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Ensuring water security by utilizing roof-harvested rainwater and lake water treated with a low-cost integrated adsorption-filtration system

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Abstract

Drinking water is supplied through a centralized water supply system and may not be accessed by communities in rural areas of Malaysia. This study investigated the performance of a low-cost, self-prepared combined activated carbon and sand filtration (CACSF) system for roof-harvested rainwater and lake water for potable use. Activated carbon was self-prepared using locally sourced coconut shell and was activated using commonly available salt rather than a high-tech procedure that requires a chemical reagent. The filtration chamber was comprised of local, readily available sand. The experiments were conducted with varying antecedent dry intervals (ADIs) of up to 15 d and lake water with varying initial chemical oxygen demand (COD) concentration. The CACSF system managed to produce effluents complying with the drinking water standards for the parameters pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), COD, total suspended solids (TSS), and ammonia nitrogen (NH_3-N). The CACSF system successfully decreased the population of *Escherichia coli* (*E. coli*) in the influents to less than 30 CFU/mL. Samples with a higher population of *E. coli* (that is, greater than 30 CFU/mL) did not show 100% removal. The system also showed high potential as an alternative for treated drinking water for roof-harvested rainwater and class II lake water.

Keywords: Low-cost activated carbon; Integrated adsorption-sand filtration; Roof-harvested rainwater; Lake water; Water security

1. Introduction

Water security is defined as reliable and continuous access to safe drinking water for health, livelihood, and development (Grey and Sadoff, 2007). In order to ensure water security, there must be access to safe and sufficient drinking water at an affordable cost to meet basic needs, which include sanitation and hygiene. The United Nations has estimated that 1.2 billion people do not drink safe water and at least 746 million people still do not have access to safe drinking water (World Bank, 2014).

The most common sources of water used for drinking water supply and irrigation are surface water and ground water. Between the two only a small amount is accessible to humans, since most of the surface water is locked in glaciers, snow caps, and ice (Gleick and Palaniappan, 2010). The ecosystem is experiencing increasing pressure due to anthropogenic activities, such as urbanization, agriculture, industry, and infrastructure development. Climate change and population growth have also strongly impacted the ecosystem (Sukereman et al., 2013). Since the last century, the use of water has increased by more than two times relative to population growth. By 2025, water withdrawal is predicted to increase by 50% in developing countries and 18% in developed countries. As such, it is predicted that almost 800 million people might not have access to treated water and face absolute water scarcity. It is further predicted that seven billion people from 60 countries will face water crisis in the year 2050 (WWDR, 2003) and

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feeding a population of nine billion people in 2050 would require 50% more water than the amount currently used (World Bank, 2014).

Malaysia, being blessed with an annual rainfall of 2900 mm, has faced a series of water crises over the last three decades (WWDR, 2003). Although the majority of the Malaysian population has access to the public water supply system, particularly in the urban areas, the mismanagement of water resources has exacerbated the water crisis (Chan, 2012). This crisis will be aggravated by increasing population, as Malaysia is expected to have a population of 43 million people in 2050 and the consumptive water demand is also expected to rise to 18.2 billion cubic meters (MNREM, 2012). To mitigate the future challenges of rapid economic development and increasing population, the Malaysian water-related authorities aim at securing water resources in order to ensure that a sufficient amount of water is available to meet the demands of both human society and ecosystems. The water security action plan entails the reduction of two major elements: consumption and non-revenue water (NRW) (World Bank, 2014). The plan is to reduce per capita consumption in urban areas from 230 L per capita per day (LPD) in 2010 to 150 LPD in 2050. The principles of integrated water resources management (IWRM) have been incorporated in the five-year development plan since the Eighth Malaysia Plan. One of the alternatives for water resources in the natural water policy is the utilization of rainwater.

Tropical regions such as Malaysia receive rainfall throughout the year and this makes the idea of utilizing rainwater as a resource an attractive option. The conventional water supply network is considered economically unfeasible, particularly in areas with limited access to the public water supply system. The current treatment system relies heavily on surface water, which is regarded as a water resource for treated drinking water. However, uncontrolled anthropogenic activities have degraded the quality of surface water and have caused prolonged drought, which in turn adds stress on production demand. As such, rainwater is considered an attractive option in the effort to meet water demand since it usually does not contain high levels of contaminants and thus can be easily treated on-site (Meera and Ahammed, 2006; Che-Ani et al., 2009). Preliminary risk analysis suggests that rainwater is of good quality in general and contains only low levels of pathogens (Dillaha and Zolan, 1985). Although groundwater could be an attractive source of water, it is not seen as a popular option in Malaysia due to the limited quantity and below-par quality, except in the northeastern region.

Theoretically, rainwater is relatively free from impurities but becomes contaminated by pollutants in the atmosphere during precipitation. In general, the presence and the concentrations of organic, inorganic, physical, and biological impurities depend on several factors, such as roof characteristics, meteorological factors, location of the roof, hydrological aspects, chemical properties of the substance, and storage material (Meera and Ahammed, 2006; Despins et al., 2009). Furthermore, the quality of rainwater might deteriorate during harvesting and storage due to wind-blown dirt, leaves, fecal droppings, and contaminants present in the catchment area. The most common impurities (or physico-chemical qualities) investigated in harvested rainwater are microbes (heterotrophic plate count and coliform), organic content (carbon and nitrogen), heavy metal (Hg, Pb, Cu, Fe, Mn, Zn, Cu, and Ni) dust, fine particles (turbidity and solids), and ions (Ca, Mg, Na, K, nitrates, and sulfates). A few studies have reported that harvested rainwater often does not meet the microbiological drinking water quality standard since most of the contaminants are fecal coliforms (*Escherichia coli*, *E. coli*) from animal origin (Yaziz et al., 1989; Handia et al., 2003; Vialle et al., 2011).

It has been determined that roof material has a significant effect on the quality of rainwater; rainwater of the highest quality is harvested using steel roofs, followed by roofs of asphalt shingles, galvanized iron, and finally concrete tile roofs (Yaziz et al., 1989; Despins et al., 2009). The location where rainwater is harvested is also important in determining the quality of water collected, in that the water collected in rural catchment areas is often of higher quality compared to that collected close to industrial areas (Despins et al., 2009).

The presence of heavy metals in rainwater is often given particular attention due to their toxicity; these metals cannot be chemically transformed if their concentrations exceed the threshold limit and they cannot be easily removed without complex treatment (Davis et al., 2001). In general, the quality of rainwater in Malaysia is good because the amounts of Hg, Pb, Cu, Fe, Mn, Zn, Cu, and Ni are below the permissible limits (Seong and Sapari, 2003). The concentrations of Pb and Hg are higher in rainwater collected between 1990 and 1997, but the amount has decreased to an insignificant level since the complete ban of leaded petrol in 1997. The levels of Na, Mg, F, Cl, NO_3^-, and SO_4^{2-} were found to meet the drinking water standard (Seong and Sapari, 2003).

Several studies have been conducted to determine the quality of rainwater and the results have shown that rainwater harvested far from highways and industrial areas does not have high levels of contamination and atmospheric pollutants (Yaziz et al., 1989; Thomas and Greene, 1993; Appan, 1997; Ayers et al., 2002; Gould, 1999). The most common collection mechanism, particularly for domestic purposes, is a roof. In Malaysia, it is recommended that the first 3 mm of rainfall be the first flush since this has been found to be sufficient to ensure high-quality rainwater (Yaziz et al., 1989). However, the antecedent dry intervals (ADIs) are also an important factor and the depth of the first flush should be increased for rainwater harvested after an ADI of 15 d (Shaheed and Wan Mohtar, 2014).

The parameter of utmost concern in harvested rainwater is the presence of microbial pathogens, particularly the fecal bacteria present in animal droppings. The collected rainwater could pose a risk to human health if it is consumed untreated (Ahmed et al., 2008, 2011). However, the focus of this study was not the utilization of untreated harvested rainwater. Instead, this study focused on providing a low-cost alternative of a locally produced treatment system that is easy to maintain for potable use.