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Metal content variation in wastewater and biosludge from Bangkok's central wastewater treatment plants

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ABSTRACT

The objectives of this study were to determine the metal contents and their variations in influent, effluent and biosludge, and to evaluate the potential environmental impact of biosludge generated from the Bangkok, Thailand central wastewater treatment plants. The variation in influent metal content was site-specific and could be related to the economic activities of small-scale companies. An activated sludge process could remove some level of the metal content via a combination of biological and physicochemical processes. The variation in metal removal efficiencies strongly depended upon the influent wastewater characteristics and composition. Metal occurrence in biosludge was similar to the metals found in the influent. Iron was the most abundant while Cd had the lowest occurrence. A longer excess sludge operational condition and storage time may increase metal contents in biosludge due to the decomposition of biodegradable organic matter by microorganisms. According to the speciation results, the biosludge studied had a low mobility and availability index, except the RK plant biosludge. Most trace metals of interest were in the less mobile and bioavailable forms. The most mobile exchangeable and moderately mobile carbonate fractions of Cd, Mn, Ni and Zn were relatively low (5–30%). Biosludge from RK had a total Cu concentration higher than the limits, and to some extent exchangeable and carbonate fractions that were relatively high (~40%).

1. Introduction

Since the early 1970s, there has been a mounting concern over the diverse effects of metals on humans and on their environment [1]. Many metals and their compounds have been found to be toxic, and most are subject to biomagnification. The presence of metals in wastewater is one of the main causes of water and soil pollution [2,3]. The accumulation of these metals in wastewater depends upon several local factors. A study of metal composition in urban wastewater in Brazil conducted by Oliveira et al. [3] found metal composition to be both complex and highly varying, according to the diverse ongoing economical activities. It has been stated that metal input in wastewater treatment systems is so variable that even down to an hour-by-hour scale it remains unpredictable [2]. Major urban inputs of sewage wastewater include households, drainage water, businesses, atmospheric deposition, pipe sediment and traffic [4–6]. Moreover, metal concentration in wastewater can be affected by people's lifestyles and their awareness of the impacts on the environment. Because most wastewater treatment plants are initially designed to remove organic matter and nutrient load, most metals are likely to be retained in the system, if it is operating by the conventional activated sludge process [1,6]. Metal removal efficiency depends on the metal concentration, its speciation, the reactivity of the available biopolymers or biomass, and the composition of other wastewater components [2,3].

During the wastewater treatment process, biosludge is produced by about 1% of the wastewater treated [7]. Since metals present in the wastewater become concentrated in the wastewater sludge, disposal of metal-laden wastewater sludge represents a definite environmental hazard. Oliveira et al. [3] reported that metal levels also correspond highly to wastewater metal concentrations' variability. The metal composition of biosludge can be extremely variable due to the irregular inputs from urban and industrial sources, with a time dependence on the industrial activities, the weather and other factors [1,8]. Coefficients of variation for metals in biosludge from eight U.S. cities have been reported as: Cd, 27–160%; Zn, 26–58%; Cu, 18–167%; Ni, 12–144% and Pb, 9–56% [8].

The objectives of this study were to determine the metal contents and their variation in influent, effluent and biosludge, to investigate the removal efficiency for selected trace metals at biological wastewater treatment plants in Bangkok and to evaluate the potential environmental impact of generated biosludge.

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2. Experiments

2.1. Description of Bangkok's central wastewater treatment systems

The six large-scale wastewater treatment plants under the auspices of the Department of Drainage and Sewerage (DDS), Bangkok Metropolitan Administration (BMA), cover a service area of 191.7 km^2 with a total sewage capacity of 992,000 m^3/day [9]. Table 1 provides the details of the five examined central wastewater treatment plants. Household domestic sources account for 75% of the wastewater generated while the remaining 25% comes from industrial and commercial sources. Domestic wastewater is mostly discharged into a public and combined drainage system without treatment. In the wet season, the drainage system also collects storm water [10]. Activated sludge process (AS) is the main treatment system applied in all BMA central wastewater treatment plants.

Wastewater excess sludge is collected from each central wastewater treatment plant and delivered to the sludge treatment center located at Nongkhaem. This center's anaerobic digestion system has a full capacity of 120 tons dry sludge/day [9].

According to the Bangkok Sewerage System Master Plan, the total sewage treatment capacity will be increased to about 80% of the generated wastewater by the year 2012. Further proposed are the safe management and disposal of biosludge, in the interest of a better environment [10].

2.2. Sample collection

Both influent and effluent samples were collected from 5 central wastewater treatment plants, by name Rattanakosin, Si Phraya, Chongnonsi, Chatuchak and Nongkhaem. The samples were collected by a grab sampling every other month from August, 2007 to February, 2008. Each wastewater sample comprised 2 subsamples, the dissolved metal sample and the total trace metal sample. At times of collection, wastewater temperature, pH, conductivity and salinity were measured. Puradisc 25 NYL disposable filters, 0.45 um, were used to obtain the dissolved metals fraction present in water samples, while unfiltered samples were collected for total trace metal analysis. All samples were acidified with concentrated HNO_3 (AR grade; Merck, Germany) to pH < 2 in polyethylene bottles which had been pre-cleaned with nitric acid and deionized water by following the standard methods for the examination of water and wastewater [11]. Samples were kept at 4 °C until performance of sample preparation and analyses.

A grab sampling of biosludge was conducted from drying beds at all 5 plants at the same time as the wastewater samples collection. Biosludge samples were collected from several spots on drying beds and combined to one representative bed sample; these were saved in clean plastic bags. Biosludge samples were kept in an ice box during transportation to the laboratory.

Upon consideration of monthly precipitation averages [12], influent, effluent and biosludge samples collected in August and October of 2007 were selected as representative samples of the wet season. By the same criteria, samples collected in December, 2007 and February, 2008 represented the dry season.

Table 1
Descriptions of researched Bangkok central wastewater treatment plants.

Treatment plant	Serving area (km^2)	Serving population	Loading capacity (m^3/d)	Loading rate (m^3/d)	Wastewater treatment process
Rattanakosin (RK)	4.1	76,000	40,000	28,058	Two stage AS
Si Phraya (SP)	2.7	120,000	30,000	21,482	Contact stabilization AS
Chongnonsi (CN)	28.5	580,000	200,000	128,070	Cyclic AS
Chatuchak (JJ)	33.4	432,500	150,000	154,953	Conventional AS
Nongkhaem (NK)	44.0	418,000	157,000	117,063	Vertical loop reactor AS

2.3. Sample preparation and analysis

Both influent and effluent samples were analyzed for both soluble and total trace metal concentrations. According to the standard methods for the examination of water and wastewater [11], a well mix of filtrated sample was analyzed directly for its dissolved metal concentration. For total metal concentration, 10 mL of well mixed, acid-preserved sample was pipetted into a pre-cleaned polypropylene tube. After that, 0.5 mL conc. HNO_3 (AR grade; Merck, Germany) was added and the samples digested vigorously in a hood at temperatures reaching 105 °C. All samples were digested for a minimum of 2 h and diluted back to the original 10 mL volume with metal-free water. Finally water samples were centrifuged and the clear portion decanted into another pre-cleaned tube and stored at 4 °C until analysis. Cd, Cr, Mo, Ni, Pb and Zn concentrations were determined by inductively coupled plasma mass spectroscopy (Agilent 7500ce, USA). Cu, Fe and Mn concentrations were analyzed by flame atomic absorption spectroscopy (Perkin Elmer 5100 PC, USA).

As soon as biosludge samples were delivered to the laboratory, all samples were air-dried in thin layers and continuously turned over and mixed to avoid fungal development. After that the dried materials were ground with a mortar and a pestle and passed through a 0.2 mm sieve. The final biosludge samples were dried in an oven at 60 °C for 24 h and kept in a desiccator until analysis.

To determine total trace metal content, an aqua regia digestion was conducted [11,13,14]. Aqua regia extraction is commonly used to determine the total metal content in samples of sludge, soil and sediment. Three replicates of 0.4 g homogenized biosludge sample were weighed into polypropylene tubes and 1 mL of conc. HNO_3 (AR grade; Merck, Germany) and 3 mL of conc. HCl (AR grade; Merck, Germany) were added. Afterwards, the polypropylene tubes were kept at room temperature for 8 h and then heated at 70 °C in a block heater for an hour. After digestion the sample solutions were allowed to air-cool, then solutions were centrifuged at 4500 rpm for 10 min and transferred to new tubes and made up to 50 mL with deionized water.

The chemical forms of metals were determined by the five-step chemical extraction procedure proposed by Turek et al. [13] and Tessier et al. [15]. This method (Table 2) differentiates the metals into exchangeable, carbonates bound, Fe–Mn oxides bound, organically bound and residual fractions. The extraction was conducted in 50 mL polypropylene centrifuge tubes. Between each extraction step, the supernatant was removed with pipette tips after centrifugation at 4500 rpm for 30 min. The residue was washed with 8 mL of deionized water after centrifugation for 15 min; this supernatant was afterward discarded.

Total metal concentrations and chemical speciation of Cd, Cr, Cu, Fe, Mn, Mo, Ni, Pb and Zn were determined by inductively coupled plasma optical emission spectroscopy (Perkin Elmer Optical 5300 DV, USA).

The accuracy of the instrumental methods and analytical procedures was checked by using standard reference materials: SRM 1640 (trace elements in natural water) and SRM 2710 (Montana soil, highly elevated trace element concentrations) from the National Institute of Standards and Technology (Maryland, USA). All tests were carried out in triplicate and their mean values were considered as the final result. Deionized water used in preparing stock solutions and in each step of the leaching procedure was obtained from a Millipore Milli-Q system. All glassware and polypropylene tubes used for the experiments were previously rinsed with 10% HNO_3 (v/v) and immediately afterwards with deionized water. All reagents used in this study were analytical grade.