Originally published by Elsevier in Habitat International 40 (2013) 65-72

Characterization, generation, and management of household solid waste in Tulsipur, Nepal

Mohan B. Dangi [a], Michael A. Urynowicz [b], Shashidhar Belbase [b]

[a] Department of Geography, California State University, Fresno, 2555 E. San Ramon Avenue, M/S SB 69, Fresno, CA 93740, United States
[b] Department of Civil and Architectural Engineering, University of Wyoming, 1000 E. University Avenue, Laramie, WY 82071, United States

Abstract:
Solid waste management in Tulsipur, Nepal has been very rudimentary and disorganized. For 11 years, the city practiced direct discharge of waste on a riverbank followed by the current disposal of waste in a creek with no soil cover or leachate treatment in place. The city's allocation of resources for waste management is also among the lowest in Nepal with 3474 residents per solid waste worker and 14.39 Nepalese Rupees or US $0.19 per person. Tulsipur collects less than one-half of the waste it generates and the waste frequently contaminates water sources. Nearly 100 Tulsipur Municipality households were investigated using cluster sampling techniques in an effort to characterize household solid waste and survey waste management practices. The waste composition study found that household solid waste is made up of 46% organic wastes, 11% dirt and construction debris, 10% plastics, 7% glass, 6% paper and paper products, 5% metals, and 5% rubber and leather. The balance included textiles (1%), hazardous wastes (1%), and other wastes (8%). Tulsipur generates 330.4 g capita^{-1} day^{-1} of household solid waste. The waste composition suggests that while organic wastes is still the largest component, recyclable items have emerged in recent years. The significant share of dirt and construction debris uncovered was an indication of urbanization in Tulsipur. Hazardous wastes rates were also higher than other Nepalese municipalities of similar size. It is recommended that Tulsipur adopt composting with a high degree of source separation for organic wastes, promote waste recovery or recycling at the local level to capture valuable items, use dirt and construction debris as a road filling substance and exchange material for new construction. Hazardous wastes also need special care. These practices will ensure that only residual wastes are deposited in landfill.

Keywords:
Waste characterization, Household solid waste, Waste generation, Solid waste management, Tulsipur, Nepal

Introduction

Tulsipur Municipality is a mid-size city in Midwestern Nepal. Situated in Dang district 434 km southwest of the capital Kathmandu between the Siwalik and the Mahabharat Mountain Ranges, Tulsipur had a population of 33,876 people with 7056 households in 2001 (CBS, 2002) (see Fig. 1). Tulsipur has 11 wards and 161 Tole Lane Organizations (TLOs). TLOs are clusters of households at the neighborhood level in a village or municipal ward that help authorities deliver local services. Among the 11 wards, ward 5 and parts of 4 and 6 are urbanized; wards 1, 2, 3, 8, 9, 10, and 11 are predominantly rural; and ward 7 is the least urbanized (Tulsipur Municipality, 2010). Agriculture is the dominant profession in the rural wards (Pandey, 2007).

With passage of the Local Self-Governance Act 1999 (LSGA) and the resulting delegation of authority to local agencies, there is greater opportunity for municipalities to respond to the needs of their communities. Organized solid waste management (SWM) has been a consistent and substantial problem for municipalities across Nepal. At present most of the daily waste produced in Tulsipur is either left uncollected or dumped haphazardly in crevasses, riverbanks, creeks, open sewers, and other depressions resulting in environmental degradation. A recent UNDP study found that effective urban planning in the city should focus on improving physical and environmental conditions (CASEC, MLD, & UNDP, 2002). The study also pointed out the urgent need for municipal planning to address the bio-physical issues in waste management covering industry/factory and sewage and socioeconomic issues including air pollution, river water pollution, and solid waste with potential application areas in SWM and hazard mapping. Similarly,

* Corresponding author. Department of Geography, California State University, Fresno, 2555 E. San Ramon Avenue, M/S SB 69, Fresno, CA 93740, United States. Tel.: þ1 559 278 4857; fax: þ1 559 278 7268. E-mail addresses: mdangi@csufresno.edu, garbagetalk@gmail.com (M.B. Dangi).

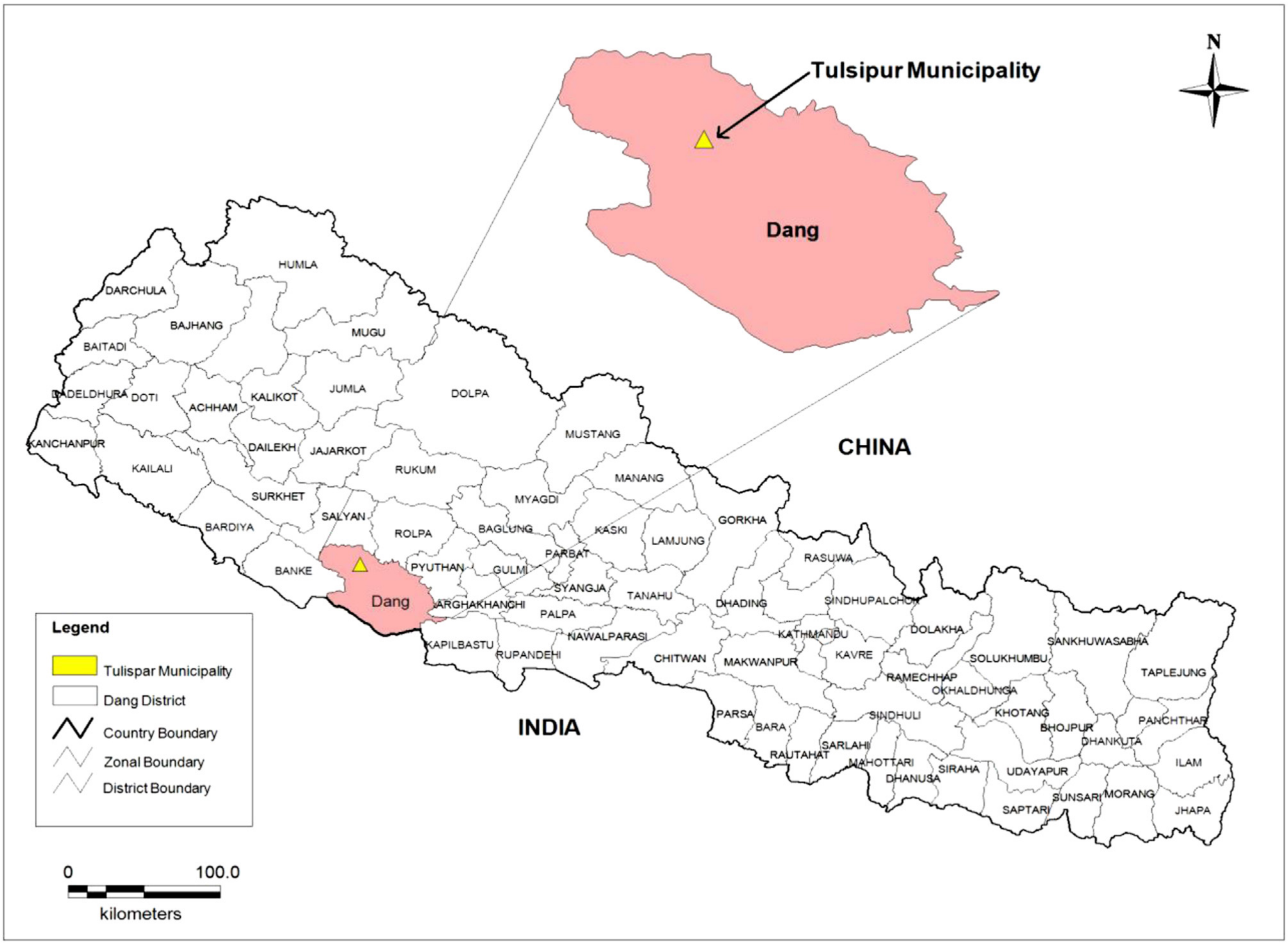

Fig. 1. Location of Tulsipur Municipality in Nepal. (Triangle within the shaded area represents the location of Tulsipur Municipality.)

SWMRMC, Clean Energy Nepal, and Environment and Public Health Organization (2004) described the waste management in Tulsipur as, "… crude and unplanned due to lack of a sanitary landfill and composting/recycling…" and recommended that Tulsipur "…start developing appropriate structures and system for effective waste management."

A reconnaissance visit was conducted from December 22 through December 31, 2006 to investigate contemporary waste management practices in Tulsipur and assist with training municipal workers, former elected officials and members of civic organizations about waste management. Existing and prospective landfill sites for the city were also inspected. After evaluating the preliminary facts, it was determined that the city lacked scientific data about existing waste stream characteristics, without which no sustainable plan to manage waste could be developed. Therefore, a field study was conducted from July 26 to 30, 2007. A subsequent follow up visit took place from June 27 to July 1, 2010. Because Tchobanoglous, Kreith, and Williams (2002) emphasize that environmentally friendly and cost-effective waste treatment options require rigorous data collection and understanding of waste parameters, this research utilized a large-scale survey and sampling of waste during the field study. The field study used cluster sampling techniques to survey 100 households from two of the most urbanized wards (5 and 6) in Tulsipur and studied the amount and types of household solid waste generated during a single day. Nippon Koei Co. Ltd. and Yachiyo Engineering Co. Ltd. (2005) found that waste generation did not vary significantly between the dry and wet months in the 440 Kathmandu households studied. Dangi, Urynowicz, Gerow, and Thapa (2008) also uncovered that waste generation did not alter noticeably over the two weeks of sampling conducted in 200 Kathmandu households. Other recent studies including Dangi, Pretz, Urynowicz, Gerow, and Reddy (2011) and Forouhar and Hristovski (2012) have used either one or two day sampling events.

The principal objectives of the field study were to uncover where the bulk of waste is coming from in Tulsipur, what's in it, how much is generated in a day, and what could be done to organize this.

Dangi et al. (2008, 2011) successfully demonstrated stratified cluster sampling of municipal solid waste for households in Kathmandu, Nepal and assessed the statistical limitations involved. The approach, which utilized a form of socioeconomic stratification across geographic areas, was based on a comprehensive review of numerous studies (Marquez, Ojeda, & Hidalgo, 2008; Mosler, Drescher, Zurbrügg, Rodriguez, & Miranda, 2006; Okot-Okumu & Nyenje, 2011; Sharma & McBean, 2007; Tchobanoglous, Theisen, & Vigil, 1993; Troschinetz & Mihelcic, 2009). A similar sampling approach has been used by Qu et al. (2009) by utilizing socioeconomic variables throughout different districts of Beijing City to obtain required number of households. In Nablus district, Palestine, Al-Khatib, Monou, Abu Zahra, Shaheen, and Kassinos (2010) applied systematic random sampling inside of strata to arrive at the required sample size. In Chittagong, Bangladesh, Sujauddin, Huda, and Rafiqul Hoque (2008) randomly chose 75 households representing five distinct socioeconomic groups to investigate household solid waste. Income distribution within family types was employed in analyzing household solid waste sampling by Ojeda-Benitez, Vega, and Marquez-Montenegro (2008). Applying three socioeconomic variables of population density, economic level, and household proximity to public roads and utilities, Philippe and Culot (2009) evaluated stratified sampling tools for measuring the household solid waste generation in Cape Haitian, Haiti.

This manuscript characterizes household solid waste stream in Tulsipur using cluster sampling techniques, presents waste generation statistics for the city, provides information about existing SWM of Tulsipur, and proffers possible ways to sustain SWM capacity utilizing local resources.

Materials and methods

Reconnaissance visit

From December 22 to December 31, 2006 researchers visited Tulsipur and toured the city's infrastructure, including newly built abattoirs, dumps, renovated open sewage system, vegetable market, Bus Park, and inner TLOs of wards 5 and 6 and examined a potential landfill site in Tuikhola area of Dang district. On December 29, the researchers presented their compiled initial findings as well as training about the safe disposal of solid waste and landfill siting criteria to Tulsipur officials. The data collected then was analyzed and a subsequent field visit was organized.

Field visit

Recruitment and training of scientists

On July 28, 2007, 40 volunteer student scientists from Rapti Babai Campus, Tulsipur were trained in the techniques required to identify 100 households, survey households, and conduct a waste characterization study. Twenty teams of two students each were formed and each team was assigned a mentor professor. The training included statistical techniques about sampling bias and a pretest of 30 survey questions that were previously tested and implemented in Kathmandu city. Additionally, students were trained to identify ten waste types (included in *sampling of waste* subsection later) examined during sampling, operate equipment and minimize instrumentation bias, use personal protective equipment, and collect, segregate, measure waste and record findings in the data sheet.

Survey of households

Assisted by researchers who have completed human subjects research education, mentors and student scientists chose 100 households using cluster sampling techniques on July 29, 2007. The sample size ($n = 100$) was about 7% of total urban households in wards 5 and 6 (Table 1). This number is comparatively higher than the percentages of households represented in Dangi et al. (2008, 2011) from the total number of households (=N) in Kathmandu city because of the smaller size of Tulsipur Municipality and its extent of urbanization in the city. As shown in Fig. 2, the inner core of Tulsipur has five north–south streets (Ka Line, Kha Line, Ga Line, Gha Line, and Nga Line). First, the inner core was divided into two halves by drawing a line across the east–west stretch of the city which passed through BP *Chowk* (intersection or roundabout). This created two equal sections in the most urbanized section of the city, north and south, where the north is more densely populated than the south. To achieve the most accurate information regarding the per capita waste generation rate in the city, more households per unit area were apportioned from the denser north. Table 1 presents relevant demographic features and the number of households studied. A total of twenty clusters with five households per cluster were identified for the study. In this way, ten clusters each were chosen from the north and the south. For the north, starting from *Sabji Mandi* (vegetable market) odd numbers of clusters (1, 3, 5, 7, and 9) were identified on the eastern side of each of the five streets and even numbers of clusters (2, 4, 6, 8, and 10) were selected on the western side of these streets. For each of the clusters, a direction was randomly chosen and the first household positioned in that direction was included in the study. Then the fifth household in the same direction was selected. With this vetting, the 1st, 5th, 10th, 15th, and 20th households in the chosen direction were shortlisted for the survey. Mentors avoided selection redundancy when overlaps occurred between two adjacent odd and even numbered clusters by conducting the survey on the opposite side of the street. Among the remaining ten clusters for the south, five of them came from TLOs between BP *Chowk* and Bank *Chowk* and another five were from between Sitalpur *Chowk* and Bank *Chowk*, where each of the ten remaining intersections served as a center point for the clusters. Again with the random selection of direction five households per cluster were chosen for the study.

Upon identification of households, mentors and student scientists conducted the survey. Survey questions included demographic information, queries relating to waste generation and management practices, resource management, governance, and effectiveness of foreign aid. During the survey, households were provided with two

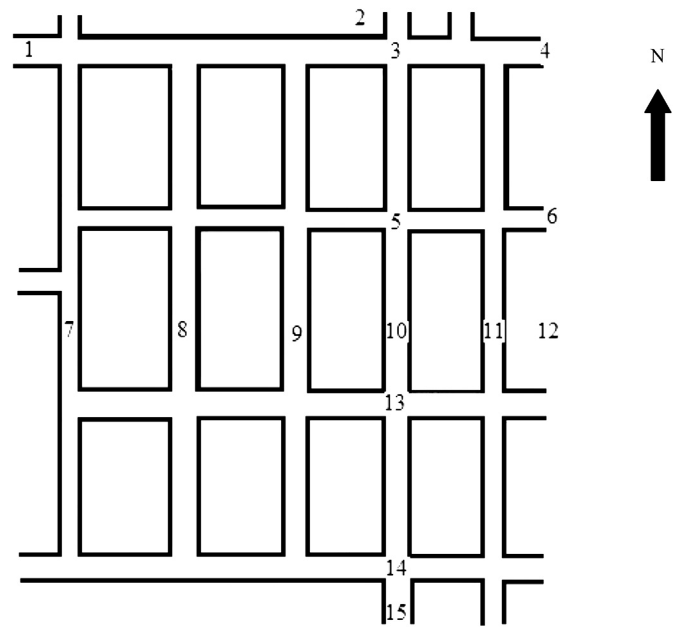

Fig. 2. Schematic of the surveyed area not drawn to a scale. (The numbers inside the schematic represent street name, cross section, highway, or location of landmarks: 1 = To Bus Park, 2 = Godam Ghar, 3 = Birendra Chowk, 4 = Ghorahi Road, 5 = BP Chowk, 6 = Sabji Mandi, 7 = Nga Line, 8 = Gha Line, 9 = Kha Line, 10 = Ka Line, 11 = Ga Line, 12 = Tulsipur Municipality Office, 13 = Bank Chowk, 14 = Sitalpur Chowk, and 15 = Rapti Highway.)

Table 1
Demographic information of studied area.

Ward number	Population[a]	Households (urban and rural)[a]	Households studied
5	6795	1190	73
6	8194	1624	21
Total	14,989	2814	94

[a] Tulsipur Municipality (2007).

plastic bags, and they were asked to store kitchen and yard wastes in one bag and the rest of the wastes in the other. They were also told that two of the student scientists would come back within 24 h to collect their wastes. To preclude any biases, households were not told that their waste would be segregated into ten different types.

Materials

Student scientists were equipped with personal protective equipment that included coveralls, face masks, eyeglasses, nitrile gloves, and closed toe shoes. Researchers added digital weighing scales (JS Ultrasport 30 or JS Ultrasport 50), pencils, and data collection sheets.

Sampling of waste

On July 30, 2007, student scientists picked up two sets of plastic bags left at each of the surveyed households by the surveying scientists. The waste discharged in a 24-h period by the households was first inspected and anything unusual was noted in the record sheet. Then one of the sampling scientists in each of the twenty groups segregated waste into ten categories: organic wastes (food and yard wastes), plastics, paper and paper products, metals, glass, rubber and leather, textiles, dirt and construction debris, hazardous wastes, and other wastes. These are typical waste types for solid waste studied across Nepal by municipalities and the Ministry of Local Development (Dangi et al., 2008, 2011; Manandhar, 2005; SWMRMC et al., 2004) and have been widely used in analyzing similar datasets in the US (Franklin, 2002). The definition of hazardous wastes was based upon sources and types by Nightingale and Donnette (2002). The waste types were measured using the digital balance in wet weight basis and the amounts were recorded in the data sheet, which were collected by the researchers and examined.

Waste characterization

No previous study has thoroughly explicated a waste composition analysis for Tulsipur (Dangi, 2011; Dangi & Gharti, 2006). While SWMRMC et al. (2004) provide constituents of waste, it fails to use statistical procedures to derive sample size and instead the study was based upon a field investigation conducted in 32 households in Ga Line only. After careful analysis of the limited data on Tulsipur, the waste composition study was performed. Although 100 households were initially part of the study, waste was collected from a total of 84 households and 94 households responded to survey questions. The lower response rate to sampling was partially due to some families had forgotten to save the wastes. In addition due to the heavy downpour on July 30, 2007, some of the scientists were cut off from the study area by flooding. The composition of household solid waste for Tulsipur is provided in Fig. 3. Organic wastes made up the highest proportion of total waste at 46% and textiles and hazardous wastes tied for the lowest at 1% each. While dirt and construction debris was second in the list after organic wastes at 11%, recyclables, including plastics (10%), paper and paper products (6%), metals (5%), and glass (7%), in aggregate were still dominant in Tulsipur. Rubber and leather (5%) and other wastes (8%) made up the rest.

Notably, organic wastes made up less of the total in this study than in studies of other Nepalese municipalities (Dangi et al., 2011; SWMRMC et al., 2004). Tulsipur's location along the major highway from Kapurkot area of Salyan district that is known for production of off-season vegetables and its easy access to vegetables and fruits grown in south-western villages of Dang district leads to little production of green vegetables in the inner core of Tulsipur. Therefore, it is expected that there was less organic wastes generated from that production. The assertion was corroborated by the

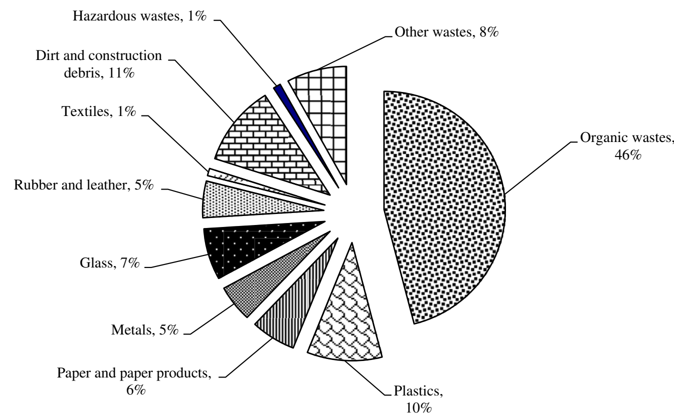

Fig. 3. Household solid waste composition for the surveyed area.

fact that in the survey, 78% of participating households attested that they don't produce their own vegetables and only 18% reported that they do. During sampling and subsequent visits, researchers also witnessed that most of the ward 5 and ward 6 households in the studied areas don't practice gardening, though more households in ward 6 have gardens. Also, most houses in Tulsipur (60%) have an area of less than 100 m^2, leaving the households little space for backyards and therefore little yard waste (Fig. 4).

The high proportion of dirt and construction debris comes from the increasing urbanization and population growth in Tulsipur that has driven new construction after over a decade of insurgency in the rural bases of Tulsipur and Dang district, a hotbed for Maoist uprising. The annual population growth rate of 4.1% for Tulsipur is much higher than the 2.2% measured in the rest of the country (CBS, 2002). The 1% of hazardous wastes found for Tulsipur is within the range obtained by Dangi et al. (2011) for Kathmandu city and slightly high for similarly sized municipalities (ICIMOD, MOEST, & UNEP, 2007; SWMRMC, 2004). Generally, the higher presence of rubber (2.4%) and inert materials (7.4%) was also observed in the SWMRMC et al. (2004) study indicating rubbers combined with leather and new homes built in Tulsipur recently have enhanced the production of rubber and leather and dirt and construction debris in this research, in that order. The composition numbers for other waste types are comparable with SWMRMC et al. (2004), especially for recyclable items, where they obtained 10.4% for paper, 7.5% for plastics, and 4.8% for textile. However, they measured organic wastes at 65%. Their small sample size ($n = 32$) and restricted geographic area (all of the samples came from Ga Line) could have contributed to affinity bias and cluster bias (Alreck & Settle, 2004) depending upon how the samples were collected.

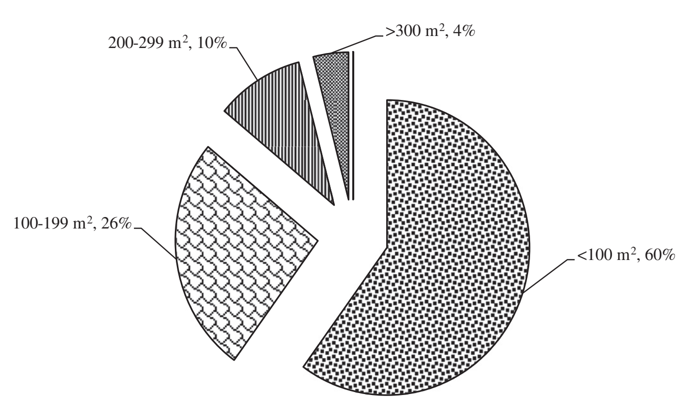

Fig. 4. Surface area of surveyed households.

Waste generation

Wastes from the 84 households sampled were analyzed and measured in g capita^{-1} day^{-1} by dividing the total wastes in wet weight basis by the number of people residing in each household. Based on this study, the average family size for Tulsipur was 5.2 people. This number is fairly close to the family size of 5.7 found for Kathmandu city by Dangi et al. (2011). Fig. 5 provides household solid waste generation data for 84 households in Tulsipur. The minimum waste generation of 2.8 g capita^{-1} day^{-1} was produced by household number 53 and the maximum of 12,033.3 g capita^{-1} day^{-1} by household number 3, as shown in Table 2. The low waste generation for household number 53 was a result of most of the residents of this house were out during sampling and only produced plastics and a few grams of metals that day. The largest waste generation was from household number 3 which had held a happy gathering resulting in discarded beer bottles, plastics, and packaging materials made with rubber. The average waste generation rate was 189.4 g capita^{-1} day^{-1} without the biggest data point and 330.4 g capita^{-1} day^{-1} with it. The data was then examined using a log probability plot as described by Tchobanoglous et al. (1993). The plot showed that the data was positively skewed which means that the average waste generation is higher than mode (Fig. 6 and Table 2). Table 2 also includes the statistical parameters of this data. The coefficients of skewness and kurtosis derived were 3.2 and 13.8 without the largest data point and 8.7 and 77.5 with it, respectively. Tchobanoglous et al. (1993) also point out that the value for kurtosis is generally 3 for normally distributed waste generation data and a certain level of skewness is expected in solid waste studies. The positive number for skewness and a somewhat higher number for kurtosis in this research imply that the distribution of waste is peaked and random throughout households and there will be no less than 0 g capita^{-1} day^{-1} of waste generation in any given day, but rationally there is no upper bound (Dangi et al., 2011). Also, the moderate standard deviation of 258.8 without the highest data point and 1317.6 with it hints that the data is closely distributed near its mean waste generation for the most part. Ignoring rare events that are expected to take place in any given day in a city could undermine overall waste generation numbers and negatively impact municipal planning and day-to-day operation of SWM (Dangi et al., 2011; Tchobanoglous et al., 1993). Therefore, this research utilized 330.4 g capita^{-1} day^{-1} as an average household solid waste generation for Tulsipur Municipality.

Table 2
Statistical parameters for waste generation (g capita^{-1} day^{-1}).

Name of the parameters	Numbers calculated
Average	330.4
Min (household number = 53)	2.8
Max (household number = 3)	12,033.3
Standard deviation	1317.6
Sample size (=n)	84
Mode	80
Coefficient of skewness	8.7
Coefficient of kurtosis	77.5

Upon multiplying the average per capita household solid waste generation rate by the projected number of people in Tulsipur in 2007 (43,112), the total household solid waste generation equals 14.2 m tons per day. This number is twofold more than 7 m tons per day that Tulsipur Municipality reports (Dangi, 2011) because it only considers solid waste from ward 5 and part of ward 6. Also, the number is somewhat higher than 9.2 m tons day^{-1} obtained by

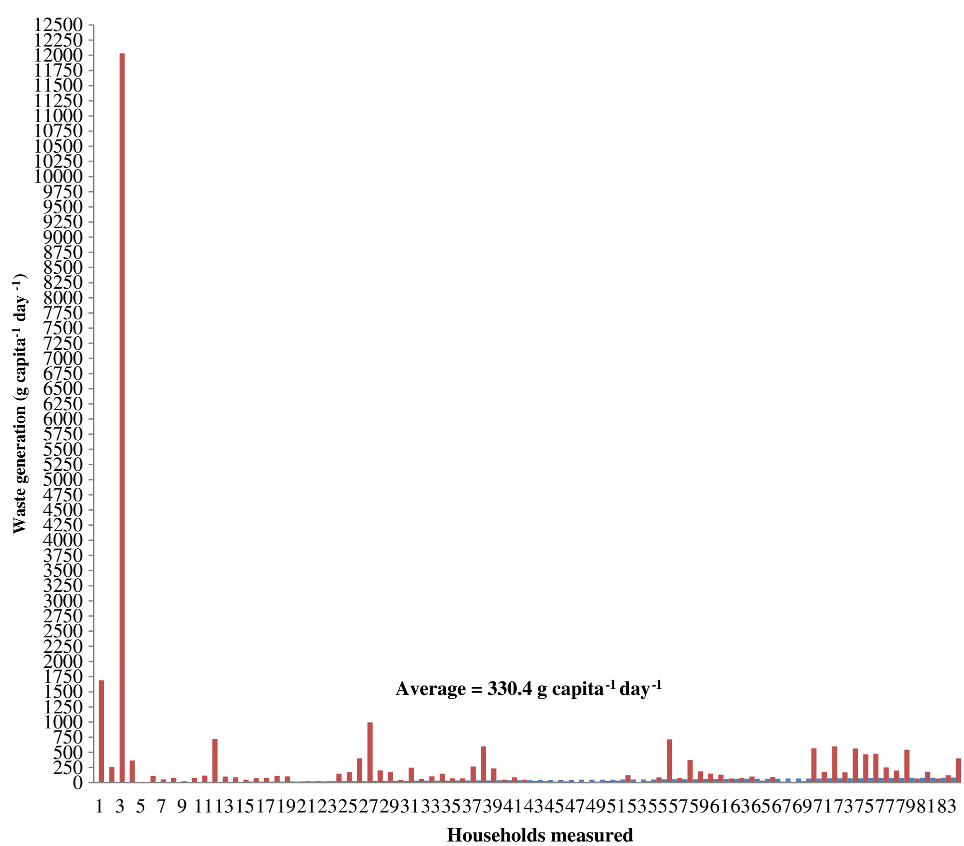

Fig. 5. Average daily per capita household waste generation.

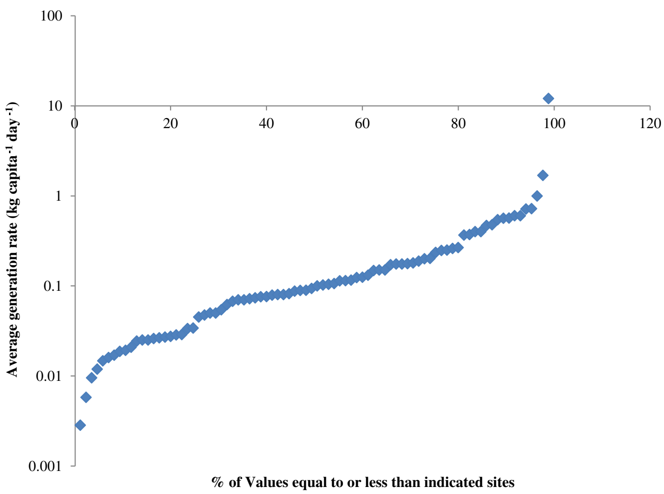

Fig. 6. Log probability plot of average waste generation rates.

SWMRMC et al. (2004). The study by SWMRMC et al. (2004) was based upon a snapshot survey of a small number of households ($n = 32$) in Ga Line of ward 5 in 2003 and they used the national average of 0.25 kg capita^{-1} day^{-1} for household solid waste generation for Nepalese municipalities that was established by Mishra and Kayastha (1998) for smaller municipalities with populations of less than 20,000 people. The numbers were based upon an outdated study that does not meet the criteria for Tulsipur in the year 2007; therefore the data from SWMRMC et al. (2004) is of limited usefulness. So, the 14.2 m tons day^{-1} of household solid waste generation obtained in this research should be treated as the basis for planning future waste treatment options in Tulsipur.

Solid waste management

Of the 7 m tons Tulsipur Municipality (2010) reports the city generates in a day, 6 m tons is collected and disposed of in a creek in Indranagar TLO of ward 6 without any soil cover or leachate management. The remaining 1 m ton of waste is left uncollected at the source of origination, along the side of the streets or mixed with sewage. Also, waste from the Bus Park area on the western edge of the inner core of Tulsipur, which is not included in the municipality's reported daily generation rate, is presently discharged into Patu *Khola* (river). Tulsipur directly discharged all of its waste to Patu *Khola* without any treatment for 11 years before the dumping in Indranagar began, thus carelessly polluting the waterways (SWMRMC et al., 2004).

There is an Environment and Sanitation Department in Tulsipur Municipality that oversees SWM, parks and greenery and management of slaughterhouses, and addresses public health issues (Dangi, 2011). This department has a compactor, a tractor, four rickshaws, and five wheelbarrows that are in use among 32 wheelbarrows allocated to the city plus nine sweepers, a driver, and an officer (Dangi, 2011; Tulsipur Municipality, 2010). While the human capital and equipments allotted to the city seem inadequate to organize 14.2 m tons day^{-1} of household solid waste, Tulsipur has not maximized the use of wheelbarrows. Most of the households or businesses drop waste on street corners, then sweepers clean the streets using brooms and collect waste in wheelbarrows. Rickshaws gather waste from houses and a tractor is used for hauling sewage sludge and solid rock materials, and the accumulated waste is subsequently taken to the dump site in Indranagar using the lone compactor.

The organized collection of waste only takes place in ward 5 and part of ward 6 (Tulsipur Municipality, 2010). The increasing urbanization in Tulsipur triggered by population growth requires the expansion of the SWM service throughout the city's wards. Moreover, recent data reports that Tulsipur has a newly established Rapti Zonal Hospital, 16 health clinics, 36 educational institutes, 15 rice mills, 11 oil mills, 51 clothing stores, 17 furniture stores, 6 brick kilns, 68 metal workshops, 26 sweet stands, 22 typing and computer institutes, 19 electronic shops, 30 tailoring places, and 14 other firms (Pandey, 2007). The numbers of firms are bound to increase with mounting population pressure and economic activity, thus yielding a larger amount of hazardous and non-hazardous industrial wastes in the city. The dump site in Indranagar is ill-suited to handle this increase with an area of only 677.3 m^2 and observation during the follow up visit showed that it was nearly full. An additional challenge is that the creek on which the dump is located drains the watershed from parts of ward 5 and several settlements of ward 6 and ultimately empties into Gwar *Khola*, a major monsoon fed-tributary of the Babai River in Midwestern Nepal. Local people, municipality staff, and elected officials were unaware of the possibility of any public health and environmental implications from contaminated water in downstream villages (Dangi, 2009).

Houses are built next to the dump site and animals often feed on the waste. In addition there is a Table Tennis Hall that's built essentially on top of the creek. Local citizens are oblivious to any health impacts from soil–water contamination caused by lack of a leachate treatment facility, and instead they are happy to have a black topped access road that goes through their TLO and the electric poles they received. Tulsipur Municipality reports that the dump site does not have any problem with leachate and excess runoff in the rainy season drains to Gwar *Khola*. However, the current practice of using sand as cover every four to five days does not meet standards for preventing leachate. Usually 6–12 inches of soil cover of clay with hydraulic conductivity of 10^{-7} cm s^{-1} (Terzaghi & Peck, 1967; Tuma & Abdel-Hady, 1973) should be applied in each working day's cell in a landfill. Based upon the particle size of the sand, it could have the hydraulic conductivity of at least twice the clay and hence would allow more water to percolate and form leachate, especially with 149.4 ml of annual precipitation and 96% of average relative humidity (Pandey, 2007) that Tulsipur has. With this dump reaching its capacity, Tulsipur is in the search of new landfill. Tulsipur Municipality believes that they could use the second half of the creek that is situated adjacent to the Table Tennis Hall on the south as a dump site for another two and half years (Dangi, 2011). Recently, a site in Butaniya area of ward 11 was shortlisted for a new landfill. While Tulsipur Municipality states that this new site has received social acceptance and it has been approved by the Sixth Municipal Council, they still have not done any initial environmental examination or the environmental impact assessment study mandated by Nepal's Environment Protection Act, 1996 (Tulsipur Municipality, 2010).

In addition, there is no formal resource recovery or composting in place and nor there is an active informal recycling sector in town, leaving landfilling as the main waste treatment strategy. In recent communications, Tulsipur Municipality cites a lack of financial resources, limited support from municipal and national governments, and inadequate technical knowhow in the delay of their plan to augment the sanitary landfill in ward 11 (Dangi, 2011).

Safe disposal of waste has been a main concern for urban residents throughout Nepal as demonstrated by a CBS (1997) survey where among the 3980 city inhabitants questioned, 59% assessed solid waste as a major environmental problem followed by sewage at 25%. A survey question designed to learn households' opinion about the most important public service delivery found that 70% of

Tulsipur households thought water supply was their most important priority followed by 12% who selected solid waste among the seven categories of public services listed (Fig. 7). Clean drinking water is a critical need in towns across Nepal and the timing of the survey, conducted during the peak summer month of July with days of rainfall that had muddied the water supply and increased turbidity, might have influenced the response from households. Then again, solid waste being the second most important priority area reflects the reality that Tulsipur needs to address its increasing waste quantity.

Only 6 m tons day^{-1} of the 14.2 m tons day^{-1} of waste produced in Tulsipur Municipality is collected, leaving more than 8 m tons of household solid waste uncollected every day. This waste, an eyesore for the public, has already tainted surface water sources, contaminated drinking water sources, and clogged sewage. UNEP, MOPE, SACEP, ICIMOD, and NORAD (2001) reported that solid waste has been a major factor polluting water sources in Nepal and Karn and Harada (2001) reported similar findings in the rivers of Kathmandu Valley. In addition, solid waste in Tulsipur shows promise for resource recovery via composting of organic wastes; recycling opportunities for paper and paper products, plastics, metals, glass, and rubber and leather; and use of dirt and construction debris in filling roads and crevasses and exchange material for new construction. However, little effort has gone into any of these practices. Although the Tulsipur Federation of Nepalese Chambers of Commerce and Industry attempted to organize public awareness activities at the TLO level focusing on the first five streets of ward 5 in 2009 (Tulsipur Municipality, 2010), this endeavor was only able to provide a wish list to improve the urban environment, including involving the public in street cleaning and stricter enforcement of LSGA codes for waste management.

A survey question designed to find out households' knowledge about local or national organizations providing information about safe handling and recycling of solid waste yielded that 85% of respondents said they have not received such services. SWMRMC et al. (2004) triangulated this data by saying, "Tulsipur Municipality does not have any programmes to involve community groups or any NGOs in waste management." Furthermore, upon going over budgetary allocations, it was found that Tulsipur spent about 2% of its expenditure or Nepalese Rupees (NR) 125,000 on SWM in the 2002/03 fiscal year and it had allocated NR 550,000 for the succeeding fiscal year (SWMRMC et al., 2004). (The exchange rate during the time of field study was NR 64.90 per US$1.) Also, Tulsipur's proportion of residents per solid waste worker of 3474:1 is higher than the average of five municipalities in Kathmandu Valley of 1659:1 (UNEP et al., 2001). Likewise, the expenditure of NR 14.39 or US $0.19 per person is extremely low for Tulsipur in comparison

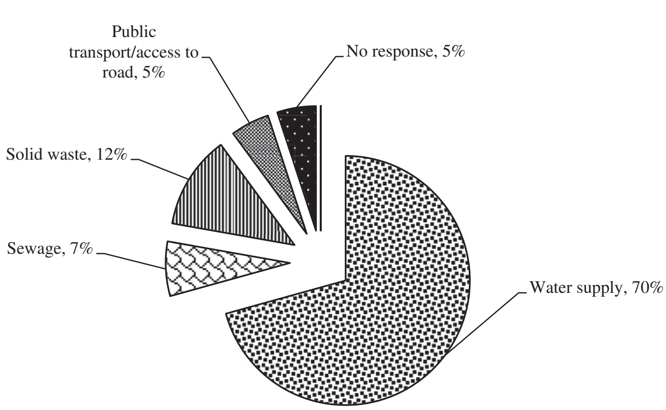

Fig. 7. Survey response for the most important public service delivery identified.

Table 3
Summary of resource allocation by the Nepalese municipalities for solid waste management.

Municipality	Pop.[a,c]	SWM worker[c]	Resident/ worker	Expense (NR)[b,c]	Expense/ resident
Kathmandu	671,421	1300	516	91,200,000	135.83
Lalitpur	156,026	189	826	13,000,000	83.32
Bhaktapur	74,176	174	426	8,573,446	115.58
Kirtipur	45,253	10	4525	1,500,000	33.15
Madhyapur	34,047	17	2003	500,000	14.69
Tulsipur[d]	38,216	11	3474	550,000	14.39

[a] CBS (2002).
[b] SWMRMC et al. (2004).
[c] UNEP et al. (2001).
[d] Data for Tulsipur was for year 2004 and for the rest of the municipalities, the data corresponds to year 1999.

to the average expenditure of five Kathmandu Valley municipalities of NR 76.51 or US $1.12 (Table 3). These findings together with the number of human resources allotted, adoption of improper waste treatment techniques, and the inadequacy and deficient use of tools and equipment to organize more than two times the amount of waste collected by the municipality prove that SWM in Tulsipur is ill prepared to deal with current waste quantity.

Conclusions and recommendations

The waste characterization conducted for Tulsipur Municipality, Nepal using cluster sampling in 100 households revealed that it generates 330.4 g capita^{-1} day^{-1} of household solid waste. The key waste constituents include 46% organic wastes, 10% plastics, 6% paper and paper products, 5% metals, 7% glass, 11% dirt and construction debris, and 1% hazardous wastes. Tulsipur's waste treatment predominantly focuses on slapdash disposal of waste in surface water sources. While Tulsipur Municipality has some human and capital resources to draw upon, it appears that the city hasn't fully capitalized on them. The composition of the waste points to a large potential for recovery of organic wastes using composting to produce high quality manure that could be used by the city's primarily agrarian base and surrounding villages. Revenue could also be produced from the high quantity of recyclables found in the study through a sizeable material recovery facility organized by a combination of Tole Lane Organizations. The considerable amount of dirt and construction debris can be captured for use as a road filling substance as Tulsipur extends its transportation network in hamlets. The noticeable quantity of hazardous wastes at households and the rise in healthcare facilities in the city also demand separate waste collection and treatment. The extremely low per capita spending in SWM in Tulsipur indicates that the city lacks the necessary resources to effectively manage solid waste. With additional resources Tulsipur would be able to adopt an integrated solid waste management approach combining source reduction, recycling and composting, transformation of waste, and landfilling. This could provide local organizations with the opportunity to sell recycled material, compost, and possibly biogas. These practices would also ensure that only residual wastes are deposited in landfills, greatly reducing the amount of waste landfilled. The adoption of an integrated solid waste management approach would also help to improve the lives of the people by providing a more safe and environmentally sustainable living condition.

Acknowledgments

The authors are grateful to the students and faculty of Rapti Babai Campus, Tulsipur for offering their facility for training and providing volunteer service for data collection. Special thanks are due to 100 Tulsipur households for taking part in survey and allowing their wastes to be sampled and Tulsipur Municipality staff and former Mayor, Mr. Dhundiraj Lamichhane as well as Mr. Dambar B. Budhathoki and Mr. Lok B. Dangi for facilitating the study. Bhim P. Pokharel, Upendra B. Bom, Rameshwor Kaphle, and Basant Budhathoki supported in additional data collection.

We also acknowledge anonymous reviewer and Professor Charles L. Choguill for their important inputs to enhance the quality of this paper.

References

Al-Khatib, I. A., Monou, M., Abu Zahra, A. S. F., Shaheen, H. Q., & Kassinos, D. (2010). Solid waste characterization, quantification and management practices in developing countries. A case study: Nablus district – Palestine. *Journal of Environmental Management, 91*, 1131–1138.

Alreck, P. L., & Settle, R. B. (2004). *The survey research handbook* (3rd ed.). Boston, MA: McGraw-Hill.

Cartography and Survey Engineering Consultant (CASEC), Ministry of Local Development (MLD), & United Nations Development Programme (UNDP). (2002). *GIS database/maps of Tulsipur Municipality*. Kathmandu, Nepal: CASEC.

CBS. (1997). *Urban population survey 1996*. Kathmandu, Nepal: National Planning Commission Secretariat.

Central Bureau of Statistics (CBS). (2002). *Statistical pocket book Nepal 2002*. Kathmandu, Nepal: National Planning Commission Secretariat.

Dangi, M. B. (2009). *Solid waste management in Kathmandu, Nepal: The anatomy of persistent failure*. Published doctoral dissertation, the Johns Hopkins University, Baltimore, MD. Ann Arbor, MI: ProQuest LLC.

Dangi, T. B. (2011, January 6 and January 18). Personal communication.

Dangi, T. B., & Gharti, L. (2006, December 28). Personal communication.

Dangi, M. B., Pretz, C. R., Urynowicz, M. A., Gerow, K. G., & Reddy, J. M. (2011). Municipal solid waste generation in Kathmandu, Nepal. *Journal of Environmental Management, 92*, 240–249.

Dangi, M. B., Urynowicz, M. A., Gerow, K. G., & Thapa, R. B. (2008). Use of stratified cluster sampling for efficient estimation of solid waste generation at household level. *Waste Management & Research, 26*, 493–499.

Forouhar, A., & Hristovski, K. D. (2012). Characterization of the municipal solid waste stream in Kabul, Afghanistan. *Habitat International, 36*, 406–413.

Franklin, M. A. (2002). Solid waste stream characteristics. In G. Tchobanoglous, & F. Kreith (Eds.), *Handbook of solid waste management* (2nd ed.). (pp. 5.1–5.30) New York, NY: McGraw-Hill.

International Centre for Integrated Mountain Development (ICIMOD), Ministry of Environment, Science and Technology (MOEST), & United Nations Environment Programme (UNEP). (2007). Waste management. In ICIMOD, MOEST, & UNEP (Eds.), *Kathmandu Valley environment outlook* (pp. 73–87). Kathmandu, Nepal: ICIMOD.

Karn, S. K., & Harada, H. (2001). Surface water pollution in three urban territories of Nepal, India, and Bangladesh. *Environmental Management, 28*, 483–496.

Manandhar, R. (2005, June 1). Basic fact sheet of solid waste management of Kathmandu Municipal Corporation. Unpublished record received electronically.

Marquez, M. Y., Ojeda, S., & Hidalgo, H. (2008). Identification of behavior patterns in household solid waste generation in Mexicali's city: study case. *Resources, Conservation and Recycling, 52*, 1299–1306.

Mishra, S. B., & Kayastha, R. P. (1998). Solid waste management *A compendium on environmental statistics 1988 Nepal*). Kathmandu, Nepal: CBS.

Mosler, H. J., Drescher, S., Zurbrügg, C., Rodriguez, T. C., & Miranda, O. G. (2006). Formulating waste management strategies based on waste management practices of households in Santiago de Cuba, Cuba. *Habitat International, 30*, 849–862.

Nightingale, D., & Donnette, R. (2002). Household hazardous wastes. In G. Tchobanoglous, & F. Kreith (Eds.), *Handbook of solid waste management* (2nd ed.). (pp. 10.1–10.36) New York, NY: McGraw-Hill.

Nippon Koei Co. Ltd., & Yachiyo Engineering Co. Ltd.. (2005). *The study on the solid waste management for the Kathmandu Valley*. Final report: main report (draft). Kathmandu, Nepal: JICA.

Ojeda-Benitez, S., Vega, C. A., & Marquez-Montenegro, M. Y. (2008). Household solid waste characterization by family socioeconomic profile as unit of analysis. *Resources, Conservation and Recycling, 52*, 992–999.

Okot-Okumu, J., & Nyenje, R. (2011). Municipal solid waste management under decentralization in Uganda. *Habitat International, 35*, 537–543.

Pandey, H. P. (2007). Tulsipur Nagarpalika samkshipta chinari [Tulsipur Municipality short introduction]. In Tulsipur Municipality Office (Ed.), *Citizen Charter* (pp. 1–6). Tulsipur, Nepal: Tulsipur Municipality.

Philippe, F., & Culot, M. (2009). Household solid waste generation and characteristics in Cape Haitian city, Republic of Haiti. *Resources, Conservation and Recycling, 54*, 73–78.

Qu, X., Li, Z., Xie, X., Sui, Y., Yang, L., & Chen, Y. (2009). Survey of composition and generation rate of household wastes in Beijing, China. *Waste Management, 29*, 2618–2624.

Sharma, M., & McBean, E. (2007). A methodology for solid waste characterization based on diminishing marginal returns. *Waste Management, 27*, 337–344.

Solid Waste Management and Resource Mobilization Center (SWMRMC). (2004). *A diagnostic report on state of solid waste management in municipalities of Nepal*. Lalitpur, Nepal: MLD.

Sujauddin, M., Huda, S. M. S., & Rafiqul Hoque, A. T. M. (2008). Household solid waste characteristics and management in Chittagong, Bangladesh. *Waste Management, 28*, 1688–1695.

SWMRMC, Clean Energy Nepal, & Environment and Public Health Organization. (2004). *Solid waste management in Tulsipur Municipality*. Kathmandu, Nepal: His Majesty's Government of Nepal.

Tchobanoglous, G., Kreith, F., & Williams, M. E. (2002). Introduction. In G. Tchobanoglous, & F. Kreith (Eds.), *Handbook of solid waste management* (2nd ed.). (pp. 1.1–1.27) New York, NY: McGraw-Hill.

Tchobanoglous, G., Theisen, H., & Vigil, S. (1993). *Integrated solid waste management: Engineering principles and management issues*. New York, NY: McGraw-Hill.

Terzaghi, K., & Peck, R. B. (1967). *Soil mechanics in engineering practice* (2nd ed.). New York, NY: John Wiley.

Troschinetz, A. M., & Mihelcic, J. R. (2009). Sustainable recycling of municipal solid waste in developing countries. *Waste Management, 29*, 915–923.

Tulsipur Municipality. (2007). Tole Bikas Sanstha tatha Tole Padadhikariharu [Tole Lane Organizations and their representatives]. In Tulsipur Municipality Office (Ed.), *Citizen Charter* (pp. 60–71). Tulsipur, Nepal: Tulsipur Municipality.

Tulsipur Municipality. (2010, November 25). *Tulsipur Nagarpalikako haalko fohar-maila sambandhi bibaran* [*Current status of solid waste management in Tulsipur Municipality*]. Unpublished report received from Tulsipur Municipality.

Tuma, J. J., & Abdel-Hady, M. (1973). *Engineering soil mechanics*. Englewood Cliffs, NJ: Prentice Hall.

UNEP, MOPE, SACEP, ICIMOD, & NORAD. (2001). *State of the environment Nepal 2001*. Bangkok, Thailand: UNEP.