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RESEARCH ARTICLE

INFLUENCE OF WASTE DISPOSAL ON WATER QQUALITY AND METHANE EMISSION FROM NAMBOL TUREL: A FEEDER STREAM OF LOKTAK LAKE IN MANIPUR, INDIA

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ABSTRACT

The current study assessed the water quality status of Nambol *Turel* to determine the extent of environmental implications caused by inappropriate wastes disposal. Households along the stream dispose their solid wastes (31 % of the houses) and liquid waste (2 % discharges wastewater) directly into the stream. Consistently, the water in the town is found more polluted compared to the upstream and downstream water. Methane emission rates were also found consistently higher in the section of the stream meandering through the town. Mean CH_4 flux during the pre-monsoon was higher compared to the flux in winter and the seasonal difference was statistically significant (ANOVA, $P = < 0.05$). The mean water temperature recorded in the stream during the pre-monsoon and winter seasons was 29.6 and 9.2^0 C, respectively and the water temperature had a linear correlation with CH_4 flux: y = 7.832x – 56.491 (R^2 = 0.6757).

INTRODUCTION

Urbanization is a silent revolution unfolding rapidly around the nucleus of many small towns globally. Rapid population growth coupled with unplanned urbanization may lead to severe environmental, economical and social problems. Out of the various problems associated with urbanization, municipal waste management constitutes the prime challenge faced by the various local civic authorities, worldwide. In India, the several public sector agencies responsible for waste management rarely have appropriate strategies, methods for mobilization of financial resources or the necessary appropriate infrastructure for organized waste management (Diaz *et al*, 1996). Like most of its counterparts, Municipal Councils in the region do not have the manpower, resources and technology to deal with the problems of solid wastes. Even though there is a wide variation in spatial and temporal, quality and quantity and generation rates, these wastes are known to create environmental problems (Hardoy *et al*, 2001 and Tchobanoglous *et al*, 1993). Improper solid waste management causes all types of pollution including air, soil, and water (Anon, 1999). Lack of planning and finance often leads to inappropriate disposal of wastes and toxic substances polluting the water resources in urban centres. Unlike the developed countries the percentage of organic content in municipal wastes in India is generally around 40-60 %. Incorporation of these wastes in water bodies enriched the carbon substrate supply for anaerobic degradation augmenting the methane (CH_4) budget. The extent of CH_4 generation depends primarily on the quantity of degradable organic materials in the wastewater (IPCC, 2006). Increasing atmospheric concentrations of CH_4 contribute to global warming and affect the photochemistry of the atmosphere (Cicerone *et al*, 1988). As CH_4 is one of the main greenhouse gases accounting for about 19 % of the direct radiative forces of climate (Houghton *et al*, 1990), there is growing interest in the sources and sinks of CH_4 and in the influences of anthropogenic activities on its exchange rates. The waste sector is the third largest source of global non-CO_2 greenhouse gas after agriculture and the energy sector (US EPA, 2006). The current study, attempts to assess the domestic waste generation and disposal pattern in Nambol town and its possible impacts on the water quality of Nambol *Turel*, and the methane emission budget from the stream.

MATERIALS AND METHODS

Nambol Town and Nambol Turel

Nambol town (24^0 40′ 25″– 24^0 44′56″N; 93^0 47′ 40″– 93^0 51′ 52″E) is an important urban centre in the hilly state of Manipur in the northeastern Indian Himalaya (Fig. 1). It has an average elevation of 766 m *amsl*. The Municipal area of Nambol covers an area of ~ 29.11 km^2 with a population of 24, 783 (Municipal Council Survey, 2012). The Nambol *Turel* (a feeder stream of Loktak Lake) from its origin in the Kangchup hills, meanders through the valley, flow passing the Nambol town before finally discharging downstream into Loktak. Loktak Lake (a Ramsar Site) is the largest freshwater lake in northeastern India. Nambol *Turel* through its course in the town receives liquid and solid wastes.

Assessment of waste generation and disposal

Studies on the household wastes generation pattern was carried out through questionnaire survey. Hundred households located along the Nambol *Turel* were randomly selected for the survey. The assessment of solid waste recovery and sales was carried out by interviewing the mobile iterant and wastes dealers. More than 20 individuals of each group were interviewed. The mobile waste pickers were intercepted during the day time. Secondary data pertaining to waste

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management were also obtained from the Municipal Office. Characterization of wastes generated in the households was carried by selecting randomly five medium sized families along Nambol *Turel*. All the households were provided with two plastic containers and the families were requested to use the containers for collecting the wet and dry domestic wastes, separately. After every 48-h, the collected heterogeneous wastes materials were segregated and each sub-group was weighed with a pan balance. The experiment was carried out for 30 days at a stretch. The amount of liquid waste generated was deduced from the amount of water consumed per day for establishing different household activities.

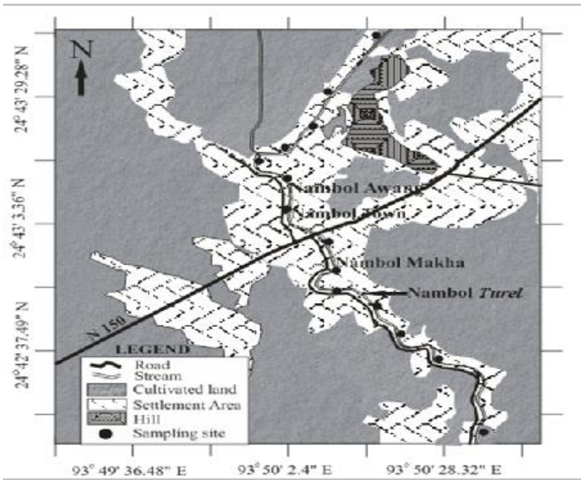

Figure 1 Nambol Town and the survey sites

Analysis of Water Quality

Water samples were collected from three sections of Nambol *Turel*: (i) the stream water in the town, (ii) downstream water and (iii) upstream water. The analyses of the samples were carried out as per A.P.H.A. (APHA, 1995), standards for the following parameters: temperature, pH, conductivity, alkalinity, hardness, Dissolve Oxygen (DO) and free carbon dioxide. The water temperature (15 cm below the surface) was recorded using an ordinary mercury thermometer at the time of sampling.

Evaluation of CH_4 flux

Methane flux measurement was carried out by closed chamber technique described by Hutchinson and Moiser (1981) [10], with floatable cylindrical chamber (internal diameter, 25 cm and height 30 cm). Gas Samples (10 mL) were drawn from the chamber in a 15 mL airtight syringe at time intervals 0, 5 and 10 min, respectively. The samples were transferred to pre-evacuated vacutainer tube (12.5 mL) by hypodermic needle (26 gauge). To avoid contamination and dilution, the gas samples were injected in the tubes a little bit higher than that of the atmospheric pressure. The butyl rubber stoppers of the tubes were sealed by glue. These tubes were brought to the laboratory and analyzed for CH_4 using a gas chromatograph (Shimadzu, GC-8A) fitted with Flame Ionization Detector (FID) and Porapak N column. The column, injector and detector temperature was maintained at 70, 130 and 130^0 C, respectively. Carrier gas was N_2, with a flow rate of 20 to 25 mL min^{-1}. Hydrogen was the fuel gas and zero air as the supporting gas having flow rates of 25 and 250 mL min^{-1}, respectively. Concentration of CH_4 in a sample was determined by calculating from the peak area obtained by injecting standard gas mixtures containing known amounts of CH_4 under the same conditions. Primary standard used was 14.04 ppmV CH_4 in N_2 for CH_4. The CH_4 flux (F) was calculated using the following equation (Debnath *et al*, 1996) [11]:

$$F = [(C_t - C_0) / t] \times H \times 42.857 \text{ mg m}^{-2} \text{ h}^{-1},$$

Where, C_0 is the CH_4 conc (ppmV) at '0' time, C_t is the CH_4 conc (ppmV) after 't' time, t is the time interval (in min) and H the head space height (in m).

Methane samples were collected from six different sites each representing the: (i) the stream water in the town, (ii) downstream water and (iii) upstream water. The gas samples were collected between 10.30 and 12.30 h, at fortnightly interval from January to May, 2013. The water temperature (15 cm below the surface) and pH was measured on the sampling sites.

RESULTS AND DISCUSSION

Socio-economic condition of the households

The results obtained from the survey revealed that, out of the 100 houses, 54 houses belong to small size families group (1 to 5 members) followed by 36 medium size families (6 to 10 members) and 10 large size families (above 10 members) (Fig. 2A). The literacy rate in these households was 84 %. A large section of the households (85 %) falls under the lower economic strata (Fig. 2B) with annual household incomes ranging between 0.5 and 2.5 lakhs (62.66 = US$ 1). About 8 % of the households have an annual income above 2.5 lakhs and 6 % of the households may be categorized as in abject poverty. Nineteen per cent of the households depend solely on governmental service for the sustenance of the family, 14 % solely on small scale business and 5 % on agricultural activities. About 49 % of the household rely on more than one of the three aforesaid occupations for livelihood. The rest of the households were engaged in others occupation such as embroidery, carpentry, tailoring, fishery-farms, poultry-farms; plying private transport, masonry, labourers, *etc.*

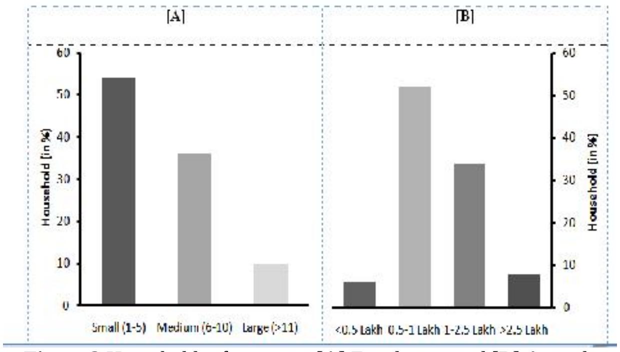

Figure 2 Household information: [A] Family size and [B] Annual income (in)

Solid waste generation and disposal

Small towns like Nambol in the region are increasingly becoming a 'throwaway society'. Average solid wastes generation in the individual household was 1.118 kg d^{-1} which amounts to per capita waste generation of 0.187 kg d^{-1}. As per the estimate given by (MoEF, 2010), solid waste generated in small, medium and large cities and towns in India is about 0.1 kg, 0.3 kg and 0.5 kg per capita d^{-1}, respectively. The waste generation rates in the Nambol fits to that of the small towns. Asnani (2006) observed that the per capita waste generation in Indian cities was between 0.2 kg and 0.6 kg. The per capita waste generation is increasing by 1.3 % per annum (MoEF, 2010). Bhide (1975) reported that the per capita solid waste generation in the cities of India during the mid-seventies, ranged from 0.150-0.350 kg d^{-1}. Dumping of wastes in nearby land represents one of the common ways of wastes disposal practice in Nambol (Fig. 3A). Fifty-four per cent of the households dumped their wastes openly in their household premises. About 31 % of the households along the Nambol *Turel* dispose their wastes either into the stream or dumped in the riverside. A small portion of the households (5 %) disposed their wastes on the roadside. Others (10 %) dispose their wastes in pits, low lying lands, drains, *etc.*

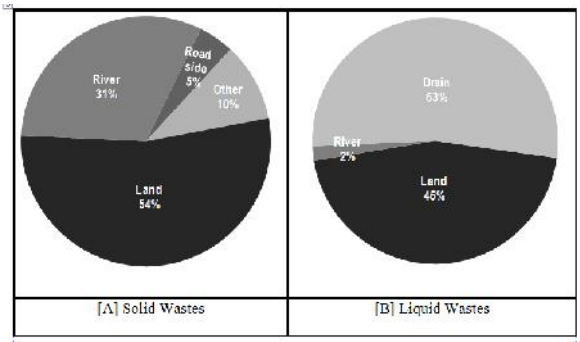

Figure 3 Waste disposal sites in Nambol Town

Liquid wastes generation

The water consumption of the studied households on per capita basis is 31.0 L d^{-1}. The water is mainly used for bathing, washing clothes, cleansing utensils, drinking, cooking, *etc.* The per capita consumption of water for toilet flushing and bathing amounted to around 7.4 L and 22 L d^{-1}, respectively. Around 53 % of the households discharge their wastewaters into the municipal drains and another 45 % way led their wastewater into their kitchen garden or low lying lands (Fig. 3B). About 02 % of the households discharge their liquid wastes directly into the stream. This is a cause of concern as the stream water is used for domestic purposes by a sizeable section of the community. About 91 % of the households in the area use tap water for drinking. The remaining houses rely on other sources such as the stream, public ponds, rainwater, hand pumps and wells (Fig. 4A). However, as the supply of tap water in the town is erratic and unreliable, the residents have to frequently resort to other sources from time to time. Rainwater forms the main source of the drinking water in most of the households for 5-6 months, during the rainy season. Around 75 % of the households depend on river for domestic uses other than drinking and cooking (Fig. 4B).

Composition of solid wastes

The composition of the household wastes generated in the town is shown in Table 1. The wastes mainly comprises of vegetable wastes, kitchen wastes, garden wastes, animal wastes, paper, wrappers, plastic and polythene, *etc.* The organic content of the waste is around 40 % and 20 % for the inorganic. Inorganic portion is mostly occupied by inert material but also include paper, plastics, glass, rubber, *etc.* The high organic content translates to high moisture content of about 50–60 % and low calorific value wastes. In India, the organic fraction of the solid waste makes up 40–85 % of the waste (NSWA, 2003). High moisture and organic content coupled with high prevailing temperature demands frequent removals (Jain, 1994). Human fecal matter is commonly found in municipal wastes (Anon, 2010). As per the Ministry of Urban Development, Government of India, 7.87 % urban households do not have access to latrines and defecate in the open, 8.13 % use community latrines and 19.49 % use shared latrines. Unlike many other parts of the country, majority of the houses in Manipur have attached toilets. In Nambol 98 % of the houses have attached toilets (Septic tank – 32 %; earthen pit – 50 %; and semi-*pucca* latrine – 6 %). The earthen dug pits represent a potent source of surface water contamination during the rainy season. Management and handling of animal wastes is not an environmental issue in the area as the population of cattle is sparse. Cattle dung are rather in short supply essentially for their demand as an ingredient of mud-plastered houses and also for preparation of dung cakes for burning.

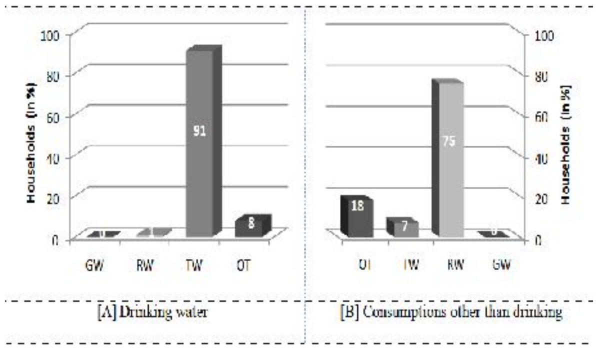

Figure 4 Dependence of households on different water sources; GW – Groundwater; RW – Rainwater, TW – Tap water; OT – Others

Table 1 Composition of Household wastes in percentages

Wastes material	%
Kitchen waste	62.5
Garden wastes	5
Paper	6
Cardboard	3
Jute bag	2
Plastic	7
Glass	2
Leather	1
Clothes	3
Rubber	0.5
Wood	1
Dust	2.5
Metals	2
Ash	2.5

Role of Municipal council

The Nambol Municipal Council currently employs six *safai karmacharis* for keeping the market and its adjoining areas free from solid wastes. Out of the six, two of them are engaged under the scheme of Swarna Jayanti Shahari Rozgar Yojana. Another 18 *safai karmacharis* are engaged for similar work covering the different wards of the town. The team of *safai karmacharis* is supervised by a male Health Supervisor and assisted by a driver. The equipments used by the workers are rather traditional in nature which includes wheel barrows, spades, shovels, *talshas*, brooms, *etc.* Two medium sized metal dustbins were used to collect wastes in the market place whereas concrete storage bins (~ 1.53 x 3.05 x 1.22 m; b x l x h) are used in the other localities. A tractor and a dumper placer are used to transport the wastes and openly dumped at a site 1 km away from the market. The site provides breeding grounds for flies, rodent and pests, besides emanating foul smell and polluting underground water through leachate seepage. The selection of site and the method of dumping wastes in Nambol are not in keeping with modern practices. Unscientific disposal of wastes is known to cause adverse impacts on all components of the environment and human health (Rathi, 2006, Ray *et al,* 2005, Jha *et al,* 2003, Kansal , 2002, Kansal *et al*, 1998, Singh and, 1998, and Gupta *et al*, 1998) . As per the directive of the (MoEF, 2010) landfills are to be designed as an engineered facility without creating nuisance and contamination of surrounding natural environment. However, due to lack of finances of the local government as in the case of Nambol, open dumping remains the dominant disposal method in most of the developing countries (Barton et al, 2008).

Role of Informal Sector

Worldwide, private stakeholders are known to contribute significantly in solid waste management. They play a very important role in recycling of wastes. In India it is achieved primarily through informal *kavariwalas* who go from door to door and collect used bottles, broken plastics, metal scraps, waste paper, *etc*. The material is then traded for manufacture of secondary products. The national waste legislation, introduced in India in 2000, endorses the principle of 'Recycle before Disposal' and also recommends waste separation as prerequisite for treatment (Delaune *et al*, 1983). In Manipur, the mobile waste collection is largely men dominated occupation. They collect the recyclable and reusable wastes and sell them to the small scale waste dealer on day to day basis. Monetary values assigned to such waste materials are quite flexible and may vary with space, time and person. The average monetary value for some of the waste materials recorded during the period of study (September, 2013) was 4.0, 18.0, 5.0, 7.0, and 4.0, (62.66 = US$ 1) respectively for a kilogram of newspaper, iron pieces, book, metal cans and plastic materials (Table 2).

Table 2 Price (in) of different wastes materials

Materials	Price kg^{-1}
Iron pieces	18.0
Iron roofing sheet	9.0
Metal can	7.0
Aluminium	75.0
Plastic material	4.0
Newspaper	4.0
Note book/book	5.0
Bronze	200.0
Copper	310.0
Battery	1200.0
Glass bottle*	0.5
Plastic bottle	5.0
Jute bag (Rice)*	5.0
Jute bag (Sugar)*	25.0

* price for single piece

The small scale waste dealer sent the accumulated metal scraps to the iron processing plant at Senapati district in the state. Most of the plastics materials are channelized into two factories in state capital, where the plastics are sorted and cut in small pieces before sending to Guwahati for further processing. The silver, copper and bronze pieces are segregated and processed for markets at Kolkota.

Role of community

Traditionally, in the rural setup, the households managed their wastes themselves through 'dilute and disperse' or 'manage in your own yard' strategy. Recent changes in the lifestyle of the people and corresponding variation in quality, quantity and heterogeneity of the wastes demands more appropriate waste management framework and strategy. In the absence of proper municipal waste management drive, most of the houses dumped their wastes in open pit and burns it periodically. Where cattle and poultry animals are available in good number composting of litter, biomass and animal excreta is generally observed. Collection of kitchen wastes for swine feeding is one of the compelling factors for segregation of wastes at source in some of the houses. While waste management at household level as such is encouraging; it has the potential of ending up with serious environmental implications. Improper disposal of household electronic gadgets including fused CFL bulbs, dry cells, damaged lead storage batteries, LED lamps, damaged mobile phones and batteries, compact disks, to mention some, may pose health problems. For instance, a total of 680 incandescent bulbs, 137 CFL bulbs, 210 tube-lights and 5562 dry cell batteries were generated per hundred households in Nambol in a year. Burning of plastics, packaging material and other wastes, widely practice by the residents are known to emit various noxious gases.

Table 3 Physico-chemical characteristics of upstream water

Parameters	Winter		Pre-monsoon	
	Range	Average	Range	Average
Water Temp. (°C)	8.4 – 9.6	8.8 ± 0.1	29.0 – 31.0	30.0 ± 0.6
pH	6.5 – 7.5	7.1 ± 0.3	7.7 – 8.3	7.9 ± 0.2
EC (μS cm^{-1})	139.0 – 156.0	149.7 ± 5.4	165.0 – 172.0	168.3 ± 2.0
DO (mg L^{-1})	2.4 – 3.5	2.9 ± 0.3	6.1 – 9.9	8.4 ± 1.2
Free CO2 (mg L^{-1})	6.0 – 8.0	7.3 ± 0.7	4.0 – 8.0	5.3 ± 1.3
TotalHardness(mg L^{1})	56.0 – 74.0	62.7 ± 5.7	60.0 – 70.0	64.0 ± 3.1
Calcium (mg L^{-1})	12.6 – 16.8	15.1 ± 1.3	15.1 – 21.9	17.7 ± 2.1
Ca Hardness (mg L^{-1})	31.5 – 42.0	37.8 ± 3.2	37.8 – 54.6	44.1 ± 5.3
COD (mg L^{-1})	52.8 – 62.4	59.2 ± 3.2	137.6– 152.0	145.3± 4.2

± *Standard Error*

Analysis of Stream water

The data presented in Table 3-5, showed that the physico-chemical parameters of the stream water varied both spatially and temporally. The water temperature in Nambol *Turel* varied between 8.3°C and 31.0°C. The pH of the stream water ranged from slightly acidic during the winter season to slightly alkaline during the warmer season. The electrical conductivity (EC) of the urban water during the winter ranged between 141 and 151 μS cm^{-1}, with an average of 146.3 ± 2.9 μS cm^{-1}. Corresponding EC of the stream water during the pre-monsoon period ranged between 168 and 190 μS cm^{-1}, with an average of 176.7 ± 6.8 μS cm^{-1}. The values of EC in the Nambol River water of Manipur ranged between 120 to 200 μS cm^{-1} (Basanta Kumar *et al*, 2011). The EC values observed in the current investigation were well below the recommended limits of conductivity prescribed by WHO (750 μS cm^{-1}). The dissolve oxygen (DO) content in the upstream water was comparatively higher (winter – 2.9 ± 0.3 mg L^{-1} and pre-monsoon – 8.4 ± 1.2 mg L^{-1}) than the stream water meandering through the town (winter –2.3 ± 0.5 mg L^{-1} and pre-monsoon – 7.9 ± 0.6 mg L^{-1}) and the downstream water (winter – 2.5 ± 0.3 mg L^{-1} and pre-monsoon – 7.4 ± 0.4 mg L^{-1}). The concentration of free carbon dioxide was higher in the section of stream meandering through the town (winter – 10.7 ± 1.8 mg L^{-1} and pre-monsoon – 7.3 ± 1.8 mg L^{-1}) compared to the upstream (winter – 7.3 ± 0.7 mg L^{-1} and pre-monsoon – 5.3 ± 1.3 mg L^{-1}) and downstream water (winter – 9.0 ± 1.3 mg L^{-1} and pre-monsoon – 6.0 ± 1.4 mg L^{-1}). The COD of the stream water closely follow the pattern of variation with that of free CO_2, with higher values in the stream flow passing the town.

Table 4 Physico-chemical characteristics of water in town

Parameters	Winter		Pre-monsoon	
	Range	Average	Range	Average
Water Temp. (°C)	8.3 – 10.2	9.4 ± 0.14	29.0– 31.0	30.0± 0.6
pH	6.8– 7.6	7.3± 0.3	7.8– 8.1	7.9± 0.1
EC (μS cm^{-1})	141.0–151.0	146.3±2.9	168.0– 190.0	176.7± 6.8
DO (mg L^{-1})	1.6– 3.2	2.3± 0.5	6.9– 8.9	7.9± 0.6
Free CO_2 (mg L^{-1})	8.0– 14.0	10.7± 1.8	4.0– 10.0	7.3± 1.8
Total Hardness(mg L^{-1})	50.0– 62.0	57.3± 3.7	56.0– 78.0	65.3± 6.6
Calcium (mg L^{-1})	9.3– 13.5	11.5± 1.2	12.6– 18.5	16.3± 1.8
Ca Hardness (mg L^{-1})	23.1– 33.6	28.7± 3.1	31.5– 46.2	40.6± 4.6
COD (mg L^{-1})	128.0– 158.0	142.3± 8.7	143.8 – 166.4	156.1 ± 6.6
±*Standard Error*				

Table 5 Physico-chemical characteristics of downstream water

Parameters	Winter		Pre-monsoon	
	Range	Average	Range	Average
Water Temp. (°C)	8.3 – 10.2	9.4 ± 0.14	28.4 – 29.2	28.8 ± 0.2
pH	6.9 – 7.6	7.3 ± 0.14	7.9 – 8.4	8.16 ± 0.1
EC (μS cm^{-1})	162.0– 179.0	169.2 ± 3.9	159.0 – 182.0	172.5 ± 4.8
DO (mg L^{-1})	1.8 – 3.0	2.5 ± 0.3	6.9 – 8.5	7.4 ± 0.4
Free CO_2 (mg L^{-1})	6.0 – 12.0	9.0 ± 1.3	4.0 – 10.0	6.0 ± 1.4
Total Hardness(mg L^{-1})	42.0 – 64.0	55.5 ± 5.0	56.0– 68.0	63.0 ± 3.0
Calcium (mg L^{-1})	13.5 – 15.9	14.7 ± 0.5	10.0 – 14.3	11.9 ± 0.9
Ca Hardness (mg L^{-1})	33.6 – 39.9	36.8 ± 1.4	25.2 – 35.7	29.9 ± 2.3
COD (mg L^{-1})	41.6 – 70.4	58.0 ± 6.0	116.0–146.4	135.2± 7.2
±*Standard Error*				

The total hardness in the upstream water varied from 62.67 ± 5.7 mg L^{-1} (winter) to 64.0 ± 3.1 mg L^{-1} (pre-monsoon). Corresponding values of total hardness, in the stream water, meandering through the town was 57.3 ± 3.7 mg L^{-1} (winter) and 65.3 ± 6.6 mg L^{-1} (pre-monsoon). In the downstream water, the average seasonal variation in total hardness ranged between 55.5 ± 5.0 mg L^{-1} (winter) and 63.0 ± 3.0 mg L^{-1} (pre-monsoon). The calcium content in the upstream water was 15.1 ± 1.3 mg L^{-1} (winter) and 17.7 ± 2.1 mg L^{-1} (pre-monsoon). During the study period the calcium content in the section of stream flow passing the town varied from a minimum of 9.3 mg L^{-1} and maximum of 13.5 mg L^{-1}. The calcium hardness in the different sections of the stream during the current investigation was: (a) upstream water (winter – 37.8 ± 3.2 mg L^{-1} and pre-monsoon – 44.1 ± 5.38 mg L^{-1}), (b) section meandering through the town (winter – 28.7± 3.1 mg L^{-1} and pre-monsoon – 40.6 ± 4.6 mg L^{-1}), and (c) downstream water (winter –36.8 ± 1.4 mg L^{-1} and pre-monsoon – 29.9 ± 2.3 mg L^{-1}).

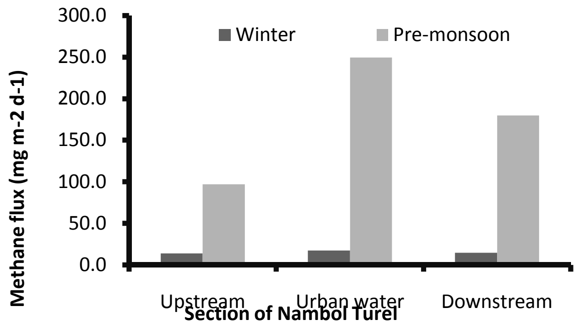

Figure 5 Average methane flux from the stream

CH_4 flux from the stream

Methane flux from the Nambol *Turel* showed both spatial (upstream water, urban water and downstream water) and temporal variation (pre-monsoon and winter) (Fig. 5). Methane emission rates were found consistently higher in the section of the stream meandering through the town compared to the flux in the upstream and downstream waters. The recorded mean CH_4 flux in the urban, upstream and downstream water during the pre-monsoon was 249.6 ± 18.7; 97.2 ± 7.7 and 179.9 ± 18.8 mg m^{-2} d^{-1}, respectively. The spatial differences was statistically significant (ANOVA, P= <0.05) during pre-monsoon, but was not significant during winter season (P= >0.05). This spatial difference in the CH_4 is largely attributed to the incorporation of *ex-situ* carbon into the stream. Spatial variability is common in measurements of gaseous fluxes, even at sites which appear to be homogenous (Delaune *et al*, 1983 and Moore, 1986). Studies on CH_4 emission in wetlands worldwide by different researchers showed varying emission rates. Barltett and Harris (1993) calculated the mean values of CH_4 flux for tropical bog and fens, swamps, marshes, floodplains and lakes as 99, 165, 233, 182 and 148 mg m^{-2} d^{-1}, respectively. The results of the current study revealed that the CH_4 flux from the stream showed a marked seasonal variation (Fig. 5). The mean CH_4 flux was recorded higher during the pre-monsoon in all the three sections of stream water (urban water, 249.6 ± 18.7 mg m^{-2} d^{-1}; upstream water, 97.2 ± 7.7 mg m^{-2} d^{-1}; downstream water, 179.9 ± 18.8 mg m^{-2} d^{-1}) compared to winter (Urban water, 17.5 ± 1.4 mg m^{-2} d^{-1}; Upstream water, 13.9 ± 1.4 mg m^{-2} d^{-1}; downstream water, 14.6 ± 1.5 mg m^{-2} d^{-1}). The seasonal difference in CH_4 flux was statistically significant (ANOVA, P = < 0.05). This seasonal difference in the CH_4 emission might be mainly due to the influence of seasonal variation in water temperature on CH_4 production. The mean water temperature recorded at the gas sampling site during the pre-monsoon and winter seasons was 29.6 and 9.2^0 C, respectively and the water temperature had a linear correlation with CH_4 flux: y = 7.832x – 56.491 (R^2 = 0.6757). Methane production and emission from natural and agricultural wetlands have been correlated to water temperature (Conrad, 1989). In the Nambol *Turel*, the methanogenic bacteria were working in the mesophilic range during the pre-monsoon and switched on to psychrophilic range (0–20^0 C) during winter season. These seasonal change in water temperatures affected a drastic fall in CH_4 production during winter

CONCLUSION

Conservation of streams and lakes requires proper management of municipal solid wastes and treatment of incoming wastewater. The Municipal Council in Nambol is nowhere in a position to handle effectively the quantum of wastes generated in the town. A sizeable portion of the wastes, both solid and liquid reached the Nambol *Turel* directly or indirectly polluting the stream. Deterioration in water quality in feeder streams like Nambol *Turel* is a matter of urgent concern taking in consideration the nature of dependence of the community on the stream water and by and large for the conservation of the Loktak Lake. Large scale incorporation of *ex-situ* carbon in the stream augmented the substrate supply for biomethanation in the stream, enhancing the atmospheric CH_4 budget. To curtail these environmental menaces, there is need for formulation of an environmentally prudent waste management strategy for Nambol giving proper emphasis on the population, rate of urbanization and nature of wastes. While doing so, special attention must be given to the portion of the town that disposes untreated waste directly into the stream. Municipal authorities on their parts should take up necessary steps to mobilize, educate and streamline the community on matters related to handling and management of wastes.

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