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Estimating emissions from open burning of municipal solid waste in municipalities of Nepal

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ABSTRACT

Open burning of municipal solid waste (MSW) is a poorly-characterized and frequently-underestimated source of air pollution in developing countries. This paper estimates the quantity of MSW that was burned in five erstwhile municipalities of the Kathmandu valley, Nepal. A household survey, a transect walk survey, an experiment to measure the fraction of waste that is combustible, a survey on fraction of population burning waste outside their houses, and a survey of the fraction of MSW burned at dump sites were performed in this study, whereas burning/oxidation efficiency, municipal populations, MSW generation rates, and emission factors were derived from the literature. The total mass of MSW burned during 2016 is estimated to be 7400 tons (i.e., 20 tons/day), which was of 3% of the total MSW generated in the valley municipalities that year. This exceeds Government estimates by a factor of three. Multiplying the burned MSW mass by emission factors, the air pollutant emissions are estimated as $PM_{2.5}$ 55 tons (OC 42 tons and EC 1.4 tons), PM_{10} 60 tons, BC 25 tons, CO_2 11,900 tons, CH_4 30 tons, SO_2 5.0 tons, NO_x 19.2 tons, CO 630 tons, NMVOC 112 tons, and NH_3 5.7 tons per year. Open burning of MSW can trigger health impacts such as acute and chronic respiratory disease, heart diseases, and allergic hypersensitivity, in addition to impacts on local climate. Improved waste-segregation practices at the source and waste-collection systems throughout the valley are needed to mitigate this pollution source and its effects.

1. Introduction

Solid waste management (SWM) has become a major concern, especially in urban areas of developing countries. Many municipalities are experiencing extreme environmental degradation as well as public health risks due to ill-timed waste management and unsanitary disposal practices (Alam et al., 2008; Nagpure et al., 2015). Recently, the open burning of solid waste was implicated as a major cause for soiling the Taj Mahal and impairing the health of Agra residents (Lal et al., 2016). In Nepal, population growth, rapid expansion of sprawling urban municipalities, increasing amounts of industrial and commercial activity, and rising consumption of packaged goods has resulted in severe air and water quality issues, poor sanitation, and the spread of diseases (Alam et al., 2008; Dangi, 2009; Pokhrel and Vivaraghavan, 2005).

At an elevation of 1400 m, the bowl-shaped Kathmandu valley lies at the foothills of the Himalayas and is surrounded by mountains and forests. The total urban area of Kathmandu valley is 96.68 km^2 (KVDA, 2017) and this area has the highest population density in Nepal. The valley contains five densely-inhabited urban centres which were previously designated as municipalities: Kathmandu Metropolitan City (KMC), Lalitpur Sub-Metropolitan City (LSMC), Bhaktapur, Kirtipur and Madhyapur Thimi. Around the time of study, the Government of Nepal designated 16 municipalities (dividing many of the earlier five into smaller areas) in the valley partly in response to the booming urban population (KVDA, 2017).

Fig. 1 contains a map of the five original municipalities referred to throughout this study and their location within Nepal. KMC is home to the nation's capital and is the most populated municipality in Nepal with an area of 49.45 km^2 (CBS, 2013) subdivided into 35 wards (KMC, 2014). LSMC was the country's third most populous municipality and is located in the south-central part of the valley, covering an area of 24.94 km^2 that was subdivided into 30 wards (LSMC, 2016). Bhaktapur is an ancient city in the eastern

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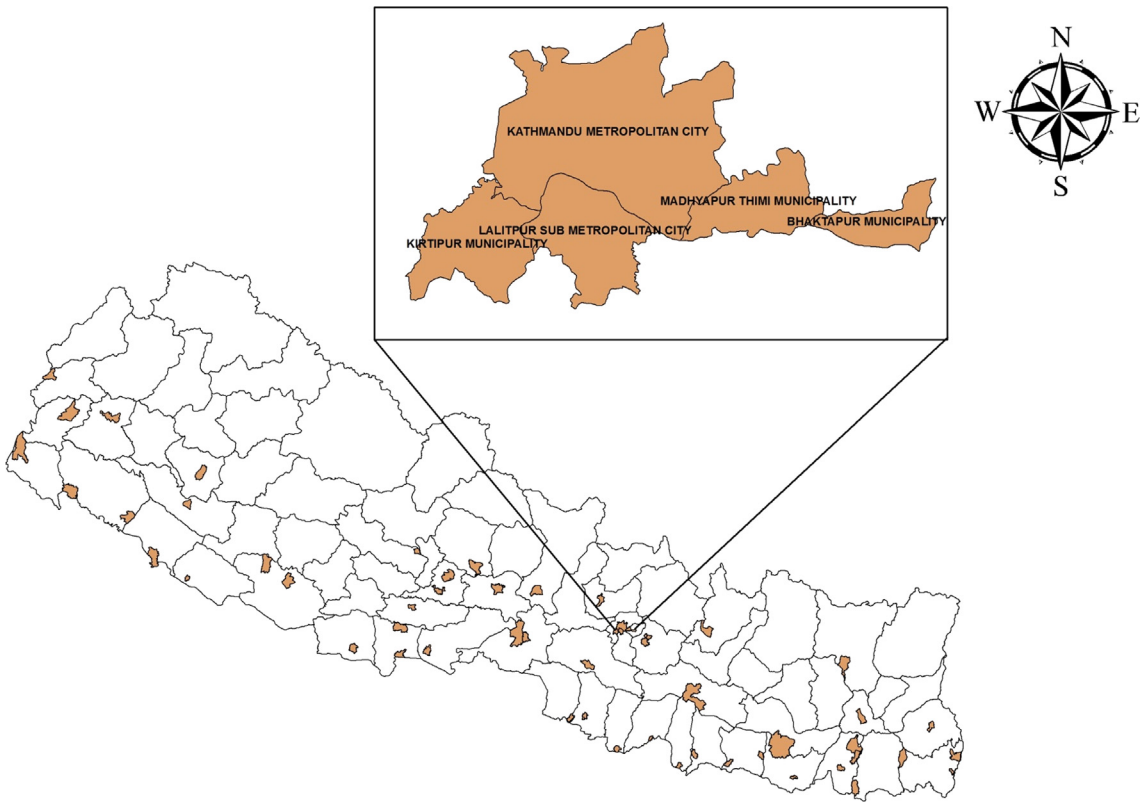

Fig. 1. Map of Nepal with political boundaries delineating the 75 districts (mostly white) and the 58 old municipalities (orange). The enlarged portion shows the five Kathmandu valley municipalities where this study focused. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

part of the valley, 16 km east of the KMC centre. It was divided into 17 wards and covered only 6.88 km^2 (Bhaktapur Municipality, 2016). Kirtipur municipality is less populated than the others and has grown around another ancient kingdom southwest of the KMC centre. Madhyapur Thimi is the newest of the five municipalities, which resulted from population infill between Bhaktapur and KMC.

Although Kathmandu valley is the most developed place in Nepal and covers the largest number of commercial and institutional sectors, the SWM in much of the valley remains unsatisfactory. In Kathmandu, SWM has become a chronic problem that has challenged and evaded development efforts for decades (Dangi, 2009). Many statistics related to SWM in Kathmandu valley are highly uncertain, as evidenced by the large variability across studies (Nippon Koei Co. Ltd. and Yachiyo Engineering Co. Ltd., 2005; SWMRMC, 2008; Dangi et al., 2011). A brief summary is provided here with the acknowledgement that these data are not necessarily consistent with each other.

About 50% of the waste from municipalities of Kathmandu valley is generated by households, 43% from commercial, 6% from the institutional, and relatively little (1%) from parks and gardens, street sweeping, and from neighboring villages (ADB, 2013). In 2012, the average per capita municipal solid waste generation rates (MSWGR) for KMC, LSMC, Kirtipur, Bhaktapur and Madhyapur Thimi were 0.46 kg/capita/day (kcd), 0.37 kcd, 0.25 kcd, 0.35 kcd, and 0.27 kcd, respectively. The most recent study (SWMTSC, 2015) showed the average MSWGR for a sub-urban neighborhood of KMC (i.e., Budanilkantha) and LSMC (i.e., Mahalaxmi/Gwarko) in 2014 to be 0.48 kcd and 0.36 kcd, respectively. Comparing ADB (2013) to the past studies (Nippon Koei Co. Ltd. and Yachiyo Engineering Co. Ltd., 2005; Alam et al., 2008), the per capita MSWGR has increased steadily in the valley municipalities. This is likely due to increased consumption of packaged goods and gradual rise of commercial and industrial activities. Moreover, a research-grade study by Dangi et al. (2011) indicates that the MSWGR is even higher than all of the aforementioned reports.

Although 71% of MSW generated in Kathmandu is organic (Dangi et al., 2011), very few neighborhoods have systems in place to compost this material (Sherpa, 2017). Within the valley municipalities, only 35.3% of waste from Kirtipur, Madhyapur Thimi (52.2%), LSMC (71.2%), Bhaktapur (86.5%) and KMC (86.9%) are collected (ADB, 2013). The situation in other low-income countries appears to be similarly abysmal despite the sizeable expenditure of financial resources on SWM (World Bank, 2012; Hazra and Goel, 2009). At present, urban areas receive more attention for MSW open burning because they are highly populated (Wang et al., 2017).

Large quantities of uncollected waste can be found along the banks of urban waterways such as Bagmati and Bishnumati (Pokhrel and Vivaraghavan, 2005). The water from these rivers is used for domestic purpose, cultivating agriculture and also has religious significance for Hindus. Sometimes uncollected waste is found in close proximity to small-scale agricultural fields where it contaminates the food supply. In communities that are far from waste-collection routes (Subedi, 2016), refuse is commonly dumped in privately-owned lots that are neither developed nor maintained (Bajracharya, 2016). Any waste that remains uncollected after a few weeks of biodegradation emits a foul odor, prompting nearby residents to burn it (Bajracharya, 2016; Sherchan, 2016).

At this point, it is useful to note that the primary issue discussed in this paper is from MSW that is burned in the open, where combustion conditions (i.e., low temperature, suboptimal air-to-fuel ratio, high moisture content) are favorable to pollutant formation (Wiedinmyer et al., 2014). This paper provides no commentary