylon*-based activated carbon, lemon leaf dust (LLD-1, LLD-2 and LLD-3), and coconut fiber dust (CFD-1, CFD-2 and CFD-3) showed moderate to high fluoride adsorption capacity ranging from 4.617 to 38.46 mg/g. However, the other adsorbents such as used tea leaves, treated banana peel, treated coffee husk, activated rice husk, *Eichhornia crassipes*, lichen, and activated silica gel showed low fluoride adsorption capacity (ranges from 0.395 to 0.81). The present adsorbent showed the adsorption capacity 1.212 mg/g and it is better than activated bagasse carbon, activated alumina, eggshell dust, and fungal biomass (Table 5).

Biosorption of Fluoride from Filed Samples

In order to check the efficacy of tested adsorbent, batch studies were conducted to evaluate the adsorption performance of the filed samples. The samples were collected from three fluoride affected villages of Birbhum district, West Bengal, India. Initially physico-chemical parameters along with fluoride level were measured and depicted in Table 6. The entire batch adsorption was performed with the best optimized conditions of the banana peel (dose 0.15 g/100 ml; pH 4.0; contact time 60 min; temperature 302 K). The studied adsorbent removed fluoride as 83.65, 78.83, and 98.80% for the water samples collected from the villages of Alampur, Saldha, and Nasipur, respectively.

Conclusions

Research was carried out to explore banana peels as a high capacity, economically viable, and low-cost adsorbent for removal of fluoride. Adsorbent characterization has been done by pH_{ZPC} , SEM, and FT-IR studies. The pH played pivotal on the sorbate adsorption capacity onto the natural banana peel biosorbent. The decrease in the solution pH led to a significant increase in the adsorption capacities of all parameters on the banana peel biosorbent with maximum adsorption capacity. Batch study results indicate that best fluoride removal condition is 10 mg/L initial fluoride concentration, 0.15 g/100 ml adsorbent dose, pH 6.0, and contact time 60.0 min. Isotherm of the batch study best fitted with D-R isotherm model with high R^2 (0.995) values. The kinetics of the batch study clearly demonstrated that fluoride adsorption on banana peel dust is nicely fitted with Bahangam and pseudo second-order kinetic models, and thermodynamic study suggests that the defluoridation with NBP is an exothermic process. The relative interference of fluoride uptake by co-ions is in the order of $\text{CO}_3^{2-} > \text{PO}_4^{3-} > \text{SO}_4^{2-} > \text{NO}_3^- > \text{Cl}^-$. Finally, the studied adsorbent showed excellent performance towards removal of fluoride from field samples. Therefore, the use of banana peel could be a cost-effective adsorbent and may provide an alternative method for removal of fluoride from contaminated water.

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