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Environmental footprints of brick kiln bottom ashes: Geostatistical approach for assessment of metal toxicity

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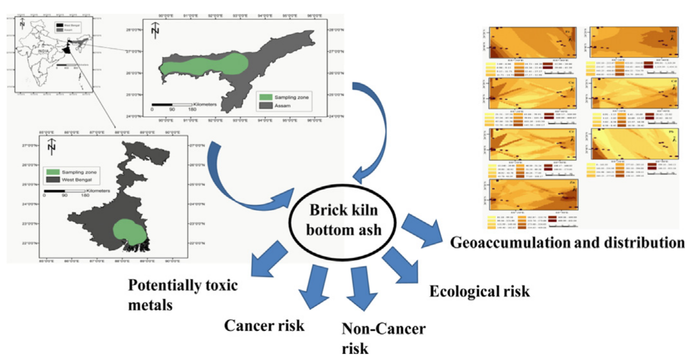
HIGHLIGHTS

- Critical characterization of brick kiln bottom ashes from two states of India
- High occurrence of toxic metals in brick kiln bottom ashes may lead to health risk.
- High ecological risk potentials were detected in brick kiln ashes.
- Geostatistics predicted wide spatial distribution of toxic elements from ash dumps.

GRAPHICAL ABSTRACT



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ABSTRACT

Coal fired brick kiln factories generate significant of brick kiln bottom ash (BKBA) that contaminate soil and water environments of areas near the dumping sites through leaching of toxic metals (Pb, Cr, Cd, Zn, Mn, and Cu). However, characteristics and environmental effects of BKBAs are yet unknown. We collected BKBA samples from 32 strategic locations of two rapidly developing States (West Bengal and Assam) of India. Scanning electron microscope images indicated spherical and granular structures of BKBAs produced in West Bengal (WBKBA) and Assam (ABKBA) respectively; while energy dispersive spectroscopy and analytical assessments confirmed substantial occurrence of total organic C and nutrient elements (N, P, K, Ca, Mg, and S) in both the BKBAs. FTIR analysis revealed greater predominance of organic matter in ABKBAs than WBKBAs. Occurrence of toxic metals (Cd, Cr, Pb, Zn, Mn, and Cu) was higher in ABKBAs than in WBKBAs; while organic and residual fractions of metals were highly predominant in most of the BKBAs. Principal component analysis showed that metal contents and pH were the major distinguishing characteristics of the BKBAs generated in the two different environmental locations. Human health risk associated with BKBAs generated in Assam is of significant concern. Finally, geostatistical tools enabled to predict the spatial distribution patterns of toxic metals contributed by the BKBAs in Assam and West Bengal respectively. Assessment of contamination index, geo-accumulation index, and ecological risk index revealed some BKBAs to be more toxic than others.

1. Introduction

The construction sector in India recorded a spectacular growth of >12% over the last decade. Correspondingly, the rate of brick production

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has gained noticeable momentum. India accounts for over 10% of the global brick production, and is the second largest producer of bricks after China; which leads to consumption of about 35 million tons of coal per year (Lalchandani and Maithel, 2013). However, the use of environmentally vulnerable fixed chimney bull's trench kiln is more abundant than eco-friendly firing technologies (Hoffman kiln, Zig-zag kiln, and Vertical shaft kiln) (Hossain and Abdullah, 2012; Maithel, 2013). Inefficient combustion and substantial loss of thermal energy in brick kilns results in a substantial use of energy, emission of suspended particulate matter (SPM), and generation of toxic bottom ashes (BKBA) (Maithel, 2013).

Recently, quite a comprehensive amount of work has been done with recycled concrete aggregate (RCA), crushed bricks (CD), reclaimed asphalt pavement (RAP), waste excavation rock (WR), fine recycled glass (FRG), and medium recycled glass (MRG) as eco-friendly and effective technology alternatives of bricks (Arulrajah et al., 2014). The shear strength and physical properties of these materials are sufficiently good to replace bricks for building construction; WR, RCA, and CB are specifically suitable for pavement constructions. Moreover, the stability of these materials has been significantly improved by developing efficient binders (geopolymer precursors, cement kiln dust, and fly ash blends) (Arulrajah et al., 2016, 2017). However, the use of these advanced technologies in the Indian subcontinent has yet to gain momentum.

In India, intensive use of brick kilns for firing and production of bricks occurs from September to March. A good amount of BKBA is generated during this period that are disposed on the land or used in construction of temporary road ways. The final burnt portions of the BKBAs are popular as filler materials for roads and embankments. Whereas, the partially combusted fractions are used as energy sources for household cooking in the villages thereby greatly pollutes the local air (Deka and Hoque, 2014). Despite a steady rise in BKBA accumulation, the issues related to their environmental impacts have been entirely ignored so far. Thus an authentic study on the characteristics and environmental impacts of BKBA is important for formulating sustainable management strategies.

Non-essential toxic metals are generally described as potential toxic elements (PTEs) in geochemical perspectives (Capra et al., 2015; Sahariah et al., 2015). Migration of such toxicants within the earth surface is largely governed by their sorption-desorption dynamics. As such, mobility pattern of metals in soil systems can be better understood through application of geostatistical methods (Bhuyan et al., 2015). Geostatistics explains the spatial distribution of elements on the basis of the theory of regionalized variability (Burgos et al., 2006). The technique uses spatial coordinates as reference and creates homogenous groups of samples that exhibit spatial autocorrelations; simply the concept of vicinity in sphere is used to formulate the likelihood for sample grouping. Kriging methods are the most popular tool among various estimation approaches (Strano, 2008). Kriging not only estimates non-sampled locations, but also generates probabilistic models of uncertainty of the undefined predicted values (Burgos et al., 2006). Such assessments are easily mapped, and the map reveals visual displays of spatial variability of target elements over the land surfaces (Goovaerts, 1997).

Various factors (nature of extractant, concentration, solid medium, and leachate pH) greatly control heavy metal leaching from coal ashes (Goswami et al., 2014). In addition, the occurrence of various chemical forms of metals influence their mobility pattern in natural ecosystems. In this context, sequential extraction techniques are useful to explain contamination potential of PTEs in soils. It is also necessary to assess the possible human health risk from such by products; high occurrences of metals may lead to carcinogenic risks or cause high dermal and respiratory distress in human beings. However, to the best of our knowledge, there is no report on quantitative health risk assessments related to BKBAs.

Overall, the knowledge about the characteristics, health-effects, ecological imprints of BKBAs is limited, and is this is of concern for rapidly growing urban settlements. Generally, sediment clays are excavated from the beds of the seasonal river, ponds, and lakes during dry season and eventually being used as basic raw material for bricks in the Indian sub-continent; while, coal is used as the burning agent in the kilns (Lalchandani and Maithel, 2013). This work was attempted to generate a comprehensive knowledge base about BKBAs, which in turn would likely to facilitate policy-decision making by environmental agencies. Hence, the prime objectives of this investigation were to a) characterize and enumerate pollution indices and human health risk potential of BKBAs generated in two rapidly developing states of India (West Bengal and Assam); and, b) to predict their impacts on the vast soil environment of the locality applying geo-statistical tools. Consequently, BKBAs from two neighboring Indian States (Assam and West Bengal) were studied. Assam and West Bengal are two rapidly developing states of Eastern India harboring a vast number of brick kilns along the banks of river of Brahmaputra and Ganges respectively. According to the census information, the decadal growth of urban population was 28% and 30% in Assam and West Bengal respectively during 2001–2011. BKBA samples were collected from 32 strategic locations of the two states on the basis of the demographic patterns and several physicochemical properties were assessed. We also computed several pollution hazard indices including human health risk assessments. Moreover, occurrence of potential toxic elements in various fractions was analyzed and their gross impact on soil quality was enumerated by the application of geostatistics tool.

2. Materials and methods

2.1. Sample collection and processing

The brick kiln bottom ash (BKBA) samples were collected from 20 sites in the state of West Bengal and 12 sites in Assam on the basis of brick kiln density. The samples were labeled as W1 to W20 and A1 to A12 for West Bengal and Assam respectively. The zones of sampling in both the States are presented in Fig. 1.

A simple random sampling technique was used for collecting composite and representative samples from the selected Brick-kiln sites. The area of each BKBA dump was estimated, proportionately represented on tracing papers, and uniformly divided into imaginary blocks of 10 m^2. Then, 10% (e.g. 10 out of 100) of blocks were selected with the help of the random numbers. The collected BKBA samples from each site were mechanically ground to powder, mixed properly to form a representative sample for each site. All parameters were analyzed taking three replicates.

2.2. Physico-chemical analysis of the BKBA samples

BKBA samples were analyzed for physico-chemical attributes like pH, electrical conductivity (EC), bulk density (BD), water holding capacity (WHC), cation exchange capacity (CEC), available S, Ca, N, P, and K, total organic C (TOC) following standard procedures (Page et al., 1982). Scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX) were applied to compare the structural and elemental properties of the BKBA samples. In addition, FTIR-spectroscopy was done to determine the abundance pattern of functional groups.

2.3. Sequential extraction of the potentially toxic elements (PTE)

BKBA samples were subjected to chemical fractionation to understand the nature of various fractions of the studied PTEs (Fe, Cr, Cu, Cd, Pb, and Zn). Total six fractions (water soluble, exchangeable, carbonate, oxide, organic matter and residual) of the PTEs were enumerated following the procedure standardized by Tessier et al. (1979). Standard solutions for all target metals were prepared from the stock solution (1000 mg L^{-1}, AR grade) in 1% (v/v) HNO_3 to calibrate the instrument (ICP-OES, Perkin Elmer, USA). Certified reference material (SRM 2710)