Journal of Cleaner Production 180 (2018) 716–727

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Life cycle assessment of defluoridation of water using laterite soil based adsorbents

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A R T I C L E I N F O

Article history:
Received 10 April 2017
Received in revised form
18 January 2018
Accepted 21 January 2018
Available online 6 February 2018

Keywords:
Fluoride
Adsorption
Surface modified laterite soil
Life cycle assessment
Groundwater

A B S T R A C T

The present study deals with the life cycle assessment (LCA) of defluoridation of water using thermally treated laterite (TTL), acid treated laterite (ATL) and acid-base treated laterite (ABTL). The scope of LCA study consists of cradle to grave approach (i.e., from the acquisition of raw materials to the management of spent adsorbent). Environmental impacts associated with the defluoridation process are interpreted with the help of CML 2001 and TRACI methods using GaBi 6.0 software. All calculations are based on the amount of adsorbent required to reduce fluoride concentration from 10 mg/L to 1.5 mg/L of 720 L water. The results from life cycle impact assessment reveal that the overall impacts are highest for TTL followed by ABTL and ATL. The fluoride adsorption capacity of adsorbents is found as the key factor influencing environmental impacts. Further, through sensitivity analysis, loading capacity of the vehicle and the distance between the mining and the processing site are found to play important role in environmental degradation, which can be reduced by selecting a vehicle with lower loading capacity due to its higher fuel economy.

1. Introduction

Groundwater contamination with various types of organic and inorganic pollutants has posed a serious threat on human health around the world. Prolonged consumption of water containing an excess amount of fluoride may lead to many types of diseases like bone and skeletal fluorosis and mottling of teeth (Jagtap et al., 2012). The maximum permissible limit for fluoride in drinking water is 1.5 mg/L as per the guidelines of World Health Organization (WHO, 2011).

The presence of fluoride in groundwater is reported in many countries like India, China, Mexico, Argentina, Pakistan, Ethiopia, Egypt, Saudi Arabia, Niger, USA etc. (Jadhav et al., 2015). China and India are the two most affected countries with nearly 35 and 26 million people respectively at fluoride risk (Jadhav et al., 2015). Many fluoride remediation techniques based on ion exchange, reverse osmosis, chemical reduction, electrodialysis, distillation, biological processes, and adsorption have been reported by many researchers (Jagtap et al., 2012). Among these techniques, adsorption has gained most interest due to its low initial cost, low energy requirement, simplicity of design and possibility to reuse the spent adsorbent via regeneration. Further, most of the adsorbents reported for the remediation of high fluoride-containing water are based on aluminum and iron due to their high affinity towards it (Jagtap et al., 2012).

Natural clays and soils show good capability for scavenging many types of pollutants from water including fluoride (Vinati et al., 2015). Various types of clays and natural geological materials like laterite soil (Sarkar et al., 2006), mechanochemically activated kaolinites (Meenakshi et al., 2008), lanthanum modified bentonite clay (Kamble et al., 2009) have been studied by different researchers for the removal of fluoride from water. Surface modification of adsorbents has also attracted considerable attention in order to increase the adsorption capacity and selectivity of the adsorbents (Maiti et al., 2011). Based on the above background, for the present study, locally available laterite soil is chosen as the raw material for adsorption of fluoride as it possesses a high amount of iron and aluminum. Further, in order to improve the adsorption capacity of raw laterite soil, its surface is modified by three different types of treatments viz. thermal treatment, acid treatment, and acid-base treatment. The adsorption capacities of these surface-modified adsorbents have been studied for removal of fluoride and reported elsewhere (Rathore et al., 2016).

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https://doi.org/10.1016/j.jclepro.2018.01.176
0959-6526/

Surface modification increases the cost of the adsorption process and produces many environmental consequences. Thus, to get a suitable adsorbent for sustainable utilization, the life cycle analysis of the adsorbent is important, which not only considers the economic aspect but also includes the system thinking and concept of sustainability (Montalembert et al., 1992). Recently, in 2015, the LCA of activated alumina, aluminum oxide amended wood char, bone char, and alum based adsorbents, which are relatively costlier than laterite soil based adsorbent for fluoride removal has been reported by Yami et al. (2015). The study of LCA reported by Yami et al. (2015) was based on adsorbents having different origins and raw materials with respect to the present study. Moreover, in the study by Yami et al. (2015), only normalized impacts are reported and hence it is difficult to compare their environmental impacts with those of the present adsorbents.

The aim of LCA in the present paper is to evaluate impacts that arise due to various processes including mining of the raw material, transportation, physical and chemical processing and finally management of the spent adsorbent by solidification in the form of clay bricks. The objective of this study is to provide a better understanding of environmental impacts associated with fluoride adsorbents through the quantification and comparison of impacts. Moreover, the present manuscript can also help in understanding the intensity of impacts of the most important factors under different scenario through sensitivity analysis and selecting the most suitable option to lower the impacts of the overall process.

2. Method

2.1. Goal and scope of study

The goal of present study is to perform LCA and compare the environmental impacts of three types of adsorbents prepared from a locally/easily available natural material. The raw material for remediation of fluoride containing water was also selected such that it is available easily in many parts of India and globally. The LCA of the materials was performed as per the protocol of the International Organization for Standardization (ISO 14040:2006, ISO 14044:2006), which consists of four phases: (1) Defining the goal and scope of problem, (2) Life cycle inventory analysis, (3) Life cycle impact assessment, and (4) Interpretation of results (ISO 14040:2006).

The present study addresses the problem of groundwater contaminated with an excess quantity of fluoride and its treatment with the help of soil based adsorbent. Soil, being a natural and very low-cost raw material, makes it economically feasible and safe for the environment. The basis of all the calculations is defined as the amount of adsorbent required to reduce the fluoride concentration of 720 L of water from 10 mg/L to 1.5 mg/L. Selection of 720 L water as a basis is based on the idea of developing a water filtration unit containing the present adsorbent, which can successfully work for 60 days to meet the drinking water requirement of a family with 4 members assuming 3 L of drinking water consumption per capita per day.

Patel et al. (2015) conducted an extensive investigation on the quality of groundwater in Ambagarh Chouki block, Rajnandgaon district, Chhattisgarh, India, by taking the samples from around 146 sites, including tube wells of Public Health Engineering Department (PHED), Government of Chhattisgarh, India and dug wells in 22 villages. The concentration of fluoride in the groundwater in that area is reported between 3.7 mg/L to 27 mg/L along with other impurities including arsenic, with an average fluoride concentration of ~10 mg/L. There are many other states in India (e.g., Andhra Pradesh, Gujarat, Uttar Pradesh, Tamil Nadu, Madhya Pradesh etc.) where the concentration of this contaminant is also observed above permissible limit (Jagtap et al., 2012). Due to this fact and considering the scenario, the initial concentration of fluoride in the water to be treated has been taken as 10 mg/L for the present study.

The scope of the present study includes all the stages starting from the mining/collection of raw laterite soil to final disposal in the form of clay bricks. The usage phase is excluded from the study and it is assumed that the total waste emissions associated with this stage are negligible. The life cycle diagram of the adsorbent is given in Fig. 1.

Based on the above-mentioned diagram it is important to clearly define the system boundaries of the process. The system boundaries for the LCA of presently considered adsorbents are presented through Fig. 2 (a) to (c).

2.2. Preparation of adsorbents

2.2.1. Preparation of thermal treated laterite soil (TTL)

For preparing TTL, raw laterite soil was crushed in a jaw crusher so as to make particles of proper size (1–1.7 mm diameter particle size) and then it was thoroughly washed several times with tap water and subsequently with distilled water in order to remove all the dust, clay and other organic matters present on the surface of it. Then the laterite soil was heated in a hot air oven at 105 °C for 6 h. This material was assigned as thermally treated laterite soil.

2.2.2. Preparation of acid treated laterite soil (ATL)

For preparing ATL, 50 g thermally treated laterite soil was added in an excess quantity of 2N HCl (200 ml) and the solution was heated at 70 °C for 3 h with thorough agitation on a magnetic

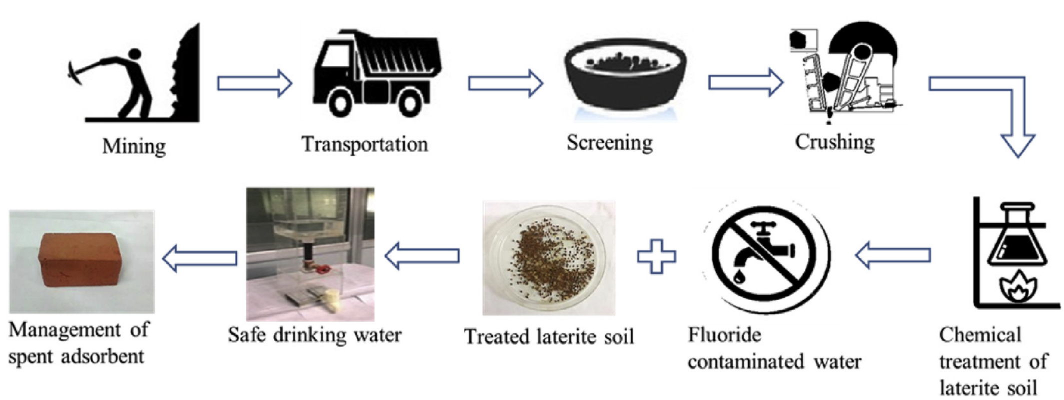

Fig. 1. Life cycle diagram of adsorbent.