Journal of Engineering and Applied Sciences 12 (7): 1800-1805, 2017
ISSN: 1816-949X

Treatment Efficiency of Riverbank Soil in Treatment of Bauxite Contaminated Water

Mohd Yuhyi Mohd Tadza and Angeline Tan Yee Ling
Faculty of Civil Engineering and Earth Resources, University Malaysia,
26300 Pahang, Gambang, Malaysia

Abstract: Rampant and unregulated bauxite mining activities in Kuantan, Pahang have caused severe deterioration to nearby Pengorak River and Pengorak Beach. Commonly, surface water is treated by using conventional water treatment method that involved coagulation, sand filtration and disinfection processes. However, conventional approach was found to be less effective in treating bauxite contaminated water in the vicinity. In recent years, the use of economical and cost-effective alternative such as Riverbank Filtration (RBF) system has gained widespread acceptance as a reliable method in treating raw water. This study evaluates the treatment efficiency of riverbank soil in Pengorak River in treating bauxite contaminated water. A laboratory scale fixed-bed filtration column test was conducted. Improvements in the water quality were then assessed following Malaysian Department of Environment Water Quality Index (WQI) and classified according to Interim National Water Quality Standards, Malaysia (INWQS). Water Quality Index (WQI) was determined on the basis of nine physico-chemical parameters namely, pH, color, turbidity, Dissolved Oxygen (DO) Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Ammoniacal Nitrogen (AN), Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). Test results showed that based on WQI and INWQS, the bauxite contaminated water in Sungai Pengorak was initially classified as Class 4 and 5 (i.e., highly polluted), respectively. Interestingly after column filtration test, the water quality improved significantly to Class 1 (clean) and 95.65 with respect to WQI. Due to close proximity to the sea, a much higher TDS value was obtained. The increased in TDS value may be attributed due to migration of salts from the sea during high tide and remained within the riverbank soil. Overall, the treated water complied with the National Drinking Water Quality Standards (NDWQS). Thus, riverbank filtration system may be a viable option for treating bauxite contaminated water.

Key words: Bauxite, filtration, water treatment, riverbank filtration, Malaysia

INTRODUCTION

Over the past few months, bauxite mining has become a controversial environmental issue in Malaysia. Bauxite, a principle ore is a main source of aluminium. Aluminium can exist in various forms in bauxite ore namely, gibbsite $Al(OH)_3$, boehmite α-AlO(OH) and diaspore, α-AlO(OH). The presence of bauxite in Kuantan was first recognized almost eight decades ago in 1937. In 2016, Malaysia became the world's top producer, accounting for nearly half of the supply to China's massive aluminium industry.

Annual output of laterite bauxite ore has increased from about 200,000 tonnes in 2013 to nearly 20 million tonnes in the year 2016. Unregulated and rampant open-cast bauxite mining activities in Kuantan, Pahang has led to severe air and watercourse pollution during a period of about 18 months. Kuantan was termed "Mars on earth" as red dust and red water flows in the capital state of Pahang. Water pollution has received extensive coverage by both mainstream and social media. The sources of water pollution were mainly related to extensive land clearing, extraction of bauxite leading to soil erosion and sedimentation washing of bauxite and effluent from the bauxite washing pond (Abdullah *et al*., 2016). Amongst the affected areas were rivers near Bukit Sagu, Bukit Goh, Bukit Ubi, Semambu and Sungai Pengorak, namely Riau River, Taweh River and Pengorak River. Similarly, Pengorak beach was also affected due to severe mud flood due to severe soil erosion and surface run off of cleared land.

Generally, depending upon geological characteristics, bauxite contains mainly aluminium oxide (40-50%), ferric oxide (20%) combined silica (3-5%) and traces of other

Corresponding Author: Mohd Yuhyi Mohd Tadza, Faculty of Civil Engineering and Earth Resources, University Malaysia, 26300 Pahang, Gambang, Malaysia

toxic metals such as arsenic, mercury, cadmium, lead, nickel and manganese (Valeton, 1972; Patterson *et al*., 1986). However, Kuantan's bauxite is characterized by high ferric oxide content ranging from 14.4-40.6% depending on different deposits. The increased in the concentrations of these elements could brought about devastating effects to overall health of the local community. Due to this fact, many locals developed fear and anger towards the bauxite mining operators. Furthermore, mining activities are often associated with Naturally Occurring Radioactive Material (NORM) (Paschoa, 1998; Golev *et al*., 2014). Thus, speculations on the effect of bauxite mining on drinking water quality raised significantly.

Four water treatment plants located downstream of the affected areas have great potentials to contaminate the drinking water sources. Reports on social media and local press claimed that concentrations of aluminium and heavy metals detected were higher than allowable limits in the treated water samples obtained from these water treatment plants. In contrast, reports from the Malaysian Department of Chemistry, Ministry of Health and other technical studies proved otherwise. Interestingly, Pengorak River that flows to Pengorak Beach showed higher concentrations of heavy metals. Despite higher concentrations of heavy metals were detected, Pengorak River is not used for water supply. Nevertheless, red mud and erosion from the mining activities flowed continuously towards the sea through this channel (i.e., Pengorak River).

Raw water from rivers are commonly treated using conventional treatment method for drinking purposes. This method involved coagulation, filtration and chlorine disinfection processes (Peavy *et al*., 1985). Aluminium sulphate or alum are commonly used as a coagulant to remove suspended solids and colloids (Peavy *et al*., 1985; Zhu *et al*., 2004; Aziz *et al*., 2007). However for bauxite industry the use of alum is expected to increase the treated water aluminium concentration. Thus, the use of alternative method such as Riverbank Filtration system (RBF) would be a better option. RBF has successfully been applied in the past for removal of suspended solids, colloids heavy metals and even pathogens (Schijven *et al*., 2002). The system utilizes riverbank soil which acts as both filter and biofilter for trapping and reducing the concentrations of particulates and pollutants. In Germany, about 18% of drinking water is produced from riverbank filtrate. Kuehn and Mueller (2000) showed that some conventional water treatment processes can be eliminated if RBF systems are used. Three main mechanisms involved in treatment of water using the RBF, namely physico-chemical, mechanical and biological processes. Physical processes such as hydrodynamics involve advection, dispersion, transport and dilution while mechanical processes include natural filtration of fine sediments by trapping of particles in pore spaces especially for particulate organic matters and pathogens (Abdel-Lah, 2013). Additionally, biological processes also occurred in RBF systems. Degradation of organic matter occurred due to metabolic processes of organisms and mineralization of secondary substrates. Physiochemical processes on the other hand, involves adsorption, solution-precipitation, redox reaction, complexation, acid-base reaction, hydrolysis, biochemical, microbial biodegradation reactions and by mixing with groundwater such as dilution (Jaramillo, 2012).

The treatment efficiency of RBF systems can be highly dependent upon several factors including soil and geological conditions as well as the quality of the source water. In some cases, modification of the riverbank with other filtration material (i.e., sand, activated carbon, zeolite) or the construction of artificial barriers may be required to increase the riverbank's treatment efficiency to drinking water standards (Rashid *et al*., 2015a, b). In general, soil consists of sand having an average particle distribution of about 2-0.425 mm is the most effective in removing particulates, contaminants and pollutants (Peavy *et al*., 1985; Kau and Lawler, 1995; Tyagi *et al*., 2013). Hence, it is anticipated that RBF may be a viable option to treat rivers contaminated by bauxite mining activities. In this study, the water quality and metal loads of Pengorak River is determined. In addition, the treatment efficiency of riverbank soil in treating bauxite affected Pengorak River is also evaluated. This study is crucial for the understanding of the potential of riverbank soil on-site for reducing environmental impact of bauxite prior to being discharge directly to the sea.

MATERIALS AND METHODS

Experimental approach: Soil sampling was carried out at selected sampling site located at Pengorak River (3°58'08.7"N, 103°24'36.7"E). Figure 1 shows the condition of the site during collection. Red mud flows directly to the sea and turn both the beach and the ocean red.

Fig. 1: View of the sampling location in Pengorak River

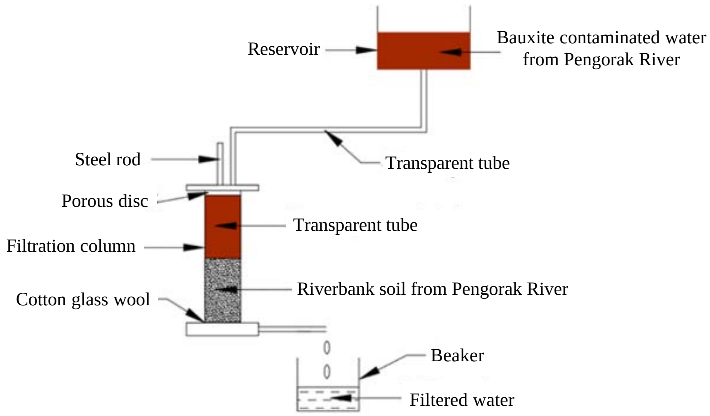

Fig. 2: Column test setup

Disturbed soil samples were collected using a hand auger up to a depth of 1 m below the ground surface. The samples were placed in sealed bags and transported back to the laboratory prior to being tested. Additionally, water samples were collected from the same location. Water samples were initially placed in plastic containers and stored in chilled room at a temperature of 4±1°C.

The geotechnical properties namely, specific gravity, particle size distribution and organic content were first determined according to BS1377 standard laboratory procedures. The six main water quality parameters namely Dissolved Oxygen (DO) Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammonia Nitrogen (AN) Suspended Solids (SS), Total Dissolved Solids (TDS) and pH were determined in accordance with AHPA standard method procedures. The water quality parameters were then used for the calculation of the Malaysian Water Quality Index (WQI).

Definition 1: For the equation WQI = 0.22 (SI DO)+0.19 (SI BOD)+0.16(SI COD)+0.15 (SI AN)+0.12(SI pH), "SI" is the sub-index function of each given parameter.

Theorem 2: WQI is equivalent to the sum of all SI of each parameters. The values calculated were then compared with the standards to ensure the water quality according to six (i.e., 1, 2A, 2B, 3, 4 and 5) different river quality classifications.

The water quality was later classified according to the Interim Water Quality Standards (INWQS). The apparent water quality, namely color and turbidity and concentrations of arsenic, aluminium, lead, nickel, copper, ferum and zinc were also measured. An Inductively Couple Plasma Optical Emission Spectrometry (ICP-OES) manufactured by Perkin Elmer was employed for this purpose. Each test was conducted in triplicates to ensure the reliability of the readings. A simple adsorption test was first conducted followed by a column filtration test. The adsorption tests were carried out at varying intervals of 5, 15, 30, 60, 75 and 90 min on soil specimens which were slowly agitated (i.e., 100 rpm) in 500 mL conical flasks on an IKA® HS 260 Control Shaker. Approximately 50 g of soil was used. Turbidity improvement was the only parameter evaluated in this test. The above tests were conducted to determine the optimum Hydraulic Retention Time (HRT). Once the optimum conditions have been determined, column filtration was carried out using a standard falling head apparatus. The water samples were retained in the column in accordance with the optimum HRT that has been determined in the adsorption tests. Figure 2 shows the experimental setup for the column filtration test.

RESULTS AND DISCUSSION

The geotechnical properties and mean initial water quality parameters are presented in Table 1. It was found out that the soil contained a high amount of fine-grained fractions and traces of organic matter. The percentage of sand in the range of 2-0.425 mm is 27.5% whereas 2.34% 70.16% is classified as silt and clays sized particles. Concurrent with the sampling location near the sea (i.e., Pengorak Beach) visual observation of the riverbank soil sample revealed that the soil also have traces of seashells. Under the INWQS, the water was classified as Class 5 or heavily contaminated. Based on this classification, the water in Pengorak River is not suitable for direct consumption and hence some treatment would be required to improve the water quality to Class 1 (i.e., drinkable level).

Water samples tested contained high concentration of suspended solids believed to be bauxite particles from the mining activity and surface run-offs. The high SS also contribute to high turbidity and color. When left

Table 1: Geotechnical properties and mean initial water quality parameters

Geotechnical properties	Values
Specific gravity (Gs)	2.65
Initial water content, wi (%)	5.73
Organic content (%)	0.41
Particle size distribution	
Percentage passing (<2 mm)	97.23
Mean initial water quality parameters*	
BOD (mg/L)	6.55
COD (mg/L)	124
DO (mg/L)	5.72
AN (mg/L)	1.43
SS (mg/L)	579
pH	7.37
TDS (mg/L)	1897
Turbidity (NTU)	1000
Color (PtCo)	4334 (Reddish orange)

*INWQS-Class 1 => 92.7 (no treatment required); Class 2 = 76.5-92.7 (conventional treatment required), Class 3 = 51.9-76.5 (extensive treatment required); Class 4 = 31.0-51.9 (suitable for irrigation only); Class 5 =< 31.0 (heavily contaminated not suitable for daily use)

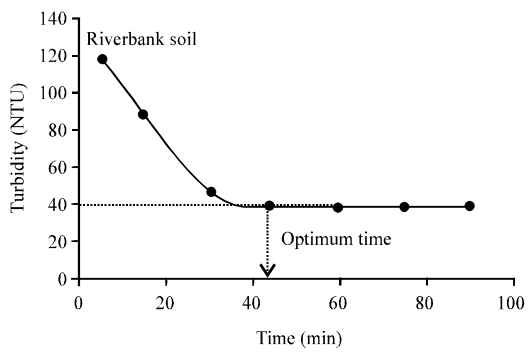

Fig. 3: Changes in turbidity with agitation time

untreated the surrounding environment is turned red (i.e., riverbank, beach, ocean in Pengorak). Concurrent with the type of bauxite being mined (i.e., laterite bauxite ore) it was also noted that the water sample also consisted of concentrations of aluminium and ferum. Except for aluminium and ferum, chemical analyses of the water samples showed no traces of other heavy metals present. aluminium and ferum detected were found to be 0.53 and 1.62 mg/L, respectively. This values exceeded the permissible limits. Figure 3 shows the changes in turbidity with elapsed time for the riverbank soil. Adsorption test results indicated that the turbidity of the water decreased with increasing agitation time. A period of approximately 45 min was found to be sufficient for the turbidity readings to be equilibrated. The filtration test results are presented in Table 2. After filtration test, it was noted that most of the water quality parameters considered in this study (i.e., COD, BOD, DO, AN, SS, turbidity and color) were significantly improved. Similarly, traces of aluminium and ferum were completely removed. Reduction in turbidity, color and SS were achieved by removal of bauxite particles (i.e., 2-0.425 mm) in the water by filtration

Table 2: Improvements in water quality parameters

Mean initial water quality parameters*	Values
BOD (mg/L)	0.80
COD (mg/L)	11
DO (mg/L)	7.39
AN (mg/L)	0.04
SS (mg/L)	3
pH	8.36
TDS (mg/L)	8330
Turbidity (NTU)	181.1
Color (PtCo)	17 (Clear)

*INWQS-Class 1 => 92.7 (no treatment required); Class 2 = 76.5-92.7 (conventional treatment required), Class 3 = 51.9-76.5 (extensive treatment required); Class 4 = 31.0-51.9 (suitable for irrigation only); Class 5 =< 31.0 (heavily contaminated not suitable for daily use)

of sand size particles in the riverbank soil (Peavy *et al*., 1985; Kau and Lawler, 1995; Tyagi *et al*., 2013). Furthermore, the removal of both aluminium and ferum concentrations were achieved by adsorption mechanism of the fine grained particles (i.e., <0.425 mm) of the riverbank soil. Based on INWQS classification, the bauxite contaminated water improved from Class 5-1 (drinkable level).

Although, the main idea was to divert the flow of Pengorak River into RBF prior to being discharge into the sea, the treatment efficiency of the riverbank soil in this study performed better than anticipated. In other words, the water quality improved significantly to drinkable standards and complied with Class 1 INWQS.

Surprisingly, despite improvements in the water quality parameters, two distinct increased was noted on pH and TDS values. The increase in these values may be attributed due to the location of the Pengorak River's riverbank soil (i.e., near the sea). The presence of calcareous seashells (i.e., calcium carbonate, $CaCO_3$) in the riverbank soil is expected to release carbonates and thus shifted the pH of filtered water from 7.37 to slightly alkaline (pH = 8.36) (Resh, 2015; Ituen, 2015). The increase in pH to slightly alkaline condition however is favorable for the adsorption of aluminium and ferum concentrations. The adsorption capacity of riverbank may be reduced if the pH was to be acidic which further allowed mobility of aluminium and ferum ions, avoiding fixation to the riverbank soil (Peng *et al*., 2009). Additionally, the present of organic content (Table 1) assisted the heavy metal uptake capacity of the riverbank (Peng *et al*., 2009). On the other hand, the presence of dissolved mineral salts in the riverbank soil is manifested on the increase in the TDS value from 1897-8330 mg/L after filtration. Soluble salts in soils are highly mobile and transported by water through mass flow and dispersion from the oceon during high tide (Tanji, 2002). During low tide however, the sea water evaporated and dissolved salts deposited within the riverbank (Tanji, 2002; Urish and McKenna, 2004). Explaining the reason for the sudden spike in the TDS value after filtration. The color of the filtered water was clear, however was slightly salty due to increase in the TDS value. Both increase in the pH and TDS values however did not affect the overall water quality of the filtered water.

According to the Malaysian National Drinking Water Quality Standards (NDWQS) the raw water quality of bauxite contaminated water is unacceptable for drinking purpose. The test results in this study is in good agreement with the findings reported by Abdullah due to this fact, the Ministry of Health circulated a stern warning to locals not to use untreated water for consumption. In comparison the filtered water complied within range of the acceptable value recommended for raw water in NDWQS. Furthermore, the filtered water obtained in this study was found to acceptable for drinking purpose criteria and safe to be used.

CONCLUSION

From the present studies, riverbank soil from Pengorak River may be considered for the construction of a RBF in treating bauxite contaminated water in the area. Although, the main intention is to minimize environmental impact of bauxite mining on the Pengorak Beach, the riverbank material was found to be very effective in improving the water quality parameters considered in this study. The results of this study revealed some latent facts about the usefulness and effectiveness of riverbank soil from the bank of Pengorak River. Based on the findings of this study, the following of conclusion are drawn.

Improvement in the water quality standards were accomplished. According to Malaysian INWQS and DOE-WQI from Class 5 and 4, respectively to Class 1 in treating bauxite contaminated water taken from Sungai Pengorak. Similarly, the treated water complied to NDWQS as is considered drinkable and safe to be used.

Only two heavy metals were detected in the raw water (i.e., Aluminium and Ferum). These two elements are common for laterite based bauxite. Traces of both aluminium and ferum were completely removed from the water after filtration test using riverbank soil.

The riverbank soil used in this study was ineffective in removing Total Dissolved Solids (TDS). TDS increased after filtration treatment due to significant amount of salt content present within the riverbank soil from salt water intrusion during high tide. Thus, the water although is drinkable but it is slightly salty or brackish.

The pH of the treated water increased slightly due to the presence of clustered calcareous seashells (i.e., calcium carbonate, $CaCO_3$) deposited within the riverbank soil.

REFERENCES

Abdel-Lah, A.K., 2013. Riverbank filtration for water supply in semi arid environment. J. Eng. Sci., 41: 840-850.

Abdullah, N.H., N. Mohamed, L.H. Sulaiman, T.A. Zakaria and D.A. Rahim, 2016. Potential health impacts of bauxite mining in Kuantan. Malaysian J. Med. Sci., 23: 1-8.

Aziz, H.A., S. Alias, F. Assari and M.N. Adlan, 2007. The use of alum, ferric chloride and ferrous sulphate as coagulants in removing suspended solids, colour and COD from semi-aerobic landfill leachate at controlled pH. Waste Manage. Res., 25: 556-565.

Golev, A., M. Scott, P.D. Erskine, S.H. Ali and G.R. Ballantyne, 2014. Rare earths supply chains: Current status, constraints and opportunities. Resour. Policy, 41: 52-59.

Ituen, E.U., 2015. Mechanical and chemical properties of selected mullusc shells in Nigeria. Int. J. Agric. Policy Res., 3: 53-59.

Jaramillo, M., 2012. Riverbank filtration: An efficient and economical drinking-water treatment technology. Dyna, 79: 148-157.

Kau, S.M. and D.F. Lawler, 1995. Dynamics of deep-bed filtration: Velocity, depth and media. J. Environ. Eng., 121: 850-859.

Kuehn, W. and U. Mueller, 2000. Riverbank filtration: An overview. Am. Water Works Assoc. J., 92: 60-69.

Paschoa, A.S., 1998. Potential environmental and regulatory implications of Naturally Occurring Radioactive Materials (NORM). Appl. Radiat. Isot., 49: 189-196.

Patterson, S.H., H.F. Kurtz, J.C. Olson and C.L. Neeley, 1986. World bauxite resources. United States Geological Survey, Reston, Virginia. https://pubs.er.usgs.gov/publication/pp1076B.

Peavy, H., S. Rowe and D.R. Tchobanoglous, 1985. Environmental Engineering. McGraw-Hill, New York, USA.,.

Peng, J.F., Y.H. Song, P. Yuan, X.Y. Cui and G.L. Qiu, 2009. The remediation of heavy metals contaminated sediment. J. Hazard. Mater., 161: 633-640.

Rashid, A., N. Aziemah, A.N. Rahim, I. Abustan and R.F. Munawar *et al*., 2015a. The potential and benefits of artificial barrier application at RBF. Appl. Mech. Mater., 802: 611-616.

Rashid, N.A.A., M.H. Roslan, N.A. Rahim, I. Abustan and M.N. Adlan, 2015b. Artificial barrier for riverbank filtration as improvement of soil permeability and water quality. J. Technol., 74: 51-58.

Resh, H.M., 2015. Hydroponics for the Home Grower. CRC Press, New York, USA.,.

Schijven, J., P. Berger and I. Miettinen, 2002. Removal of Pathogens, Surrogates, Indicators and Toxins using Riverbank Filtration. In: Riverbank Filtration, Chittaranjan, R., G. Melin and R.B. Linsky (Eds.). Springer, Amsterdam, Netherlands, ISBN:978-1-4020-1133-7, pp: 73-116.

Tanji, K.K., 2002. Salinity in the Soil Environment. In: Salinity: Environment-Plants-Molecules, Lauchli, A. and U. Luttge (Eds.). Springer, Netherlands, Amsterdam, ISBN:978-1-4020-0492-6, pp: 21-51.

Tyagi, S., R. Dobhal, P.C. Kimothi, L.K. Adlakha and P. Singh *et al*., 2013. Studies of river water quality using riverbank filtration in Uttarakhand, India. Water Qual. Exposure Health, 5: 139-148.

Urish, D.W. and M.T.E. Kenna, 2004. Tidal effects on ground water discharge through a Sandy Marine Beach. Ground Water, 42: 971-982.

Valeton, I., 1972. Developments in Soil Science 1: Bauxites. Elsevier, Amsterdam, Netherlands,.

Zhu, K., E.D.M. Gamal, A.K. Moawad and D. Bromley, 2004. Physical and chemical processes for removing suspended solids and phosphorus from liquid swine manure. Environ. Technol., 25: 1177-1187.