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Creating Eco Societies

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-The art is based on "Wastewater"- the theme for World Water Day 2017

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Editorial

It gives us immense pleasure to share with you this "Journal of Environment and Public Health", a collection of research papers from the WASH sector. ENPHO is one of the prominent organizations contributing in the areas of safe Water, sustainable Sanitation, better Hygiene (WASH), environment and public health. It combines research and action to develop, demonstrate and disseminate sustainable and appropriate WASH technologies and approaches. This publication aims to disseminate research findings and information on WASH. The papers included in this publication resonate with the theme of World Water Day 2017 i.e. "Wastewater".

Furthermore, we intend to give continuity to this publication as a yearly publication, publishing on the occasion of World Water Day.

We would like to express our sincere gratitude to all the authors/contributors for their papers and support in making this publication successful. We highly anticipate constructive feedback and suggestions from readers to make further improvement in coming days.

Thank you all for your kind cooperation and support.

Environment and Public Health Organization (ENPHO)

Contents

Status of wastewater generation and management in urban Nepal 1-6
Shrestha, P., Shrestha, R. and Dangol, B.

Characterization of wastewater in Nepal 7-12
Dhakal, I. and Nakarmi, P.

Situational assessment tools for citywide sanitation planning 13-20
Sherpa, M. G., Manandhar, A., Thapa, B. and Lüthi, C.

Performance of DEWATS in Nepal 21-26
Shrestha, J. and Kalu S.

Decentralized integrated wastewater and solid waste management 27-31
Shrestha, R.

Potential of wastewater use in irrigated agriculture: Case of Harisiddhi wastewater treatment plant, Nepal 32-39
Dongol, R. and Baidya, M.

Productive reuse of organic waste in rooftop farming: A case study from Kathmandu Metropolitan City 40-44
Shakya, S., Shrestha, J. and Kansakar, L.K.

Human urine application in rice and potato production 45-50
Nakarmi, P., Shakya, S., Dhakal, I. and Kansakar, L.K.

Co-treatment of faecal sludge with wastewater treatment systems: A systematic review 51-58
Dangol, B.

Faecal sludge treatment and reuse system in Mahalaxmi Municipality, Nepal 59-64
Rajbhandari, R. and Dangol, B.

Water quality of Bagmati river in Kathmandu valley: 2011-2014 65-73
Bhandari, B., Joshi, L., Shrestha, P. and Nakarmi, P.

Status of wastewater generation and management in urban Nepal

Shrestha, P., Shrestha, R. and Dangol, B.

Abstract

Wastewater management is an emerging issue in urban areas, mostly in low-income countries including Nepal. Considering the need of better wastewater management, there is a need for updated data and information on wastewater generation and treatment. This paper presents the estimated wastewater generation in urban areas and current status of wastewater management in Nepal. The intensive literature review on wastewater management including production and treatment were done to gather data and information. The data shows that 70% of total urban wastewater production is collected in on-site sanitation system and 30% is collected by sewer. The theoretical estimation of total wastewater production in urban area is 867 MLD. It was found that only 7% of wastewater is treated in Nepal. Both centralized and decentralized systems were found to be implemented at various scale.

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Key words: grey water, sewerage, treatment, urbanization

Introduction

Wastewater management is global issue. An estimated 90 percent of wastewater in developing countries is discharged directly into water bodies(Corcoran *et al.,* 2010). Sato (2013) found that about 70% of wastewater is treated in high-income countries compared to about 8% in low-income countries. Most of the growing cities have inadequate and outdated sewerage infrastructures due to which wastewater is the main factor of increasing dead zones in water bodies around the world (WWAP, 2012). Rapid urbanization and urban population growth has resulted in increased wastewater production and the number of people vulnerable to the impacts of severe wastewater pollution. The world population data sheet 2016 shows that 54 percent of the world population is living in urban areas (Population Reference Bureau, 2016). World Urbanization Prospects 2014 has listed Nepal as one of the top ten fastest urbanizing countries in the world (as cited in Bakrania, 2015). Central Bureau of Statistics (2016) estimates that population living in urban areas of Nepal increased from 6.4% in 1981 to 38.2 % in 2014. After declaration of new municipalities in 2015, the population living in urban areas has increased to 42.5% (Figure 1). With the increased urban population, the wastewater generation in urban Nepal is increasing. The proper wastewater management is, therefore, persisting issue in Nepal.

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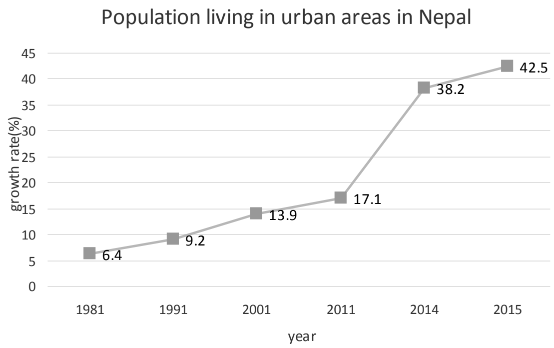

Figure 1: Urbanization trend of Nepal

According to the census 2011 in urban areas, 30 percent households are connected to sewerage systems, 60 percent households have on site sanitation systems such as septic tank and pit latrine and about 9 percent households do not have access to latrines (CBS, 2012). The Government of Nepal has plan to connect the entire urban household with sewerage system by 2030 (NPC, 2016). The baseline data and target for wastewater treatment is, however, missing in the plan. The recent data on wastewater management including production and treatment in urban areas of Nepal is very limited.

The objective of the paper is to present current status of wastewater management in urban Nepal and to estimate the current wastewater generation.

Methodology

The data on wastewater production and management were collected by intensive literature review of published and web-based online sources. The census reports were reviewed to compile population, household data that were further used for estimation of wastewater generation. Several reports and documents published by the government and non-government agencies were studied to understand and document status of wastewater management in Nepal.

Results and Discussion

History of Wastewater management in Nepal

There are no specifically written evident about the ancient practices of wastewater management in Nepal. The *Hiti* system, established as water supply technologies since the Licchavi period (300 AD – 879 AD) in Kathmandu Valley, can be found integrated with the wastewater management. The *Hiti* is ancient water supply system with an underground water conveyance and stone spout of water serving as a tap. The system uses shallow aquifers. *Hities* are located either next to the aquifer or are connected to the far away the aquifer using burnt clay or wooden channels with gravity flow. Normally wastewater from the *Hities* are drained out the settlement through underground *Dhon*, the drainage. In some cases, this water is collected in a pond and utilized for agricultural products washing, duck farming. Similarly during Malla dynasty (1200-1768) the sewers in the major settlements of Kathmandu valley were built as a combined sewer for domestic sewage, basically grey water and surface drainage. The sewage was thrown freely in open fields with the outfalls located in open fields. The collected water was used for irrigation purposes. Rana dynasty (1898-1950) had further developed the sewerage system of core area of Kathmandu Valley. The main sewers made of bricks were circular or oval in section with diameter of 600 mm. Absence of toilets with flushing facilities in Valley during Rana dynasty led the construction of sewers only for storm water drainage and after 1950, was changed into combined sewer system with feeding unauthorized sanitary sewers from houses and industries (Nyachhyon, 2006). The development of modern sewer system in the country started towards 1920s that include 55 km long brick channel to collect and dispose combined sewer and rainwater runoff in Kathmandu and Patan (Nyachhyon, 2006 cited in Shukla *et al.,* 2012). Sustainable management of wastewater is one of the traditional practices since Malla period in Kathmandu Valley which can be seen in the historical Newar settlements yet. The old aged tradition comprises systematic collection, conveyance, storage (treatment) and safe disposal of domestic wastewater which is further reused mainly in agriculture.

Current scenario of wastewater management in Nepal

Wastewater production and sewer system in Nepal

The source of wastewater in Nepal are mostly domestic and commercial (washing and other sanitary activities) with addition of industrial wastewater in urban areas. Approximately 93 percent of the total wastewater generated in the cities is domestic and remaining 7 percent is industrial wastewater (KUKL, 2013). The census data shows that 70% of wastewater production particularly faecal sludge has been managed by using on-site sanitation system whereas the remaining (30%) of wastewater production is collected by existing sewer network (CBS, 2012). The projected population of the country in 2016 is 28.3 million with the growth rate of 1.35 percent per annum out of which 12 million has been projected as urban population based on census of 2011. With the consideration of water demand of 100 lpcd for urban areas and 80 percent of total water use is turned into wastewater, the theoretical calculation of domestic wastewater production in urban areas of Nepal is 867 MLD.

Based on the data 30 percent of urban household are connected to sewer network, 288 MLD of wastewater of total estimated volume is conveyed through the sewer network. The calculation showed that only 7 percent i.e. 20 MLD out of 288 MLD is being treated through the existing functional centralized and decentralized wastewater treatment plants in Nepal. The remaining 93 percent wastewater that is not connected to sewer, is disposed into the nearby rivers without treatment. There are five major centralized system installed in Kathmandu valley out of which only one system at Gujeshowri is currently functioning and it contributes to about 86.1 percent of wastewater treatment. The remaining 13.9 percent of wastewater is treated by 22 decentralized systems that are functioning properly (Figure 2). Due to higher volume of wastewater disposal in nearby rivers, the receiving rivers are being polluted and their protection has also been a challenge.

Wastewater treatment in Nepal

In 1975, modern technologies of wastewater treatment system was introduced for first time in Nepal with the establishment of wastewater treatment plant at Hanumaghat. In early 1980s wastewater treatment wastewater treatment plants were established at Kodku and Dhobighat, and Sallaghari (KUKL, 2013). To avoid the pollution in Bagmati river along the religious area of Pashupati Nath, High Power

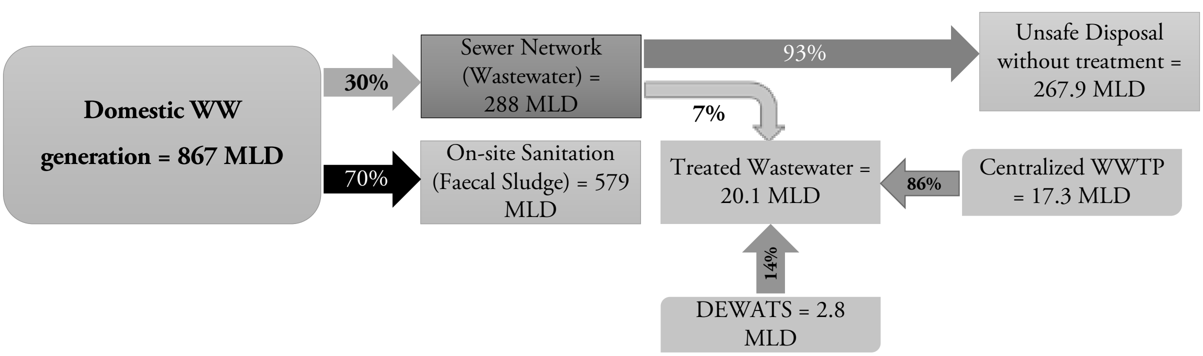

Figure 2 : Domestic wastewater flow diagram of urban areas in Nepal

Commission for Integrated Development of Bagmati Civilization (HPCIDBC) constructed Guheshwori wastewater treatment plant which came into operation in 2001 (Shukla *et al.,* 2012). These treatment plants comprise primarily of oxidation ponds and activated sludge oxidation ditch. Guheshwori treatment plant is the only centralized system out of five centralized systems that is currently functioning (Table 1).

The Kathmandu Valley Wastewater Management Project implemented by KUKL/PID with the support from ADB has set target to treat 90.5 MLD and 382.1 MLD of wastewater by 2020 and 2030 respectively in Kathmandu valley (KUKL, 2013).

In 1997, decentralized wastewater treatment system (DEWATS) was introduced in Nepal as constructed wetland technology in Dhulikhel hospital (Shrestha *et al.,* 2001) observed more than 95 percent of major pollutants had been removed during time interval of 1997-2000 (Jha and Bajracharya, 2014). After its successful operation, more than 60 DEWATS have been established at community, municipality and institutional scale throughout the country. From the latest study conducted by ENPHO (2017), 22 out of 60 DEWATS was found to be in operation and most of them are managed by institution and community (Figure 3). Bagmati Action Plan (2009-2014) has also recommended DEWATS as a new approach to manage wastewater in peri-urban and rural areas in Kathmandu valley (GoN/NTNC, 2009).

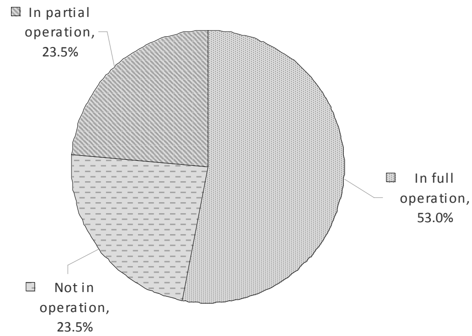

Figure 3 : Existing operational status of DEWATS (Source: ENPHO, 2017)

Conclusion

This paper reviews the existing trend of wastewater production and the status of its management. Urbanization is taking place rapidly and uncontrollably and the trend is more significant in last few years. As a result, wastewater production is abruptly increasing and lack of proper wastewater management is posing significant threats to human health, well-being and economic activity.

The theoretical estimate of the wastewater generation is 867 MLD in urban areas where 70% is collected in on-site sanitation system and 30% is collected by sewer. Nearly 7% of wastewater is treated out of which 86% is contributed by centralized wastewater treatment system and 14% by DEWATS. The Government of Nepal has plan to manage wastewater in Kathmandu Valley by establishing centralized and decentralized wastewater treatment systems.

Table 1: Status of Decentralized Wastewater Treatment Plants of Nepal

SN	Location	Year of operation	Catchment Served	Design Capacity (MLD)	Current Operational Status
1	Hanumanghat	1975	North-east Bhaktapur	0.5	Not in operation
2.	Kodku	1982	East Lalitpur	1.1	Not in operation
3	Dhobighat	1982	Kathmandu & Lalitpur	15.4	Not in operation
4	Sallaghari	1983	North & South Bhaktapur	2	Not in operation
5	Guheshwori	2001*	Gokarna & Chabahil	17.3*	In partial operation

Source: KUKL, 2013 and Shukla *et al.,* 2012
*: Source, CBS, 2012

The rapid urbanization, steep population growth and increasing unplanned settlements are some of the key challenges to ensure provision of wastewater management services to all in the future. In addition, proper operation and maintenance, viable business plan including financing aspects and operation models should be considered to ensure the functionality and sustainability of wastewater treatment systems.

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Characterization of wastewater in Nepal

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Abstract

Across the world, there continues to be huge volumes of wastewater discharged directly into rivers, streams and oceans. Disposing of wastewater is largely an issue in developing nations like Nepal. It is important to treat the wastewater before it comes in contact with the environment. In order to treat the wastewater and to design the treatment system, it is crucial to know the nature of the wastewater, as the quality of effluent largely depends upon the influent characteristics. The capacity and efficiency of treatment systems are designed based upon the influent concentrations and the effluent requirements. This study analyzed 269 untreated wastewater samples received by the Environment and Public Health Organization (ENPHO) laboratory and characterized them in terms of pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Nitrate (NO_3), Ammonia (NH_4), Total Kjeldahl Nitrogen (TKN), Total Phosphorus (TP), Total Suspended Solids (TSS), Oil & Grease (O&G) and Dissolved Oxygen (DO). Based on the source of generation, these samples were categorized as domestic, industrial or hospital wastewater. The mean BOD and COD values of tested samples were found to be 377 mg/L and 638 mg/L respectively. The maximum COD was found to be 10,032 mg/L and maximum BOD was found to be 5,050 mg/L. Significant differences were found in TKN and DO values among different types of sources. Difference in characteristics of wastewater from different sources indicates the necessity of their characterization before choosing treatment options. In general, the high values of the tested parameters in comparison to the national industrial effluent standards show the urgency of the treatment of wastewater owing to the practice of its unsafe disposal into the environment without any treatment.

Key words: BOD, COD, DO, effluent, TKN, TSS

Dhakal, I., & Nakarmi, P. (2017). Characterization of wastewater in Nepal. *Journal of Environment and Public Health*, 1(1), pp. 7-12. Published by ENPHO, Kathmandu, Nepal.

Introduction

Untreated sewage, industrial wastewater and agricultural runoff are the major water pollutants in Nepal (WaterAid, 2008). This effectively converts the water resources into open sewers, thus causing serious disturbances in the aquatic environment and impacts both the ecosystem and human life. According to the 2011 census of Nepal, 4.52 million people (17% of the population) live in 58 municipalities of Nepal. Among them, 91% of households have toilets (CBS, 2011a). Of those households, 30% have toilets connected to sewer systems while 47.5% have toilets connected to septic tanks (CBS, 2011b). As most pipelines are directly connected to a water body or river, only 5% of generated wastewater is being appropriately treated (WaterAid, 2008). Also, the wastewater generated in most industries in Nepal is mixed with the municipal sewerage system (Jha *et al.,* 2011). In case of Kathmandu, wastewater of all kinds including grey water, leachate from dumping sites and septage from septic tanks is released directly to water bodies without any treatment (Ellingsen, 2012). It is imperative to treat this wastewater before it enters the environment. When designing wastewater treatment systems the nature of the wastewater must be considered, as the quality of effluent depends much upon the influent characteristics. The capacity and efficiency of treatment systems are calculated based upon the influent concentrations and the effluent requirements (Gross, 2005). As the nature of wastewater depends upon its origin, not all types of wastewater need similar treatment. For instance, domestic wastewaters have high organic loads while industrial wastewater may be loaded with heavy metals (Henze and Comeau 2008; Sperling 2008). With the rising awareness and interest in treatment of wastewater in recent years, understanding the characteristics of wastewater is critical to design a suitable capacity to address the treatment needs of particular types of waste. This study therefore highlights the difference in characteristics of wastewater based on the source of generation.

Methodology

Of 714 wastewater samples tested at ENPHO during the last five years (2012-2016), 269 untreated or raw wastewater samples were selected for analysis. Treated samples and effluent from treatment plant were not considered for this study, as the source of generation of treated wastewater samples were not known in most cases. The characteristics of wastewater were analyzed in terms of 10 parameters (Table 1).

Characteristics of Influent

Of 269 untreated wastewater samples, 82% (220) were domestic, 13% (35) were industrial and 5 (14) were hospital wastewater (Figure 1).

Table 1: Test Methods Used for Analysis of Different Parameters

SN	Parameter	Reference
1	pH	APHA, AWWA, WEF (2012), 4500-H B
2	Chemical Oxygen Demand (COD)	APHA, AWWA, WEF (2012), 5220 B
3	Nitrate (NO_3)	APHA, AWWA, WEF (2012), 4500-NO_3 B
4	Total Kjeldahl Nitrogen (TKN)	APHA, AWWA, WEF (2012), 4500 - Norg B
5	Total Phosphorus (TP)	APHA, AWWA, WEF (2012), 4500 P F
6	Total Suspended Solids (TSS)	APHA, AWWA, WEF (2012), 2540 D
7	Biochemical Oxygen Demand (BOD)	APHA, AWWA, WEF (2012), 5210 B
8	Oil and Grease (O&G)	APHA, AWWA, WEF (2012), 5520 B
9	Ammonia (NH_4)	APHA, AWWA, WEF (2012), 4500-NH_3 F
10	Dissolved Oxygen (DO)	APHA, AWWA, WEF (2012), 4500-O C

Based on the sources, wastewaters were categorized as domestic, industrial or hospital wastewater for further interpretation.

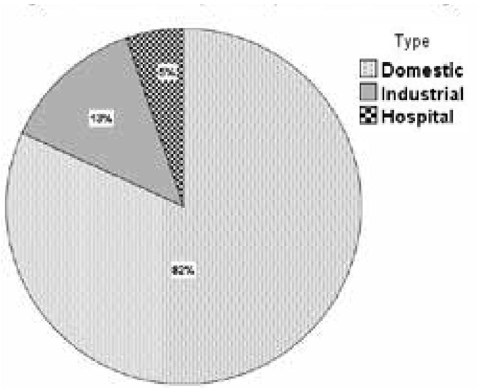

Figure 1: % of Wastewater Samples with Respect to Different Sources of Generation

The composition of typical domestic, industrial and hospital wastewater is shown in Table 2.

Table 2: No. of Samples Analyzed for Different Parameters Based on Sources of Generation

Type	Domestic	Hospital	Industrial	Grand Total
pH	51	10	6	67
TSS	138	10	6	154
BOD	50	14	25	89
COD	200	14	32	246
Ammonia	19	10	2	31
DO	8	13	-	21
TP	64	-	2	66
TKN	11	9	-	20
Nitrate	45	10	-	55
Oil & Grease	21	10	10	41

One way ANOVA test was carried out to test the difference in wastewater characteristics among different sources of generation. Pearson correlation test was applied to identify the relationships between the parameters tested. All the statistical analyses were carried out at 95% confidence interval and data were analyzed using SPSS.

Results

The overall mean value of BOD and COD was found to be 377 mg/L and 638 mg/L respectively (Table 3). Differences were observed among COD values of all sources; the highest was observed in industrial sources, followed by domestic and then hospital wastewater. In the case of BOD, the mean value was found to be highest in domestic wastewater. TSS values were found to be highest in industrial wastewater and lowest in hospital wastewater. Conversely, pH was found to be highest in hospital wastewater and lowest in industrial wastewater. Oil and grease was found to be highest in industrial wastewater and lowest in domestic wastewater (Table 3).

Table 3: Mean, Maximum and Minimum Values of Tested Parameters Among Different Sources of Wastewater

Parameters	Type								
	Domestic			Industrial			Hospital		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum	Mean	Minimum	Maximum
pH	7.04 (± 0.92)	4	9	6.67 (± 1.51)	5	9	7.1 (± 0.32)	7	8
TSS (mg/L)	356 (± 704.89)	3	6150	429 (± 767.85)	16	1984	195 (± 362.66)	6	1144
DO (mg/L)	1 (± 1.31)	0	3	-	-	-	4 (± 3)	0	8
BOD (mg/L)	420 (± 732.01)	8	5050	411 (± 509.07)	10	2275	166 (± 233.56)	3	652
COD (mg/L)	640 (± 1002.07)	16	10032	766 (± 1372.09)	0	7488	329 (± 467.9)	6	1373
Ammonia (mg/L)	118 (± 106.46)	24	370	17 (± 23.33)	1	34	48 (± 51.25)	19	183
Nitrate (mg/L)	6 (± 6.14)	0	34	-	-	-	4 (± 3.14)	1	10
TKN (mg/L)	385 (± 294.66)	65	846	-	-	-	44 (± 36.02)	17	112
TP (mg/L)	16 (± 18.83)	0	98	2 (± 2.12)	0	3	-	-	-
Oil & Grease (mg/L)	18 (± 27.83)	0	121	37 (± 55.06)	0	159	2 (± 2.23)	0	6

Of the tested parameters, only TKN and DO were found to be significantly different among the sources (p-values < 0.05). Statistically, BOD was found to be significantly correlated with COD, TKN and TSS. Similarly, COD was found to be significantly correlated with TSS, BOD, ammonia and TKN (p-values < 0.01) (Table 4).

Discussion

The study indicates that the characteristics of wastewater vary among sources. Mean values for BOD, ammonia, organic nitrate and total phosphorus were found to be higher in domestic wastewater compared to other sources. The high value of BOD in domestic wastewater reflects the high organic matter content from carbohydrates, fats and protein in the waste. Sukumaran *et al.,* (2008) stated that when wastewaters with high BOD enter water bodies, assimilation of organic matters by microbial activity, and hence the oxygen consumption, leads to hypoxic conditions in water bodies with consequent adverse effects on aquatic biota and aesthetics of water (Noorjahan, 2014). Similarly, high levels of nitrate and phosphorus can lead to eutrophication which increases algal growth and ultimately reduces dissolved oxygen in the water. Algal blooms not only disrupt the aesthetics of a water body but can also hinder water treatment processes such as filtration, coagulation, sedimentation and chlorination.

In the case of industrial wastewater, TSS, COD and oil & grease were found to be the highest and BOD was found to be similar to domestic wastewater. The high COD may be due to the high concentration of inorganic oxygen demanding wastes from different industries like paper mills and dye industries, which cause lowering of DO levels in water. The oil & grease layer reduces biological activity in the treatment processes and also causes clogging of pipes in treatment units, thus leading to high cleaning and maintenance costs (El-gawad, 2014). TSS was found to be positively and significantly correlated with BOD and COD (Table 4). The correlation of TSS, BOD and COD indicates that removal of suspended particles through settlement only – a simple wastewater treatment component – can remove much of the BOD and COD from wastewater.

Though the mean values of the studied parameters are comparatively lower in hospital wastewater, it is important to understand that the main constituents of hospital wastewater are different than household or industrial wastewaters. Hospital waste can comprise of infectious liquids, antibiotics, estrogens and metals such as mercury or platinum, used in different medication procedures (Pauwels & Verstraete, 2006).

Table 4: Correlations (p-values) Among Tested Parameters

Parameters	TSS	BOD	COD	Ammonia	pH	Nitrate	Oil & Grease	TKN	TP	DO
TSS	-	.000	.000	.013	.071	.210	.066	.000	.054	.049
BOD	-	-	.000	.049	.018	.677	.197	.000	.170	.094
COD	-	-	-	.008	.044	.470	.848	.001	.017	.083
Ammonia		-	-	-	.302	.178	.340	.002	.002	.075
pH	-	-	-	-	-	.240	.465	.002	.578	.696
Nitrate	-	-	-	-	-	-	.879	.933	.807	.190
EC	-	-	-	-	-	-	-	.000	.382	-
Oil & Grease	-	-	-	-	-	-	-	.849	.909	.914
TKN	-	-	-	-	-	-	-	-	.079	.046
TP	-	-	-	-	-	-	-	-	-	.185
DO	-	-	-	-	-	-	-	-	-	-

Table 5: BOD/COD for Different Sources of Wastewater

Ratio	Domestic	Industrial	Hospital	Medium Strength Municipal Wastewater (Henze & Comeau, 2008)
BOD/COD	0.66	0.54	0.50	0.4
COD/TKN	1.66	-	7.56	8 to 12
BOD/TKN	1.09	-	3.81	4 to 6
COD/TP	39.51	510.63	-	35 to 45
BOD/TP	25.94	274.11	-	15 to 20

Mara (2004) found the BOD/COD ratio of untreated domestic wastewater to be approximately 0.5. This study found the BOD/COD ratio for domestic, industrial and hospital wastewater to be 0.66, 0.54 and 0.50 respectively (Table 5). Abdallaa and Hammamb (2014) revealed that if BOD/COD is >0.6, the organic matter in the wastewater is mostly biodegradable, and can be effectively treated biologically (Zaher and Hammam, 2014). Therefore, domestic wastewater in Nepal, due to the presence of high organic loads, can be treated by biological processes. The low COD/TKN and BOD/TKN ratios in the domestic wastewater show the organic concentrations are not sufficient for nitrogen removal by biological denitrification. Comparatively, the hospital wastewater had high COD/TKN and BOD/TKN ratios, indicating the possibility of nitrogen removal by biological denitrification. The COD/TP and BOD/TP ratio was extremely high for industrial wastewater, suggesting phosphorus can be removed through a biological phosphorus removal process. Similarly, the results of COD/TP and BOD/TP ratios of domestic wastewater indicate the presence of sufficient organic matter for biological phosphorus removal (Henze and Comeau, 2008).

Table 6: Tolerance Limits for Industrial Effluents to be Discharged into Inland Surface Waters (GoN 2012)

Characteristics	Tolerance Limit
Total Suspended solids, mg/L, Max	200
pH	5.5 to 9.0
Biochemical oxygen demand (BOD) (mg/L)	100
Oils and grease, mg/L, Max	10
Ammonical nitrogen, mg/L, Max	50
Chemical Oxygen Demand, mg/L, Max	250

As Government of Nepal has not set the standard for domestic wastewater, therefore the results obtained were compared with the effluent standard for industrial wastewater (GoN 2012).

Table 7: % of Samples Not Within the National Effluent Standard

Parameter	Domestic	Hospital	Industrial
pH	8%	All within range	33%
Oil & Grease	48%	All within range	50%
TSS	37%	20%	33%
BOD	72%	36%	80%
COD	59%	29%	66%
Ammonia	63%	30%	All within range

Table 8: No. of Times the Maximum Value of Parameters Exceeded the National Effluent Standard Value

Parameters	Domestic	Industrial	Hospital
pH	0.7	-	1.5
TSS	30.8	-	5.7
BOD	50.5	22.8	6.5
COD	40.1	30.0	5.5
Ammonia	7.4	0.7	3.7
Oil & Grease	12.1	15.9	-

Comparing with the standard, the pH of the tested samples from hospital wastewater were found to be within range. Most samples from all sources of wastewater were found to exceed the standard (Table 7). TSS, BOD and COD were found to exceed the standard by more than 30 times. Exceeding the standards in most of the parameters for all sources of generation indicates that these waters, if introduced to water bodies without any pre-treatment, is bound to cause severe pollution. Therefore the treatment of wastewater is essential and very relevant within the present context.

Additionally, the study clearly indicates the differences in characteristics of wastewater depending on the sources. Since all contaminants cannot be removed by the same process, it is important to know the wastewater characters in order to determine the required steps for treatment, dosing time and dosage of chemicals to optimize costs and minimize losses in treatment.

Conclusion

The study shows the varying nature of wastewater generated from different sources. Parameters that signify the presence of high organic matter, such as BOD, ammonia, organic nitrate and phosphorus, are higher in domestic wastewater. In industrial wastewater, oil and grease, COD and total suspended solids (TSS) are higher. The high values of the tested parameters compared to the national effluent standards indicate the need for appropriate wastewater treatment before disposing them into water bodies. Since the nature of wastewater varies among sources, the characteristics of wastewater should be taken into consideration prior to design of wastewater treatment plants for their effective and long running operation.

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Situational assessment tools for citywide sanitation planning

Sherpa, M. G., Manandhar, A., Thapa, B. and Lüthi, C.

Abstract

The Citywide Sanitation Planning approach was validated in Tikapur Municipality in collaboration with the Third Small Towns Water Supply and Sanitation Sector Project. An array of situational assessment tools was used to understand the environmental sanitation context namely stakeholder analysis, Kobo Toolbox, GIS, Shit Flow Diagrams, and Sanipath. This paper highlights the outcomes, pros and cons of some of these tools. With a carefully designed capacity building and orientation programme, planners, engineers and decision makers can easily understand and apply these tools. As a way forward, beyond ODF, CSPs should be taken up as the next step to improve and upgrade environmental sanitation situation in urban areas, especially: municipalities, small towns and emerging urban settlements.

Key words: CSP, FSM, sanipath, shit flow diagram

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Introduction

Small and medium-sized towns carry the major brunt of urbanization and according to the United Nations, more than half of the population in developing regions live in cities of less than 0.5 million people (UN, 2011). Most future urban growth in middle- and low-income countries is expected to occur in these towns. Unlike larger, and often richer towns, small towns face a lack of financial and institutional capacity as well as the availability and affordability of technology. This is most apparent in the poor state of basic urban services such as water, sanitation and solid waste management. To improve urban services, some of the major requirements are targeted programmes, adequate investment and sector innovations.

As per the National Plan for Small Town Water Supply and Sanitation, 265 small towns (153 in the Terai and 112 hill), with a total population of 3.6 million, have been identified in Nepal (ADB, 2009). This plan, endorsed by the Government in January 2000, was updated and redefined within the framework of the National Urban Policy in 2007. The plan quantified the water supply and sanitation needs of small towns, estimated the cost of providing improved services, and proposed a re-vamped institutional framework. Small towns are defined by the following criteria: (i) population

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of 5,000–40,000; (ii) located on a road linked to a strategic road network and (iii) having at least one secondary school and a health post in addition to grid electricity, basic telecommunications, and banking (ADB, 2009). The Government of Nepal and the ADB has been implementing the Small Towns Water Supply and Sanitation Sector Project (STWSSSP) since the year 2000. The project is now in its in third phase (2014-2021) of implementation and is currently being implemented in 21 towns.

Building on previous sanitation planning initiatives like Strategic Sanitation Planning or Community-led Urban Environmental Sanitation (CLUES), we explored the possibilities of using integrated, multi-stakeholder City Sanitation Plans (CSPs) as a model planning framework for weak institutional small town settings in Nepal. Tikapur, a small town located in the far western part of Nepal was selected as the site for validation of the CSPprocess. The timeline of the planning validation was between April 2016 and February 2017 (10 months). The planning initiative was supported by the Swiss Agency for Development and Cooperation (SDC) and the ADB-supported Third Small Towns Water Supply and Sanitation Sector Project (TSTWSSSP).

This paper discusses the validation of novel situational assessment tools and how these could be applied in small town settings. The final outcomes of the planning process or the final environmental sanitation improvement plan is not discussed in this paper.

Rationale to citywide approach to sanitation planning

Much has been written about the inadequacies of conventional sanitation planning approaches which can be summed up as:

- too great an emphasis on infrastructure and insufficient attention on improving services,
- insufficient attention to service delivery requirements for low-income and informal settlements,
- overlooking the role of small-scale service providers, and
- plans or proposed implementations are not suited to the particular, often weak, technical and financial capacities of small towns.

We considered the learnings of recent city sanitation planning as required by the National Urban Sanitation Policy in India, which experienced some major limitations in their implementation. Firstly, many Indian CSPs tended to favour networked solutions and sideline faecal sludge management (FSM) solutions, due to the limited knowledge and awareness of FSM at the municipal level. Secondly, a fragmented approach limited to toilet provision and open defecation free status, neglecting the entire sanitation delivery chain. Thirdly, the non-inclusive character of many CSP processes which were produced by external consultants or NGOs without considering needs of special user groups like women, the disabled or elderly and children.

In the validation of small town CSP, we sought to address the following issues:

- Integrated, multi-stakeholder approach that addresses the entire sanitation delivery chain;
- Improved analysis of the situation and awareness raising, using state-of-the-art tools; and
- A less costly and time-consuming planning exercise that meets the human and financial resource needs of small towns.

Methods

In the Tikapur planning exercise, a series of sanitation planning tools were used. These mainly included: the geographic information systems (GIS), Shit Flow Diagrams (SFDs), SaniPath and semi-structured interviews using the mobile data collection tool - Kobo Toolbox.

Household Survey: A careful situational analysis is the cornerstone of any successful planning. In Tikapur this consisted of a structured household survey with 400 households, three focus group discussions and the production of a GIS map based on the Quantum GIS free shareware package with the help of Google Earth Pro©. Using the GIS mapping tool, a detailed situational analysis was done at ward level for issues like toilet coverage, storm water drainage or water provision.

Shit Flow Diagram: For the first time the Shit Flow Diagram (SFD) was validated in Nepal, a powerful tool to communicate and visualize how excreta physically flows through a city or town. The information was gathered from a variety of sources and then triangulated.

The SFD can be used as an advocacy and assessment tool that is easily understood by non-experts and decision-makers as the SFD diagram clearly differentiates between safe (green) and unsafe (red) disposal (Figure 2).

Sanipath: A further tool we tested was the Sanipath risk-based assessment tool for the assessment of exposure to faecal contamination. It is used to measure exposure pathways like drains, drinking water, surfaces, toilets, soils or stormwater (www.sanipath.org).

Results and Discussion

A crucial bottleneck for realistic planning of infrastructure and basic services in Nepal's exponentially growing small- and medium-sized towns is the lack of reliable and up-to-date data. Within the framework of the STWSSP in Tikapur Municipality, the need for simplified, contextualized planning tools which are easy to utilize, and add value to an integrated planning approach that covers the entire sanitation value chain is highlighted. This section discusses some of the key tools used as part of the situational assessment, how it was used and the pros and cons.

Analysis of stakeholder roles and capacities

Stakeholder analysis is essential to gain insight into the positions, interests, and the decision-making power among the various parties. It is about finding out who plays an active part in the planning process and who influences processes. Three different stakeholder categories were analyzed with respect to the CSP as discussed below:

Process stakeholders

Process stakeholders are institutions driving forward the planning process and are vital in achieving the main outcomes of the process, primary and secondary stakeholders. The TSTWSSSP of DWSS represented by the Project Management Office (PMO) and Regional Offices (RPMO), Eawag-Sandec and 500B Solutions Pvt. Ltd. were identified as the process stakeholders. All three institutions provided support to facilitate the planning process in Tikapur. The Building Design Authority, which is the design and supervision consultant, provided technical supervision for the Tikapur Water Supply and Sanitation Sub-project and hence was also categorized as a process stakeholder.

Primary stakeholders

Primary stakeholders are institutions who have a primary stake in the process, are able to influence the decision making or are directly affected by the planning decisions. Tikapur Municipality, Water Users and Sanitation Committee (WUSC), Tikapur and Households and Town Development Fund (TDF) were identified as the primary stakeholders.

Tikapur Municipality has a keen interest in the planning process and its outcomes. By the power vested, it is positioned to make critical decisions to address the different environmental sanitation problems. For example, it has the capacity to co-finance prioritized sanitation interventions of the CSP. Likewise, using the Local Self Governance Act, it can develop appropriate bylaws for solid waste, wastewater and faecal sludge management, and create enabling conditions to introduce the private sector.

Tikapur WUSC is the representative body of the users and implementing the TSTWSSSP at the local level. On behalf of the users, it takes strategic decisions to execute project activities. With strong local links, it coordinates and creates an enabling environment to smoothly implement project activities. WUSC is currently managing the existing water supply system and collects charges from users. There is a strong possibility that drinking water and sanitation services may be integrated in the future and that a combined tariff could be collected from households. Households are also considered one of the primary stakeholders because they have a strong interest in upgrading their sanitation status.

The Town Development Fund (TDF) is a government-owned autonomous body that provide financial, technical and institutional support to organizations involved in the construction and development of municipalities and urban centers. TDF is the financial lending arm for the sub-project in Tikapur. TDF possess the resources and capacity to finance capital-intensive interventions of the CSP. For example, it could authorize a detailed technical investigation and finance establishment of a storm water management system.

Secondary stakeholders

Secondary stakeholders are those who have an interest in the planning process but do not necessary have influence over the decision-making process. There are many local institutions in the town project area such as schools, hospitals, college, factories, restaurants and local youth clubs that could provide support to roll out the CSP. However, a further analysis will be required to map out their capacities and how they could be involved during the implementation process. The role of the private sector was not found prominent in the environmental sanitation sector. The Municipality has plans to involve the private sector for solid waste collection and transportation.

Sanitation situational analysis

The sanitation situational analysis was carried out using a variety of tools and methods. A brief overview and the results have been discussed below.

Sample survey using Kobo Toolbox and FGDs
The mobile data collection application, *Kobocollect* based on ODK coding language, was used for baseline data collection. Results showed that on-site sanitation is the predominant form of sanitation systems in Tikapur (Figure 1). Most households are served by pour flush toilets which are connected to single pits (60%) and

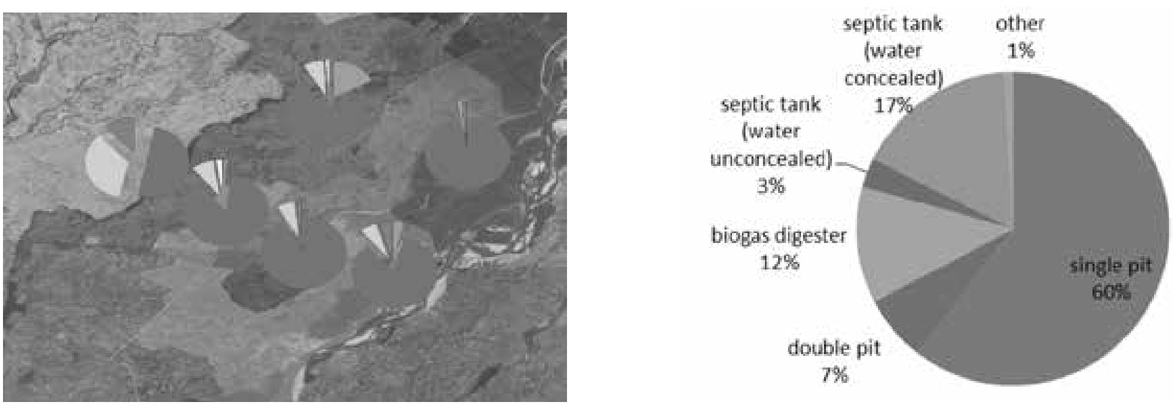

Figure 1: Situational analysis of toilet access in Tikapur - left and analysis of containment systems found in Tikapur -right
Source: Eawag/500B Solutions

double pits (7%). Likewise, a significant number of households have toilets connected to a biogas digester (12%). Baseline survey results and FGDs showed that FSM, storm water and solid waste management were the top three priority areas requiring immediate attention.

Shit Flow Diagram

The Shit Flow Diagram (SFD) was produced as part of the CSP using data on sanitation practices at ward level (Figure 2). Despite the absence of some information, an evidencebased SFD was developed based on the collected data.

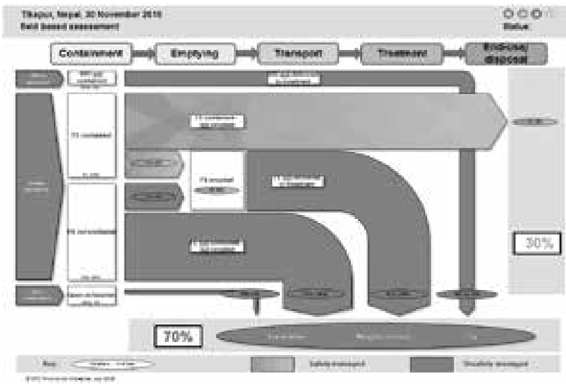

Figure 2: SFD for Tikapur differentiating between safe and unsafe disposal of human waste in Tikapur.
Source: Eawag/500B Solutions

Formalised FSM management is absent in Tikapur. Like many other small towns in Nepal, there is a high toilet coverage, due to the successful ODF campaigns in the past decade. Faecal sludge was found either not emptied or was directly disposed into the local environment, resulting in very unhygienic urban environmental conditions.

The SFD of Tikapur shows that 30% of the sludge is currently safely handled. This was due to the large portion of containment technologies that have either never been emptied or are connected to a biogas digester and single pit latrines in the rural areas. At some point, the sludge must be emptied and the existence of treatment infrastructures will be essential even for the current "safely" handled sludge (i.e. contained, but not emptied).

The practice of transferring the sludge into an alternative pit, even though it is the safest option in absence of formalized emptying services, has not been considered as a satisfactory treatment option. This decision was based on the lack of information on how these alternative pits were built and also to not send a wrong message to Tikapur's residents. However, in Tikapur's rural areas, this option might still be the best option for managing faecal sludge if sufficient land is available and the risk of groundwater contamination is low. Overall, there is a lack of awareness on how to safely operate and maintain sanitation systems.

Sanipath

The results of Sanipath rapid assessment tool are presented in what is called "people plots" which represent two important values: (i) the proportion of the population that is exposed to a pathway of infection (percentage exposed) and (ii) the level of contamination of this pathway (dose).

Results of the rapid assessment in Tikapur Municipality showed that a large proportion of the surveyed population, both adults and children, were exposed to all the three studied pathways: pumped drinking water, surface water and flood and field water (Figure 3).

Water quality tests on hand pumps showed that contamination was more localized and site specific, as determined by some cases of medium to high contamination. Unsurprisingly, community hand pumps which were often leaking and are located near open drains and private pumps located close to pit latrines were most prone to contamination. Surface and flood and field water had high contamination and one of the main reasons could be the unimproved faecal sludge disposal system.

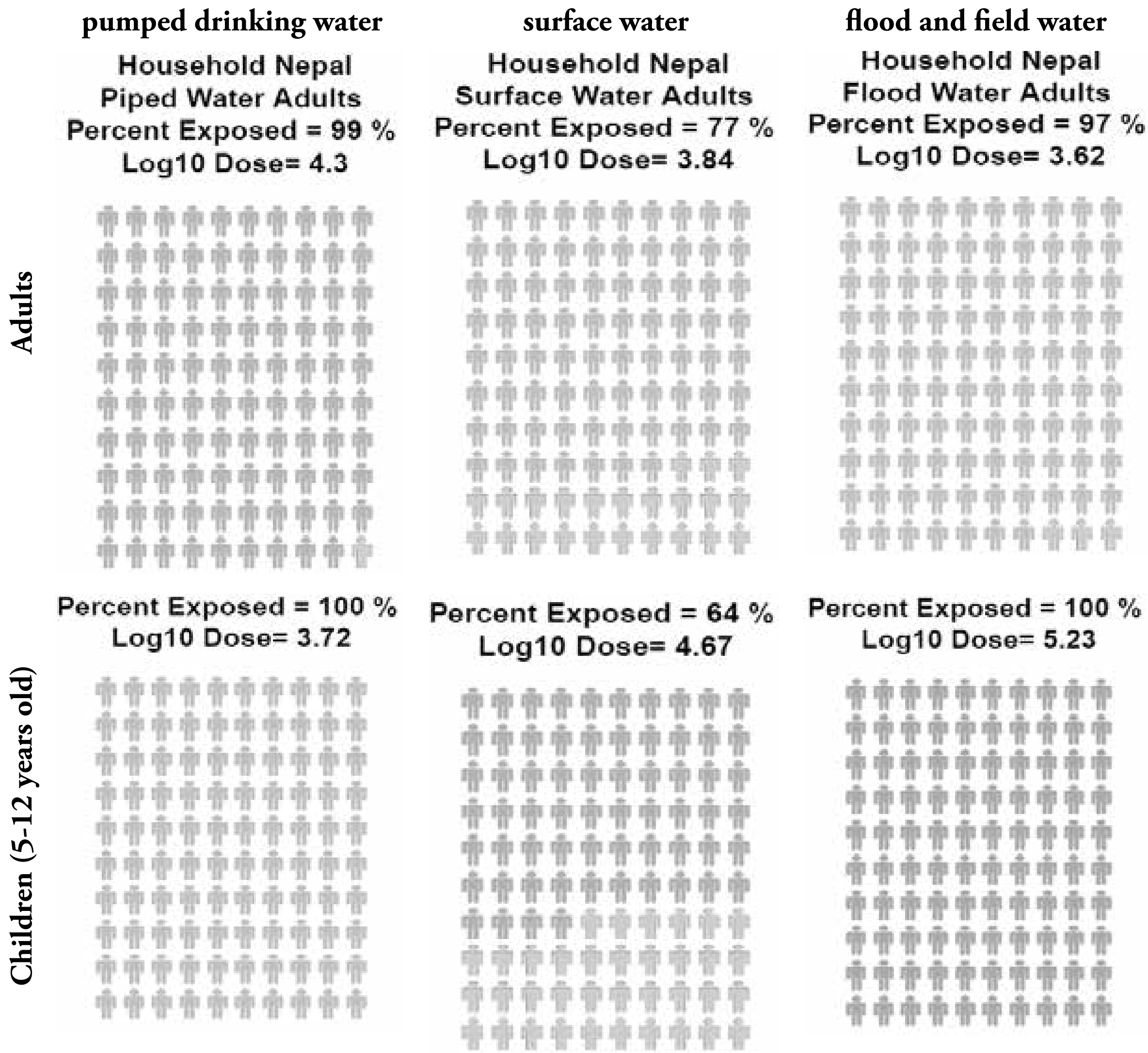

Figure 3: People plot based on Sanipath assessment in Tikapur
Source: Eawag/500B Solutions

A brief analysis of the different assessment tools discussed above is provided in Table 1. Each of the six tools that were validated in Tikapur has its merits, but not all were as accessible or easily applied.

Table 1: Pros and Cons of Different Assessment Tools Used for the CSP in Tikapur

SN	Assessment tools	Pros	Cons
1	Google Base Maps	▪ Provides up-to-date satellite image of the settlement ▪ Helpful to draw system boundaries, identification of landmarks and other specific areas of interest ▪ Helpful in visualizing and planning	▪ Normally, updated maps of the settlement are not available, needs manual verification and updates
2	GIS	▪ Provides a strong framework for managing spatial information with full transaction support and reporting tools ▪ Provides a visual framework for conceptualizing, understanding and prescribing action in a distinct spatial setting ▪ Allows for better decision making	▪ Adequate knowledge and skills required to use the applications
3	KOBO Toolbox for household surveys	▪ Free application to conduct household surveys ▪ Easily uploaded into a smart phone ▪ Easy steps to prepare required set of questionnaire for survey ▪ Conveniently used by people who have hands-on experience in using smart phones ▪ Data transferred to a central online platform for further processing and analysis	▪ Translating questionnaire into the local language, uploading and getting the system configured takes additional time ▪ Requires good internet connection to transfer data into the central online platform
4	Stakeholder analysis	▪ Helps to map out the range of stakeholders who could be useful for the planning process and to roll out the interventions	▪ Requires good support from the local community and authority to understand the context and collaboration potentials – often not easy to obtain
5	Shit Flow Diagram	▪ Provides a clear analysis of the excreta flow pathways along the sanitation chain ▪ Easy to follow and understand ▪ A good sensitization tool for non-experts	▪ Needs a reliable and adequate data set to produce a good SFD
6	Sanipath	▪ Provides quantitative results to show pathways of faecal contamination ▪ Provides strong evidence to take corrective measures/actions to cut specific routes of contamination	▪ Assured budget is required for water analysis from different pathways, which is not always possible ▪ Difficult to transport samples to laboratory unless a field lab is available ▪ Convincing donors to integrate such sophisticated tools into a tight planning process is a challenge

Conclusion and Way forward

Beyond ODF, CSPs should be taken up as the next step to improve and upgrade environmental sanitation situation in urban areas, namely municipalities, small towns and emerging urban settlements. If carried out correctly, CSP provides a holistic framework and approach to address environmental sanitation challenges from a systems perspective and facilitates selection of the best alternative for a given context.

A variety of diagnostic tools were validated in Tikapur as part of the situational assessment to provide a clear picture of the environmental sanitation status (Figure 4). We believe the tools applied in Tikapur can be useful and add significant value for similar planning processes in other urban settlements to improve their urban environments. Given appropriately targeted

Figure 4: City sanitation planning toolbox validated in Tikapur
Source: Eawag/500B Solutions

capacity building and short orientation programs on the different tools, planners, engineers and decision makers will be able to understand and use the tools for future planning.

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Performance of DEWATS in Nepal

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Abstract

Decentralized wastewater treatment systems (DEWATS) are gaining attention in developing countries for treating wastewater. However, sustainable operation of DEWATS over long-term has continued to be a great challenge. This study focuses on exploring the influence of managerial practices for the sustainable operation and performance of DEWATS. DEWATS under different management set-ups were chosen, and managerial aspects and physical conditions of different modules were explored. The performance of DEWATS were also assessed by comparing the pollutant levels in the inlets and outlets from available secondary data. It was found that DEWATS with good physical status were better at pollutant removal. The maintenance of good physical status of DEWATS is the function of continuous operation and maintenance which is governed by the responsibility, capacity and knowledge of the management committee and mobilization of caretaker. Even where there is an effective management committee in place, lack of technical knowledge and capacity and financial limitations may hinder good performance of DEWATS.

Key words: decentralized system, effluent, management, O&M

Introduction

Wastewater treatment systems have been gaining attention in order to conserve natural ecosystems and improve public health. Nowadays, particularly in developing countries like Nepal, it has been realized that Decentralized Wastewater Treatment Systems (DEWATS) are more appropriate due to their cost-effectiveness compared to centralized systems (Jha and Bajracharya, 2014). Often the acronym DEWATS is used to describe a specific set of relatively simple, non-mechanized treatment technologies (such as anaerobic baffled reactors, anaerobic filters, constructed wetland, ponds, etc.). These modules do not require energy input and are easy to operate and maintain. Depending on the context, a decentralized wastewater treatment system can also use any other wastewater treatment technology.

DEWATS has been promoted as an approach rather than just a technical hardware package (Sasse, 1998). In principle, DEWATS constitutes both technical and non-technical aspects for sustainable operation. Technical aspects contain simple, non-energy consuming, easily operational and maintainable technological units/modules which are also capable of reuse/recovery of energy and resources. Non-technical aspects include the decentralization of responsibility and capacity which would be effective and efficient only through good governance (Fladerer, 2010). Moreover, the sustainable operation of DEWATS is influenced by several factors including the levels of motivation of the management committee, financial sources to cover major repairs, concern for performance of DEWATS and external technical support (WSP, 2013).

In the context of Nepal, DEWATS have been promoted and constructed by governmental and non-governmental organizations working towards environmental conservation in support of national and international donor agencies. In addition, the private sector has also been engaged in designing and constructing DEWATS. The major benefit of DEWATS is its low cost of operation and maintenance. However, lack of maintenance may degrade the physical status of different modules. This may hinder the performance of the DEWATS and in the long run may lead to collapse of the system (WSP, 2013). For efficient operation and maintenance of DEWATS, apart from simple technological combinations, there is a need for good management practices and effective financial mechanisms. Therefore, it is assumed that despite the simple and efficient technology, management practices may have a greater influence over the status and performance of DEWATS.

Objectives

This study was carried out with the broad objective of exploring the performance of DEWATS installed and managed by different sectors in Nepal. These can be split into the following specific objectives:

- To explore the existing management practices of DEWATS managed by different sectors
- To explore the overall physical conditions of DEWATS under different management sectors
- To explore influences of management practices and physical conditions on the performance of DEWATS for treating wastewater under different management sectors

Methods

For the purpose of study, DEWATS in Nepal were first categorized as private, community or municipal systems. Interaction was carried out with management committee members to explore existing management practices. Managerial aspects, provision of caretakers and their knowledge, operation and maintenance (O&M) mechanisms and financial arrangements were discussed. In addition, direct field observation was carried out at 30 DEWATS to explore the overall physical conditions. The performance status of DEWATS was studied based on secondary sources (ENPHO 2010). Finally, a qualitative comparison was performed amongst the three categorizations of DEWATS based on management aspects, physical condition and performance.

Results

Existing Management Practices

DEWATS installed and operated in private sectors, such as in schools and hotels, were constructed mainly as private entities in response to the nuisance created in surrounding areas due to unmanaged wastewater. The possibility of reusing treated wastewater for gardening or toilet flushing has also attracted many private sector companies to install these kinds of systems. Private systems are generally managed by an owner or head of an institute. Gardeners, guards or technicians without any knowledge or experience in wastewater management are responsible for regular O&M with limited guidance from the designer of the system or through direct supervision of the owner. In most of these systems, all financial expenses for regular O&M were covered by the owner with some exceptional cases in systems supported by donor agencies.

Community level DEWATS are often installed with the support of international or national non-government organizations working in the sector of environmental conservation, health and hygiene. These systems are mainly installed to demonstrate DEWATS as an alternative wastewater treatment system to conventional centralized wastewater treatment systems at the community level. Reuse or recycling of wastewater and resource recovery (e.g. biogas production) have been integral parts of such systems. In most of these systems, users committees were formed prior to construction. They were engaged during the planning phase, to coordinate with users, to select appropriate sites and during construction of the system. Cash or in-kind contributions have been managed by the users. It was observed that users committees were trained to execute regular managerial and basic operational activities after the construction phase. For regular operation and maintenance, one member from the users committee was appointed as a caretaker and given basic O&M training in order to execute daily operational activities of the system. A well-documented operational plan was prepared to sustain the system, including basic O&M guidelines and means of collecting service fees from users and visitors. However, it was observed in some systems that users have no willingness to pay the service fees. Thus there was lack of sufficient financial means to execute regular operational activities and maintenance of the system. This lack of financial means led to a decline in the motivation and enthusiasm of members of user committees and their participation in management of the system.

Most municipal level DEWATS were initiated in 2009AD through a government-supported program to conserve water sources in urban areas from direct discharge of influents from sewers. These systems were constructed through a partnership between central- and local-level government bodies with financial support from international development agencies. They were handed over to the municipality (local-level government) after completion of the system. Overall management of these systems and performance of regular O&M was executed through the Environmental and Social Unit or Urban Planning Unit of the municipality. In some systems, a caretaker was appointed for regular O&M while in others local labors were hired as needed. Financial sustainability of the system under the local governance act was accomplished by the municipality initiating collection of a wastewater service tax and a one-time connection fee from users.

Physical Conditions of Systems

Physical conditions of DEWATS managed by the private sector were generally well maintained. The unique features of systems in this category were the arrangement of modules according to site conditions and land availability. In many systems modules were designed as part of a garden, which adds aesthetic value to the premises. Desludging of septic compartments, cutting of reeds in constructed wetlands and general cleaning of systems were observed as being carried out regularly. However, maintenance work requiring technical knowledge, such as maintaining the position of feeding buckets, swivel pipes and other pipe networks for feeding wastewater into constructed wetlands, were not properly maintained.

An attempt had been made in many community sector systems to protect physical infrastructures of systems by constructing fences around them. In general, direct visible components of various modules of systems were well maintained, such as cleaning of manual screens, installation of manhole covers for settling compartments and regular removal of decayed reeds and weeds.

However, it was found that accumulated scum and sludge were not removed regularly, cracked connecting pipes were not replaced and the position of swivel pipes in constructed wetlands were misplaced. In addition, excessive or scattered and uneven planting of reeds in constructed wetlands were common. Channelized flow in constructed wetlands and clogging of filter media were the most common problems observed in systems. In a few systems, significant rehabilitation of major modules was urgently required. In some systems where biogas digesters were installed, biogas was still generated despite other consecutive modules being completely nonfunctional or only partially functional.

It was observed that municipal DEWATS constituted preliminary treatment modules such as screens with manual cleaning, grit chambers and grease and oil traps. Primary treatment modules were based on anaerobic reactors, such as septic tanks followed by anaerobic filters in a few systems. Finally, constructed wetlands had been incorporated for final treatment before discharging effluent. In general these systems were protected by fencing, and caretakers were provided on-site shelter in some systems. Despite the provision of shelter for the caretaker, physical conditions were not satisfactory in most of these systems. The most common problem was higher influent diverted away due to silt and sand deposition at the inlet channel. Further, a lack of regular cleaning and cutting of reeds in wetlands was observed. Also, the practice of regular removal of scum and desludging of the septic compartment was not observed despite the installation of a sludge drying bed in all such systems.

Performance Evaluation of Effluents in Different Systems from Different Sectors

It was observed that the removal efficiency of private (after 10 years of operation) and community (after 4 years of operation) sector DEWATS were found to be similar in terms of BOD and COD removal (>90%). However, removal efficiency of municipal DEWATS (after 2 years of operation) was lower (72%-73%) compared to those of the private and community sectors (Figure 1). It can be concluded that the performance of private DEWATS is higher than that of community sector, followed by that of municipal sector.

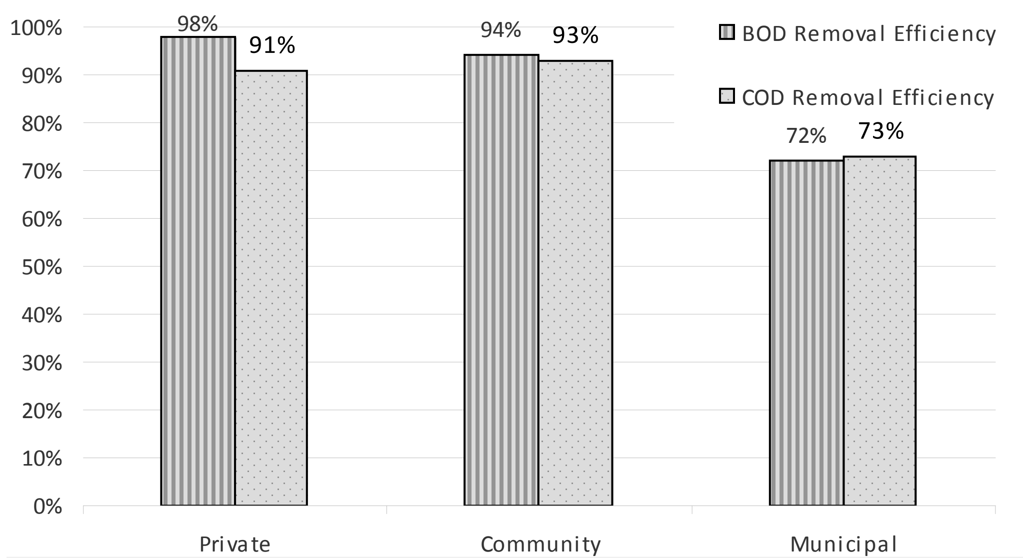

Figure 1: Removal Efficiency of DEWATS in Different Sectors

Discussion

DEWATS consisting of different modules function well when the modules are in good physical condition. Also, the performance of the system is higher when the influent quality and quantity are within design parameters. For example, one of the major parts of the treatment system based on retention and degradation of organic matter is the settling tank, which functions well when the sludge is filled no more than 2/3 of its capacity, otherwise removal efficiency of Total Suspended Solids (TSS) is drastically reduced (Kurniawan *et al.,* 2016). Similarly, for constructed wetlands only settled, solids-free wastewater should be introduced. Distribution of wastewater in a constructed wetland should be uniform throughout the width of the inlet zone in order to avoid clogging (Sasse, 1998). Hence, for maintaining good physical condition, good operation and maintenance practice is essential. This is governed by several factors including responsibility of the management committee and caretaker, capacity and knowledge of the management committee and caretaker and also financial matters.

It was observed that DEWATS managed by the private sector had relatively efficient and effective management due to the self-decision making authority of the owner. Improperly managed systems may be directly or indirectly detrimental to the owner, therefore prompt execution of regular O&M was generally carried out, resulting in good physical conditions of these systems. This is thus reflected in the good performance in removal efficiency of private sector managed DEWATS, even after 10 years of operation.

Despite active participation throughout the planning phase, implementation and well documented operational plan, systems managed at the community level have higher risks of degrading physical conditions of various modules. This is due to the lack of direct personal benefit to the members of the users committees. Similarly, the absence of direct benefits to users reduces the enthusiasm and motivation of the community users to financially contribute towards necessary O&M. For example, the Sunga Community Wastewater Treatment Plant at Thimi, Bhaktapur, which functioned well during the initial phase, has now become completely defunct due to lack of financial resources. These funds are needed in order to overcome subsidence in the constructed wetland, however local users are not willing to contribute towards maintenance of the system.

There are additional challenges in the case of Nepal, where working in such wastewater treatment systems is regarded as an undignified job. Due to the social stigma, it has been very difficult to appoint long-term caretakers for DEWATS. The community based wastewater treatment plant at Sano Khokana, Lalitpur was only performing partially as a result of insufficient regular maintenance due to the absence of a caretaker. Incapability of management committees to retain caretakers has further worsened the physical conditions of different modules and their components. Finally, insufficient financial resources results in a lack of responsibility towards the system by all users, caretakers and management committee members. Similarly, it was observed that there is no specific unit within the local authority responsible for O&M of DEWATS within the municipal sector. Confusion over which is the most appropriate unit to manage the system, as well as lack of coordination between units, has led to insufficient regular monitoring by caretakers and hence a deterioration in the condition of systems. This was reflected in the results of DEWATS managed by the municipal sector, whose performance was relatively lower even after only two years of operation.

Conclusions

The management committee of DEWATS within the private sector tends to be highly motivated in comparison to that of community and municipal sectors. This leads to more efficient O&M activities, which in turn leads to good physical condition of DEWATS and sustainable long-term performance. For community managed systems, motivation levels are much lower due to financial constraints and lack of enthusiasm of the community members and users committees. Lack of coordination and information sharing among different units of local authority towards the management of wastewater treatment systems has hindered the performance of DEWATS within the municipal sector.

It is recommended that despite well documented operational plans and management committees in place, reliable financial resources must be identified. Thus for financial sustainability, a business model should be developed. At the municipal level, a strong coordination between the technical unit and social unit must be developed in order to promptly address any problems that arise.

Acknowledgements

We would like to thank all members of wastewater management committees for cooperating and sharing their experiences on the management and operation of DEWATS. Also, we are thankful to the caretakers of all systems for assistance during observation of systems. We also appreciate Mr. Rajendra Shrestha, Director of Outreach Division at ENPHO for valuable guidance.

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Decentralized integrated wastewater and solid waste management

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Abstract

Ineffective management of solid waste and wastewater are two major problems in cities in the developing world. In Kathmandu Valley, for example, disposal of waste and untreated wastewater from 2.5 million residents into the Bagmati River has significantly polluted the river and surrounding environment. As collection and transportation costs make up more than half the total cost of solid waste management and wastewater treatment systems and large, central systems for waste and wastewater management are often difficult to establish and maintain, decentralized solutions can play an important role for addressing both of these issues. Furthermore, systems that combine waste and wastewater management can offer significant benefits from a technical, financial and managerial perspective. In Nepal, a few systems have been established at the institutional- and community-levels to treat organic solid waste as well as wastewater and produce valuable products such as biogas and slurry. Because such systems can generate more biogas and reduce the cost of waste and wastewater management, users are incentivized to effectively operate and maintain them. Biogas generation from cow dung and decentralized wastewater treatment systems are not new to Nepal, but Decentralized Integrated Wastewater and Solid Waste Management Systems are new and offer more environmental as well as economic benefits. Integrated systems in institutions such as children's homes, monasteries and prisons as well as community-based systems in Sano Khokana and Bharatpur demonstrate these benefits. This paper analyses the technical, financial and managerial performance of these systems using several case studies and suggests ways to promote them further in Nepal and other countries.

Key words: biogas, community scale system, financial, management, technical

Introduction

Wastewater (WW) and solid waste (SW) management are two sectors causing major challenges in developing countries like Nepal. Ineffective management of WW and SW make these challenges even more complicated and problematic. In Kathmandu Valley, for example, disposal of untreated wastewater and solid waste in the Bagmati River has significantly polluted the river environment. A study conducted by the Asian Development Bank (ADB) in 2013 revealed that the total SW generation from five municipalities of Kathmandu Valley was 611 ton/day and that 70-80% of this SW was biodegradable. The volumes of wastewater generated and collected in the wastewater management systems of these five municipalities were found to be 99 and 49 MLD per day, respectively. There are several technologies and systems that have been implemented for the management of SW and WW separately at the household-, institution- and municipal-level. Unfortunately, these implementations have not been successfully designed or met expectations. In fact, most of them are no longer in operation.

A number of factors have been identified as contributing to the malfunctioning of these systems. Among these factors, the most prominent are technical complications and weaknesses, insufficient finances and other financial problems, managerial weaknesses and lack of accountability. Technically, most of the existing systems were designed to treat or manage either SW or WW, not both together. More specifically, very few systems with biogas technologies are fed by both SW and WW.

From a managerial perspective, small, simple, decentralised units are easier and cheaper to manage, and the operation and maintenance (O&M) costs are negligible as well. Additionally, such systems do not rely upon mechanical units and therefore require neither fuel nor highly skilled manpower for operation and maintenance. This makes these systems financially affordable, which improves sustainability, especially in low-income communities.

The management of these systems is crucial for sustainability and is directly related to the availability of O & M funding and incentives. Unfortunately, sanitation is often a low priority not only for the general population but also for the government, which contributes to the perception that investment in sanitation is a waste of money. When this is the case, the potential for income from WW and SW treatment, even if in small amounts, can generate positive attention. In this way, decentralised integrated solid waste and wastewater treatment systems (DISWATS) are one of the most promising solutions to SW and WW management, as they rely upon natural processes and generate energy, and thereby incentives, from waste.

Methodology

This study is based on a literature review, questionnaire, and field visits. It relies upon qualitative methods, case studies and fieldwork to assess some of the community and institutional DISWATS in Kathmandu Valley, Dhulikhel, Pokhara and Bharatpur.

Literature review

There have been a number of research studies on household-, institution- and community-scale biogas production. These studies have mainly focused on the technical aspects of biogas production and its efficiency and not on financial and managerial aspects. A recent report by AEPC estimated that more than 300,000 household scale biogas plants have been constructed and that 200 institutional and communal biogas plants have been installed, although there are no records of these systems (AEPC, 2017). At the household level, cow dung is the major feedstock for biogas production, which is why it is known locally as *Gover Gas*. About 70% of these household systems are connected to toilets, whereas institutional biogas plants are typically designed to manage feacal sludge, kitchen waste, and slaughter house waste (AEPC, 2017).

Case study

Solid waste and wastewater treatment systems with combination of different technologies, wastes and users are considered in this study. The following plants were selected for case studies:

- Community DEWATS with Biogas Plant, Shrikhandapur
- Biogas Plant, Barahi Hotel, Pokhara
- Biogas Plant, Schechen Monastry, Kathmandu
- Community Biogas Plant, Lankhu, Bharatpur
- Amaghar Children's home, Godavari, Kathmandu
- Bajra Academy, Lalitpur

Data collection

A questionnaire is prepared and used with different key actors like operators, biogas users and owners. In the questionnaire, following three aspects were taken into consideration.

- Technical Aspect
- Financial Aspect
- Managerial Aspect

Findings and discussion

Technical Aspect

Most of the designs of the community / institutional biogas plants of Nepal are enlarged version of GGC 2047 model (BSP, 2017). In fact this model is specially designed assuming that the feedstock as cow dung. From the study it was found that design of biogas plant should be modified as per the nature of designated waste so that it performs with good efficiency. If the organic waste that requires more time for the anaerobic digestion, then the design of the digesters should be larger compared to the organic waste requiring less digestion time. In DEWATS at Shrikhandapur, owing to small inlet of the system designed for cow dung and wastewater, solid waste feeding is not being possible.

Needles to mention organically rich material produces more biogas. Separate sewer system (SSS), therefore, is best as it conveys concentrated wastewater comparative to combined sewer system (CSS). CSS enforces to bigger sized biogas plants because of higher volume wastewater resulting higher investment and more land consumption as well as higher operation & maintenance cost.

Centralized treatment systems (composting plant, landfill, traditional wastewater treatment) are not reliable and sustainable methods of waste management as it dissipates methane gas into environment, consumes large areas, makes nuisance to surrounding, requires highly skilled manpower and needs higher investment, operation and maintenance cost. DISWATS could be a sustainable solution that overcomes drawbacks mentioned above, recycles nutrients and produces energy.

As it requires large amount of water, biogas plant is not feasible in water scarce areas. Integrated solid waste and wastewater system, therefore, could be a good technological alternative since wastewater replaces amount of water required for biogas plant. Likewise solid waste maintains C/N ratio (20-30:1) mostly in the case of black water that generated from public toilet/institutions may contain comparatively higher nitrogen.

Waste and wastewater management system should be aesthetically attractive or designed to suit the landscape or beautification of nature that makes easy to convince people. Otherwise most of people rejects such system because of smell, unpleasant looking.

Financial Aspect

Financial aspect is one of the major factors for selection and sustainability of DISWAT System. Most of the sanitation systems are not properly managed or are not in operation in the absence of the fund especially in case of public system whereas most of the systems having funds to maintain are functioning. In addition people, however owner or operator, are satisfied and happy with biogas since it neutralize full or certain portion of fuel cost.

In community biogas system biogas will be incentive to operate and maintain the system and it provides monthly cost of caretaker. In Khokana and Dhulikhel biogas plant is good example as other part of treatment system is not properly maintain whereas biogas is working well. Besides they comparatively show more concern towards biogas unit and its problems.

In Amaghar they are not only saving monthly 2 LPG cylinder which cost NRs 3000 in local context. But they are also saving NRs. 30,000 per year that they used to expend previously for desludging of septic tank. Similarly the slurry or sludge can be sold as fertilizer.

Managerial Aspect

Management is fundamental for sustainability and further development of any system. It is more critical in the sanitation system as it is the least priority sector not only for people but government as well. Also management becomes extremely poor in case of community or public systems. It includes series of activities as follows

- providing after sales services by construction company/agency
- orientation and training on operation and maintenance to operator, owner and users
- informing clearly on the limitations and benefits of systems
- establishment of O&M fund
- regular supervision and maintenance

During the study it was found that management is the most serious. Even in institutional systems managerial part was found very weak. At the same time, accountability towards nature, incentives from systems is encouraging people to manage the system well in some cases. Based on the field observations, the management of the systems was found good in Shrikhandapur DEWATS, Biogas at Sechen Monastery and Biogas at Barahi Hotel. Proper collection and segregation of waste, regular operation and maintenance, trained and responsible operators were the key traits for the successful operation of these systems.

Conclusions

From the study it can be concluded that the integrated way of treatment of waste is one of the most appropriate methods. Blackwater and organic solid waste can be treated together which produces more biogas giving more incentives or payback to owner or operator. In

Table 1: Monthly O & M Cost and Income/Saving from Biogas

Plant	Monthly O&M cost (NRs)	Monthly Income/Saving (NRs)	Saving per month (NRs.)
Community biogas at Dhulikhel	2500	2500	0
Community biogas at Khokana	1500	1750	250
Biogas at Amaghar, Lalitpur	2000	3000	1000
Biogas at Sechen Monastery	2000	3000	1000
Biogas at Barahi Hotel	2000	4500	2500
Community biogas at Lankhu	4000	4590	590
Shared biogas, Gulariya	2000	3000	1000

addition it also saves water which is essential to add in ratio of solid waste feeding as wastewater subsidies the need. Nevertheless, the system should be improved in technical aspects.
The system performs regularly and sustain if managerial and financial aspects is also proper and attractive.

For biogas digesters at institutions, issues of strong ownership and responsibilities for maintenance work are crucial points which need special attention. If the system is not properly operated and maintained, there will be adverse effects such as methane emissions (greenhouse gas) or health risks from leaking gas in the kitchen. Following the positive experience in Nepal, ICRC will pursue this approach in prisons in other countries and support the promotion of biogas plants for institutions (prisons, schools, and hospitals) in order to improve the sanitary conditions and provide renewable and clean cooking energy.

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Potential of wastewater use in irrigated agriculture: Case of Harisiddhi wastewater treatment plant, Nepal

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Abstract

Harisiddhi wastewater treatment plant (Scheme number 1) was completed in 2005. The partially functional treatment plant treats domestic wastewater from 100 households and the effluent of the treatment plant mixes with a surface drain and finally drains to *Karmanasa* River. The wastewater treatment plant is being operated and maintained by the community. This paper mainly reflects upon the local perception of the wastewater treatment plant focussing on finding out the potential for wastewater use in agriculture in terms of technical and financial aspects only. Wastewater quality and quantity analyses were conducted to assess the technical aspects; participatory tools such as questionnaire survey, key informant interview and observation were carried out to assess local perception, environmental benefits and financial aspects of the treatment plant. Two different aspects were studied regarding the wastewater use in agriculture i. use of treated effluent and ii. use of treated effluent mixed with the surface drain. The survey showed great acceptance for the wastewater treatment plant as the improvements are visible in the surrounding environment. The quantity, accessibility and reliability factors indicate the possibility of combined treated and diluted wastewater use in agriculture. The potential for treated wastewater use alone is very low whereas the potential for the use of combined treated and diluted wastewater is very high. The potential for use of wastewater effluent is directly associated with the quality of treated wastewater, which is questionable at the moment. Reconstruction of the reed bed and proper and timely maintenance of the wastewater treatment plant is required to achieve its goal of wastewater use in agriculture or for the safe disposal in the water bodies.

Key words: effluent,local knowledge, quality, reuse, SAR

Introduction

In Nepal, approximately 60 % of the total irrigable land has some form of irrigation facility, while less than one-third has year round irrigation (Shakya, 2014). Changing rainfall patterns, unpredictable rainfall and inadequate irrigation coverage has led to a threat in the sufficient and timely availability of water for the agricultural sector. Drying up of water sources and issues of priority rights

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has limited the quantity of water available for agriculture. The 2011 national census provided an annual population growth figure of 1.3 %; the increase in food production led by population growth threatens water security for agriculture. Sufficient quantity of quality water for agriculture has been threatened by changing climatic patterns and competition of water use among its users for different purposes; Irrigation is prioritized second after drinking water by the Water Resources Act (GoN, 1992). Hence, alternative sources for irrigation, along with freshwater irrigation, need to be evaluated for water security for agriculture. Although wastewater has a direct impact upon humans and the environment, it has been set as a second priority in the national projects, termed as P2 projects as indicated in the red book by the National Planning Commission (DWSS, 2014). This eventually has led to less budget provision for wastewater treatment across the country. Wastewater Policy and Strategy (draft) recognizes wastewater as a renewable and reusable resource (DWSS, 2014). However, most of the wastewater collected is disposed directly to nearby surface water sources without any treatment. Wastewater in Nepal is primarily organic in nature. According to international practices, wastewater can be used for agriculture after primary treatment. This would lead to a solution for both issues; safe disposal of wastewater and the provision of irrigation water for agriculture in water scarce areas.

Study Area

Harisiddhi Wastewater Treatment Plant is the first of its type in the country. To address the arising problem of safe wastewater disposal and maintain sanitary conditions in the area, people of Harisiddhi demand a wastewater treatment plant whose effluent could also be fed into their agricultural land (Figure 1). This idea of wastewater use originated from the centuries long local initiative where the inhabitants in the urban fringe of Kathmandu Valley use human waste in agriculture.

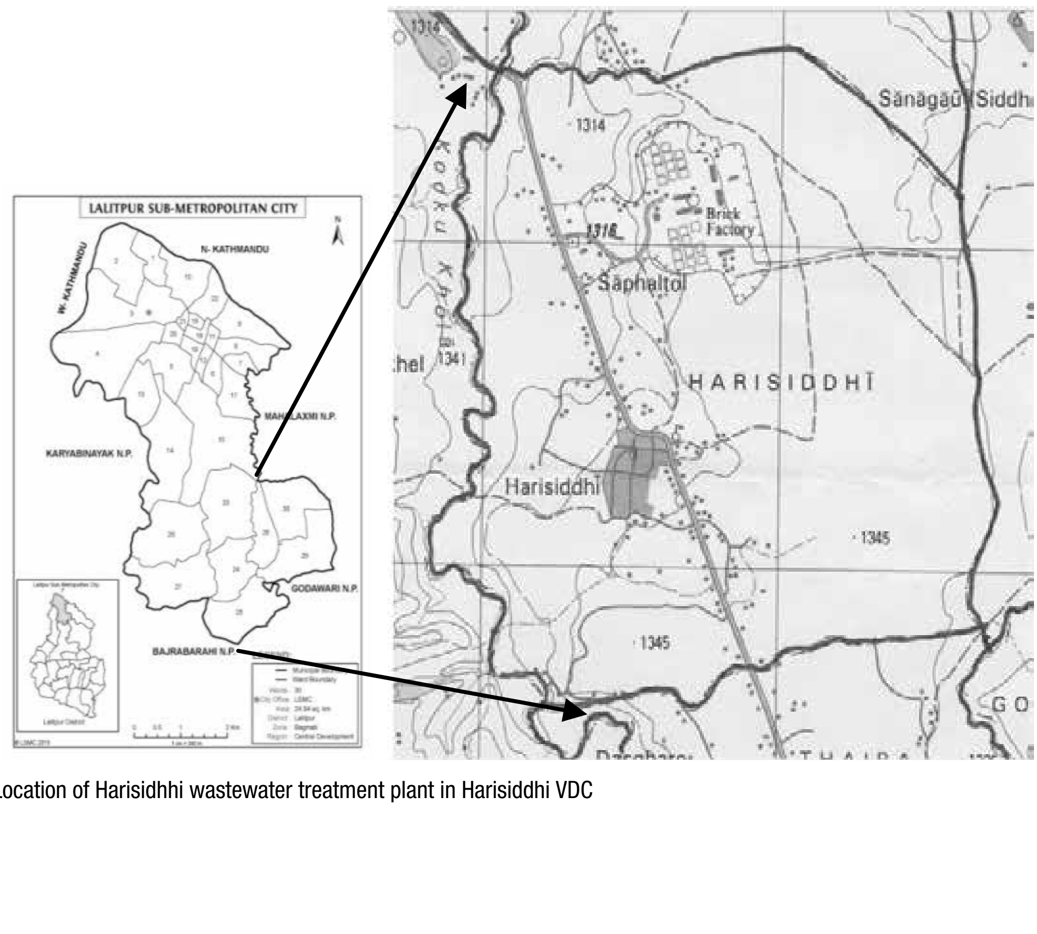

Figure 1: Location of Harisidhhi wastewater treatment plant in Harisiddhi VDC

Harisiddhi Village Development Committee (VDC) consists of four wastewater treatment plants located at four different locations so that wastewater can be collected under gravity. Three plants are completed and one is currently under construction. Among the completed wastewater treatment plants, only one (Scheme number 1) is functional, serving 100 households primarily treated by means of a grit chamber and an Anaerobic Sludge Blanket Reactor (ASBR) and secondarily by a reed bed system (Figure 2). The final effluent combines with a surface drain downstream in the agricultural area and finally discharges to nearby stream, contradictorily differently from its prior purpose.

The collapsed units of wastewater treatment plant due to April 2015 earthquake are still not reconstructed. The wastewater from the ASBR is collected in sludge drying beds and directly discharges at present. This reflects the poor management of the wastewater treatment plant and symbolizes the condition of few existing treatment plants in the country. The reasons for the poor functioning treatment plants should be considered, allowing for the consideration of use of the effluent within agriculture.

Methodology

One sample of effluent from the wastewater treatment plant and two samples of effluent combined with the surface drain were collected for wastewater quality analysis. Concentrations of the following key physio-chemical and microbial parameters where analysed the a laboratory;

- pH
- temperature
- total suspended solids
- electrical conductivity
- Biological Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- total nitrogen
- phosphorus
- potassium
- faecal coliform

Effluent volume at some irregular intervals was also taken to assess the quantity of treated wastewater. A questionnaire survey was conducted with 80 households (use of Cochrane formula at 95 % confidence interval and standard error of 5 % amongst 100 households) to gain an understanding of the local perception of the wastewater treatment plant and its potential contributions. In addition, data was also collected by observation wherever relevant and deemed necessary. Observations were made to identify the current status of the infrastructure, to confirm the current use of wastewater and the sectors using wastewater. As this research is aimed at investigating the potential use of wastewater in irrigation, analyses from different dimensions such as technical, financial and local perception towards the wastewater treatment plant was carried out.

Data Analysis

Wastewater quality parameters data was compared against the Guideline Values of Irrigation Water Quality Standards of Nepal and Food and Agriculture Organization (FAO). The mode value of time required to collect 1 litre of effluent was calculated. The discharge of effluent was calculated by using this time value. Reliability was assessed by using discharge data. Cost analysis was carried out using the costs of

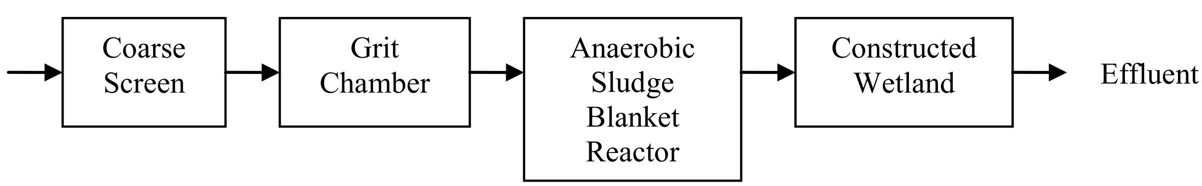

Figure 2: Layout of Harisdddhi wastewater treatment plant (Scheme number 1)

irrigation by wastewater application in agriculture and the cost of current practices of irrigation. Likert scale was used to assess the local perception of the wastewater treatment plant.

Results and Discussion

Local perception towards wastewater treatment plant

Before the construction of Harisidhhi wastewater treatment plant, only 65 % out of surveyed 80 households had toilets connected to septic tanks, the remaining 35 % used community toilets. Separate toilets where available for male and female users however they were in an unhygienic condition with scattered human waste around the VDC giving unpleasant aesthetics, awful odour and bad environment. Almost all households now are connected to a sewer line and 78 out of 80 (97.5 %) households responded that wastewater from their kitchen, toilets and bathrooms are disposed to the sewer line. Two respondents (2.5%) responded that their wastewater is disposed to a septic tank due to technical difficulties with connecting to the sewer. Most of the respondents, 67 households (83.75 %) know the purpose of the treatment plant. However, the real implementation of effluent into agriculture is still lagging in the VDC. The effluent from the treatment plant combines with the surface drain which ultimately disposes to the *Karmanasa* River. 68 households (85 %) stated that they knew where the effluent is disposed of, while the remaining 12 respondents are unaware of the fate of treated effluent. Of the mentioned 68 respondents, 29 (36.25%) stated that the effluent is disposed to the surface drain and finally to the river. 35 households (43.75%) stated that the effluent is disposed to the river and 4 respondents stated that the effluent is disposed to the surface drain and finally to agricultural land. However, during field visit it was observed that during dry season, the water from the drain was collected to an artificial ditch and pumped by a nearby private brick kiln for brick production. Therefore, no water from this drain discharges to the river.

Diverse responses were obtained about the benefits of the wastewater treatment plant. The main benefit of the treatment plant identified by the households was the reduction of wastewater disposal cost; 25 % of respondents did not know the benefits of the treatment plant and 2.5 % of the respondents thought that there is no benefit of such treatment plant. The details of the respondents view about the perceived benefits of the wastewater treatment plant are presented in Figure 3.

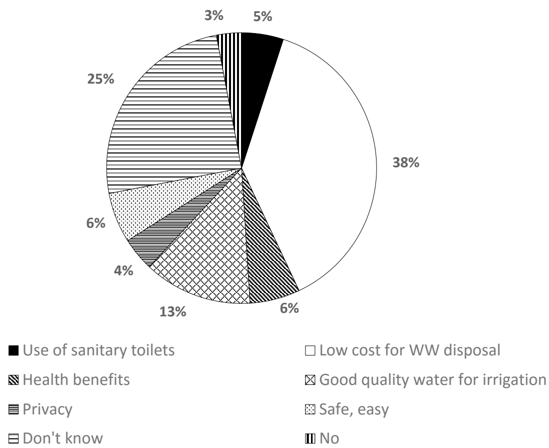

Figure 3: Perceived Benefits of Wastewater Treatment Plant

Before the construction of the treatment plant, the locals used to empty their septic tanks for Rs 2000 to Rs 5000 in frequencies of between 3 months to 3 years, depending on the number of family members. The charge was depends upon the bargaining capabilities of the household through a series of negotiations with the tanker owners. The households stated that this was a tedious process and depends on the monopoly of tankers. Therefore, the disposal charge associated with the treatment plant was proven to be a desirable and cheap solution for the people. Support for the treatment plant was present from its planning and implementation phase. It was assessed that no conflicts regarding the construction of the treatment plant took place based on the responses of 73 respondents (91.25%). The land where the treatment plant is located is public land and was previously the location of the community toilet. Local people are aware of the benefits of wastewater use in agriculture. The beneficial factors associated with the use of wastewater in agriculture as mentioned by the local people were water security and fertilizer value.

Technical aspects of Harisiddhi wastewater treatment plant

There are a small number of wastewater treatment plants in the country and even fewer are functional. Experts also accept this fact and that with the exception of some small local level treatment plants, none of them are totally functional. The state of the functional treatment plants is also not satisfactory. This is supported by their operational status and effluent quality.

Quality

From the wastewater analysis data, it is clear that majority of the parameters analysed were not removed to meet any of the referred standards and guidelines. Only pH and electrical conductivity meet the guideline values and standards whereas all other parameters, including BOD, COD and faecal coliform, exceed the permissible value. The turbidity, total nitrogen and potassium values could not be compared as none of the guidelines and standards prescribe a limiting value. The details of comparison is presented in Table 1.

The quality of the diluted effluent was also considered as the effluent is mixed with the surface drain prior to its use in agriculture. The seasonal flows are considerably different in our context. With both the earlier considerations, the diluted water sample was collected on 24th March 2016 and surface drain sample was collected on 22nd July 2016 for analysis. A sample of wastewater effluent could not be collected due to site conditions. Some additional parameters like Total Dissolved Solids (TDS), Sodium Absorption Ratio (SAR) and Suspended Solids (SS) were considered during the second water quality analysis.

The sample analyses showed that the majority of parameters do not meet any of the standards considered. For the diluted sample collected on 24th March, only pH and electrical conductivity meet the standards. However, it is observed that due to heavy dilution during rainy season, BOD, COD, SS and TDS are also well within the limits. Total Nitrogen and phosphate has

Table 1: Wastewater quality of treated effluent and surface drain

Parameters	pH at 21°C	Turbidity (NTU)	Electrical Conductivity (μmhos/cm)	Total Nitrogen (mg/L)	Total Phosphate (mg/L)	Potassium (mg/L)	COD (mg/L)	BOD_5 (mg/L)	Faecal coliform (MPN index/100 mL)	SAR (mg/L)	TDS (mg/L)	SS (mg/L)
Wastewater treatment effluent	7.4	42	1170	101.1	9.16	14.17	600	181.2	1100+	-	-	-
Wastewater quality of surface drain (24 March 2016)	7.3	28	965	57.17	4.88	9.21	440	163.2	1100+	-	-	-
Wastewater quality of surface drain (22 July 2016)	6.9	73	456	13.3	1.74	14.15	50	14.15	1100+	5.1	297	180
Nepal WQ Guideline for Irrigation water	6.5-8.5	-	4000	-	-	-	-	-	1	2	40	50
Generic Standards Part III	5.5-9	-	-	-	-	-	250	50	-	-	-	50
FAO standards	-	-	700-3000	-	5-30	-	-	-	<=1000	3-6	450-2000	-

been reduced by more than 200 % but turbidity has increased by around 300 %. As per FAO guidelines, for SAR 3-6 and EC 300-1200, infiltration is slight to moderate, which means there is a chance of infiltration of this diluted water to pollute groundwater. TDS was measured at less than 400 mg/l, salinity is none which means there are no chances of salt deposition in soil when irrigated by this mixed effluent.

Quantity

The reliability of wastewater in terms of quantity was also checked by calculating the effluent discharge on site. The time taken to fill up a known volume was recorded and used to calculate the wastewater discharge. The calculated discharge was 0.048 l/s indicating low flow which is also substantiated by the responses of the respondents. The discharge of the surface drain was calculated to be 0.228 l/s during dry season, whereas the discharge is almost 20 times higher during wet season. During the observation, it was found out that 68.75 % of the respondents own land downstream of the treatment plant. The combined discharge available in the surface drain, which is approximately 6 times the discharge of the effluent, is sufficient to irrigate the land accessible by the drain. This land cannot be solely irrigated by the effluent.

Accessibility

It was observed that 51 out of 55 (92.73 %) respondents who own the land downstream of the treatment plant use the surface drain water for irrigating their land both during dry and wet season. The drain water is applied in a cascade system, from higher land to lower land and between land holders turn by turn. The remaining 7.27 % of land owners do not have access to the surface drain water and are totally rain-fed. Hence, the treatment plant effluent, diluted with the surface drain, is accessible to the majority of respondents. During extremely dry seasons, land holders having land adjoining to the river pump water from the river. However, this is a small number of farmers and do not belong to the catchment of the wastewater treatment plant.

Reliability

The effluent is a reliable source of water with little deviation in its discharge during a period of one month measured at different times and occasions. This discharge is available throughout the year. The discharge data for the effluent in wet season could not be calculated as the drain from the treatment plant laid beneath the high flow level in surface drain during the month of heavy rainfall in June. Comparing the discharge data of the surface drain in wet and dry seasons, the discharge in wet season is approximately 20 times the discharge in dry season due to monsoon.

Financial status of wastewater treatment plant and wastewater use in agriculture

The financial resource for construction was managed by the government with 20 % contribution from the community, both in cash and kind. The user's committee collected Rs 2,500 from each household for contribution and also contributed labour for excavation and site clearance. The main source of finance for operation and maintenance of the treatment plant and associated infrastructures is a monthly tariff collection of NRs 50 per household. Among the nine members of the sewer subcommittee under the Water Users' committee, five members are engaged in tariff collection. The tariff is collected once every three months; this is currently on hold due to the devastating earthquake. The tariff is used to pay cleaning staff and buy different tools and equipment to clean the treatment plant and sewer line. The cleaning staff is paid Rs 2,000 per month. A conservative calculation estimates that a net saving of NRs. 18,000 occurs.

The treated effluent from the wastewater treatment plant combines with the surface drain at a similar level to that of the drain. In dry season, the invert level of the sewer carrying the treatment plant effluent is just above the level of the dry season flow of the surface drain. In the wet season the drain is totally submerged by the surface runoff. It is not possible to construct a new channel parallel to the existing one due to the limited space. It is therefore necessary to construct a crossing across the drain to irrigate agriculture land solely from the effluent.

The adjacent land on other side of the effluent sewer, parallel to the drain, is low with a rising elevation totalling approximately 2 m. This makes the construction of a separate system more difficult. Hence, it is mandatory to construct a piped system under pressure or pumping mechanism to carry the effluent to the agricultural land. Owing to the huge investment associated with the construction of a sole wastewater effluent supply and its minimum discharge, it is highly infeasible to construct a separate effluent drain to use in agriculture. The analysis of wastewater use in agriculture is hence carried out for combined discharge from the wastewater treatment plant and the surface drain. All the respondents who have land downstream of the treatment plant and whose land is accessible to surface drain water use the water for irrigation. They pose an obstruction in the drain to irrigate their lands. All the respondents stated that one day of labour was sufficient to irrigate their land. One day of labour costs approximately Rs 600 - Rs 800 for women and Rs 700 - Rs 1000 for men. The possible mechanism for the diluted wastewater use in agricultural land will remain the same and the cost for irrigation will also be same as there is no other viable possibility for irrigation of land and this condition is strictly site specific.

Conclusion

Harisiddhi wastewater treatment plant has significantly contributed in providing aesthetic look to the VDC. However, the quality of effluent is not good enough for use in agriculture or disposing to surface water source. The diluted effluent mixed with surface drain also does not meet the standards and cannot be used for agriculture or disposal to river during dry season but can be used for agriculture and disposal to the stream during rainy season. The quantity of effluent is not sufficient to irrigate the agricultural land downstream of the treatment plant. The combined discharge from the surface drain and the effluent is sufficient to irrigate the land both in dry and wet season. The surface drain combined with the effluent is accessible to the agricultural land and the effluent is highly reliable with little deviation in discharge. However, the reliability of the diluted effluent is dependent upon the season with high discharge in wet season and low discharge in dry season. The surrounding households have good knowledge of the benefits and adverse impacts of wastewater use in agriculture. The acceptability was high for use of wastewater in agriculture. There is no possibility of the sole use of the effluent to supply the surrounding agricultural land. The use of effluent diluted by the surface drain water is highly possible and is currently practiced. There is no change in the cost of irrigation due to there being no changes to any existing infrastructures. Farmers are aware of the wastewater quality and are among those who prefer it the least due to the associated impacts. The potential for treated wastewater use alone is very low and the potential for combined treated and diluted wastewater use is very high. It potential use is directly associated with the quality of treated wastewater. Reconstruction of the reed beds is essential to maintain quality of treated wastewater alongside the proper and timely maintenance of other components to achieve maximum removal efficiency. If possible, and depending upon the financial budget, the user committee should recruit a full time technician for regular operation and maintenance, revision of tariff is necessary.

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Productive reuse of organic waste in rooftop farming: A case study from Kathmandu Metropolitan City

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Abstract

Rooftop farming (RTF) has been introduced in Kathmandu as an alternative solution to managing urban waste and wastewater through recycling and reusing organic waste and grey water generated at household level since RTF was initiated by the Kathmandu Metropolitan City (KMC) with technical support of development agencies - Environment and Public Health Organization (ENPHO) and Institute for Social and Environmental Transformation Nepal (ISET-Nepal). This study has been carried out to estimate the potential rooftop area available for rooftop farming in KMC. Also, this study estimates a total volume of compost that can be generated from organic waste and the current demand of compost for rooftop farming. The study shows that 34% of the households in KMC are practicing some form of kitchen gardening and rooftop farming. Hence, it was assumed that these households will culturally accept RTF and thus total rooftop farming area in KMC was estimated to be 5.7 sq. km. Similarly, the total demand of compost manure for rooftop farming is 63.3 tons per day which equates to 40% of potential compost generation from organic waste of Kathmandu. Grey water generated at household level can be effectively and efficiently applied for watering crops.

Key words: compost, RTF, urbanization, waste calculation, waste to resource

Introduction

Rooftop farming (RTF) is the production of fresh vegetables, herbs, fruits, edible flowers and possibly some small animals on rooftops for local consumption (Dubbeling & Massonneau, 2014). It can be one of the solutions for urban waste management by maintaining the essence of the statement "Waste to Resource". The compost produced from organic waste and recycled grey water can be a cost effective and locally generated source of fertilizer and water for rooftop farming, thereby, supporting the productive re-use of waste and wastewater. Rooftop farming has been formally introduced in Nepal recently in 2013 through public awareness

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campaigns and programs by Kathmandu Metropolitan, Environment and Public Health Organization, Clean Energy Nepal, along with many other NGOs and local organizations. The practice is currently limited to particular groups, communities or areas. The exact number of households practicing RTF is not known.

Many people from rural areas of the country migrate to Kathmandu seeking better opportunities of livelihood. Kathmandu Valley is home to 2.5 million people and Kathmandu district is the most rapidly growing district in the country in terms of population with a 4.71 percent growth per annum (CBS, 2012). Uncontrolled and rapid urbanization of Kathmandu Valley has a multi-sector adverse impact on the environment. Solid waste and wastewater are the most visible environmental nuisance and major causes of pollution in the urban areas of Kathmandu Valley. Managing these pollution sources has become a daunting task as a result of this haphazard urbanization. Traditionally, waste was considered a 'Resource' in Kathmandu Valley and solid waste and wastewater generated from households were recycled or reused for agriculture purposes. However at present, wastewater from the urban areas of Kathmandu Valley is directly discharged into the Bagmati River and its tributaries without any treatment. Similarly, solid waste is either conveyed to landfill sites or dumped haphazardly.

Rapid urbanization, unprecedented population growth and reduction in local food production have exerted immense pressure on adequate food supply in the Kathmandu Valley. This has resulted in the dependency upon food either from outside the valley or from foreign countries. Between 1984 and 2000, agricultural land in the valley decreased from 62% to 42% (ICIMOD, 2007). Thus, this paper assess the viability of rooftop farming for recycling and the productive use of urban waste in Kathmandu.

Objective

The overall objective of the study is to assess the potential of recycling and productive reuse of urban waste in rooftop farming in Kathmandu. The specific objectives are:

- To assess the rooftop area feasible for rooftop farming in KMC.
- To estimate the quantity of organic solid waste and wastewater (grey water) that can be transformed into compost and used as resources for RTF.

Methodology

The study was conducted through a literature review on waste and wastewater management practices in Kathmandu Valley. Additionally, the findings from the assessment of 139 households practicing rooftop farming under the UPAF (Urban and Peri Urban Agriculture and Forestry) project implemented by KMC, ENPHO and ISET Nepal in 2012 was reviewed. Rooftop area was calculated on the basis of land use mapping of KMC. Crop water demand, compost required and cropping pattern were derived from available literature and information from local farmers.

Results and Discussion

Available Rooftop Area

On the basis of land use mapping, the total residential area of Kathmandu Valley is 24 sq.km comprising 200,000 households. Out of these households, approximately 34% of urban dwellers were found to practice kitchen gardening or RTF for domestic consumption (ENPHO, 2012). Thus, it was assumed that at least this portion of households in Kathmandu would adopt RTF. It was also assumed that only 70% of the available rooftop area would be utilized for RTF. Hence, the total RTF area in Kathmandu equates to 5.7 sq. km. as shown in calculation 1.

Calculation 1: Available Roof top Area for RTF
Total Residential Area: 24 sq. km.
Roof top area =34% of 24= 8.16 sq. km.
Cultivable Roof Top Farming area=5.7 sq. km.

Estimation of Demand and Supply of Compost: Since use of compost generated from household organic wastes and greywater is embedded in the concept of RTF, this section assesses the production of compost from organic waste in KMC and its utilization in RTF.

According to a study carried out by Asian Development Bank in 2013, it was estimated that 504 tons of solid waste is generated per day in KMC. Out of this, 63.22% is organic waste which can be decomposed to produce manure (ADB, 2013). Under suitable conditions and adequate decomposition, this volume of organic waste can produce 160 tons of compost per day as shown in calculation 2.

Calculation 2: Compost produced per day in KMC
Total Solid Waste generated = 504 tons per day
Composition of organic waste = 63.22% of total waste
= 318.63 tons per day
Compost manure generated = 50% of organic waste
(Since organic waste generally consists of 40-60% of moisture, for the calculation, 50% loss as moisture during composting process has been assumed)
= half of organic waste produced
=160 tons per day

The total demand for compost was estimated based on the above mentioned cultivable roof top area and available secondary data on the manure required for the cultivation of crops. As per the Agricultural Information and Communication Center, the requirement of compost varies from 5 to 15 tons per hectare for different crops. The study also revealed that 10 tons per hectare of compost produced maximum yield of rice grain (Plaza and Oilseed, 2010). Thus, 10 t/ha was assumed the required compost amount for crop cultivation in RTF. Hence, total demand for compost manure in RTF is 63.3 tons per day as shown in calculation 3.

Calculation 3: Total demand of compost manure for RTF per day
1 hectare of cultivation area requires 10 tons of compost,
i. e. 10000 sq. m. = 10 tons of compost per season [1 season is equivalent to 3 months]
which implies, 5.7 sq. km. = 5,700,000 sq. m of cultivated area demands
= 5,700 tons of compost per season
= 63.3 tons per day

This shows the current demand of compost manure, 63.3 tons per day for RTF, is only 40% of estimated total potential compost production of 160 tons per day (calculation 2).

Estimation of grey water utilization: Approximately 68.92 MLD (Million liters per day) of wastewater is generated in Kathmandu Valley (Shukla, Timilsina and Jha, 2012) which is approximately equivalent to 344 liters per day per household. In general, the volume of grey water accounts for 50% to 80% of the domestic household water uses and thus the wastewater generated (Al-Mashaqbeh, Ghrair and Megdal, 2012). Thus, 45 MLD, 65% of water use, was assumed to be grey water which is discharged into nearby drainage.

Besides reusing organic solid waste as compost, RTF also provides an opportunity to reuse grey water produced at household level. Water demand for crops may vary according to their types which is presented in Table 1 below (National Committee on Plasticulture Application in horticulture, n.d.). Water demand for crops was calculated at a household level so as to reuse grey water generated at household level.

According to Table 1: crop water demand for crops for total cultivable RTF, crop water required is 3.17 MLI to 15.66 MLI in initial phase and 6.3 MLI to 28.6 MLI in peak phase

Table 1: Crop Water Demand for Crops for Total Cultivable RTF

Crops	Initial Phase crop water demand (Liter per Irrigation per Plant (L/I/P))	Peak Phase crop water demand (L/I/P)	Cropping area per plant (cm^2)	Number of plant (Cultivable area/ cropping area)	Water requirement Initial Phase (MLI)	Water requirement Peak Phase (MLI)
Tomato	0.45	1.15	75*60	12693333	5.71	14.6
Cauliflower	0.74	1.35	45*60	21155556	15.66	28.6
Beans*	0.25	0.5	45*45	46628571	11.66	23.3
Garlic*	0.05	0.1	5*5	2284800000	114.24	228.5
Strawberry*	0.05	0.1	30*30	63466666	3.17	6.3

*: Crop water demand calculated based on experience shared by local farmer

Table 2: Crop Water Demand as Crops per Household (230 sq. ft.)

Crops	RTF area (HHS cm^2)	No. of plants (HHs) = RTF Area / No. of plants	Crop water demand Initial Phase= No of plant* initial water demand (Liter/irrigation)	Crop water demand Peak Phase	Monthly crop water demand (Initial Phase) LI	Monthly crop water demand (Peak Phase) LI
Tomato	230000	51	23	59	138	353
Cauliflower		85	63	115	378	691
Beans*		188	47	94	282	563
Garlic*		9200	460	920	2760	5520
Strawberry*		256	13	26	77	153

*: Crop water demand calculated based on experience shared by local farmer

except for garlic. This indicates that the demand of water for cultivable RTF in KMC is lower than the volume generated. Table 2 also shows crop water demand for different crops is 13 L/D to 63 L/D in initial phase and 26 L/D to 63L/D in peak phase which implies that grey water generated at household level is sufficient to irrigate rooftop farming in crops.

Conclusion

It can be concluded that the promotion of rooftop farming provides an opportunity to reuse urban waste into resources. Currently, there is demand of 63.3 tons of compost per day which is 40% of the potential compost manure production from the waste generated in Kathmandu. Also, crop water demand for different crops is 13 L/D to 63 L/D in initial phase and 26 L/D to 63L/D in peak phase, thus grey water generated at households can be effectively applied for rooftop crop irrigation.

Recommendation

It is recommended that awareness campaigns be scaled-up to raise the awareness of the benefits of rooftop farming at household and community level while using organic waste for composting. Also, further research should be conducted on the quality of greywater or compost being used in RTF and the quality of crops produced.

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Human urine application in rice and potato production

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Abstract

This study was carried out to evaluate the effect of human urine on rice and potato production while comparing yields from urine application, chemical fertilizer application and farmer's common practice. Urine application supplemented with compost gave significantly higher yield in rice ($p<0.05$) compared to two-split or three-split urine application, chemical fertilizer or farmer's practice. Potato yields, though not significantly different among treatments ($p>0.05$), were generally higher in plots treated with urine and compost combined. Rice yield from farmer's common practice was lower compared to application of chemical fertilizers. In case of potato, the yield from farmer's practice is slightly higher than that from plots treated with urine alone and is comparable or even higher than yield from plots treated with chemical fertilizers. Furthermore, organic matter in soil increased with every treatment, with the highest organic content reported in soil treated with urine supplemented with compost. The study indicates that urine in combination with compost can act as a valuable fertilizer and a potential substitute for chemical fertilizer for rice and potato cultivation. Diverting urine from wastewater streams for its use in agriculture can also reduce nutrient load in wastewater thereby saving valuable energy and resources required for wastewater treatment.

Key words: compost, ecological sanitation, fertilizer, human waste, organic matter

Introduction

The emerging concept of "Closing the Loop" emphasizes ecological sanitation for food security and considers human waste a valuable resource for increasing soil fertility and food production. A major source of nutrients in wastewater is human excreta,most of which is contributed by urine. Urine typically contributes around 80% of nitrogen, 50% of phosphorus, and 90% of potassium in the total nutrient load (Larsen *et al.,* 2001).While use of human excreta in agriculture is an age-old practice, the concept of Ecological Sanitation (Eco San) toilets has fostered separation of urine and faeces, their use as fertilizers as well as curbing of unsafe excreta disposal (Karak and Bhattacharya, 2011). A urine-separating system can save about 80% of

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water used for toilet flushing which can account for 30% of average direct daily water use. A family of four could save around 80 litres of water per day with such system(Larsen *et al.,* 2001). This in turn can reduce wastewater load along with nutrients and can significantly decrease the energy requirement for wastewater treatment (Wilsenach and Van Loosdrecht, 2003).

Use of urine in agrilculture can reduce emission from fertilizer production and contamination of agricultural soils by heavy metals through synthetic fertilizers (Larsen *et al.,* 2001). Especially in developing world where chemical fertilizers are expensiveand not readily available, urine can be a quick acting, nutrient-rich fertilizer(Gensch *et al.,* 2011; Feineigle, 2011), that provides significant quantity of water to agricultural crops. Studies suggest human urine as clean fertilizers because of the lower concentrations of heavy metals in human urine than farmyard manure and artificial fertilizers (Richert *et al.,* 2010). Johansson *et al.* (2002) suggest that though urine can possibly be cross-contaminated with faecal pathogens, it is effectively sterile under high pH and high temperature (e.g. >20°C) when stored for ≥6 months (Beal *et al.,* 2008).In general,urine has nitrogen concentration of 3-7 gm/L and each human being produces 0.8–1.5 L of urine per day (Richert *et al.,* 2010). The nutrients in ionic form in urine are readily available and therefore is comparable to chemical fertilizers (Jonsson *et al.,* 2004).Literature suggests that urine produced by a person in one year has enough fertilizer value to feed him the amount of cereal the person consumes in a year (Ganrot, 2005).Different studies on fertilizer value of human urine suggests increase in yield of different vegetables and maize due to the readily available nutrients (Sene *et al.,* 2013).

Urine application can help improve soil fertility and decrease the use of inorganic fertilizers. Urine application in agricultural crops can also reduce the nutrient load entering into the wastewater streams, thus saving energy and other resources necessary for wastewater treatment.

This study evaluated the effect of human urine application (and its application method) on rice and potato production, the first and the fourth most important crops of Nepal respectively (Joshi *et al.,* 2003). Crop yields from urine application, chemical fertilizers and farmer's common practice (urea and animal manure) were compared.

Objectives

The overall objective of the study was to assess applicability of human urine in agriculture. The specific objective of the study was to compare the yields of rice and potato from different kinds of fertilizers including the common practice of applying animal manure and urea.

Materials and Methods

Study site and materials

The field experiment was carried out in Gundu, Bhaktapur for three consecutive years (2009-2011) in a total cultivation area of 58.75 m^2 (five plots measuring 11.75 m^2 each for five different treatments). The soil properties were analyzed at the start of the experiment (Table 1).

Table 1: Soil attributes before the experiment

Parameters	Value
pH	7.2
Electrical Conductivity (EC)	491 (µs/cm)
Organic Matter (OM)	0.20%
Total Nitrogen (TN)	0.10%
Total Phosphorus (TP)	0.20%
Available Phosphorus	0.02%
Moisture Content	1.70%

The soil was characterized to be sandy loam; 55% sand, 9% clay and 36% silt.

The plants used for study were rice (Variety Khumal-11) and potato (Variety Janak Dev) which were planted sequentially: rice planted in May/June and harvested in October/November;

potato planted in January and harvested in April/May. The space allotted per plant of rice was 20 x 15 cm^2 and 75 x 25 cm^2 for potato. Actual yields were measured and transformed to kg/ha for rice and tons/ha for potato. The potato harvest was also followed by soil analysis every year.

The yields obtained under different treatments for rice and potato were compared statistically.

Treatments

Five different treatments (Table 2) were tested. A narrow protective plastic strip (2 feet deep) was used between treatment plots to prevent cross contamination.

The chemical fertilizers used were urea (46% N), di-ammonium phosphate (18% N and 46% P) and murate of potash (60% K). The fertilizer dose for rice was 80:30:30 and for potato 150:100:30. Urine dose for the crops were calculated to be 20 litres (Richert *et al.,* 2010) each for both, rice and potato per season. The analysis of urine used for the study was carried out at Environment and Public Health Organization (ENPHO) laboratory (Table 3).

Table 2: Treatment details

Treatment	Application Method
T1: Two-split urine	Half volume (1/2 dose) of calculated dose of urine was applied at the time of planting and half (1/2 dose) was applied on day 25-30 after planting.
T2: Three-split urine	1/3 volume (1/3 dose) of calculated dose of urine was applied at the time of planting, whereas the rest of the volume was applied at two different times i.e. 25-30 days (1/3 dose) and 50-60 days (1/3 dose) after planting.
T3: Urine supplemented with compost	Half volume (1/2 dose) of calculated dose of urine was applied at the time of planting along with compost @ 10 tons/ha per crop per season. The other half was applied on 25-30 days after planting.
T4: Chemical fertilizer	Half volume (1/2 dose) of recommended dose fertilizers was applied at the time of planting whereas the other half was applied at 25-30 days after planting.
T5: Farmer's common practice	Use of animal manure and then addition of urea at 20-25 days after plantation.

Urine application

Urine was collected separately from faeces from Eco San Toilets (system that separates faeces and urine), and stored for one month before its use as recommended by Richert *et al.,* 2010. Urine samples were analyzed for pH, nitrogen, phosphorus and potassium content (Table 3) at ENPHO laboratory every year.

In case of rice, urine was directly applied without dilution, whereas in case of potato, urine was diluted in the ratio 1:3 (urine: water) at the time of application (Richert *et al.,* 2010). The total dosage of urine was 20 litres (Richert *et al.,* 2010) each for both crops.

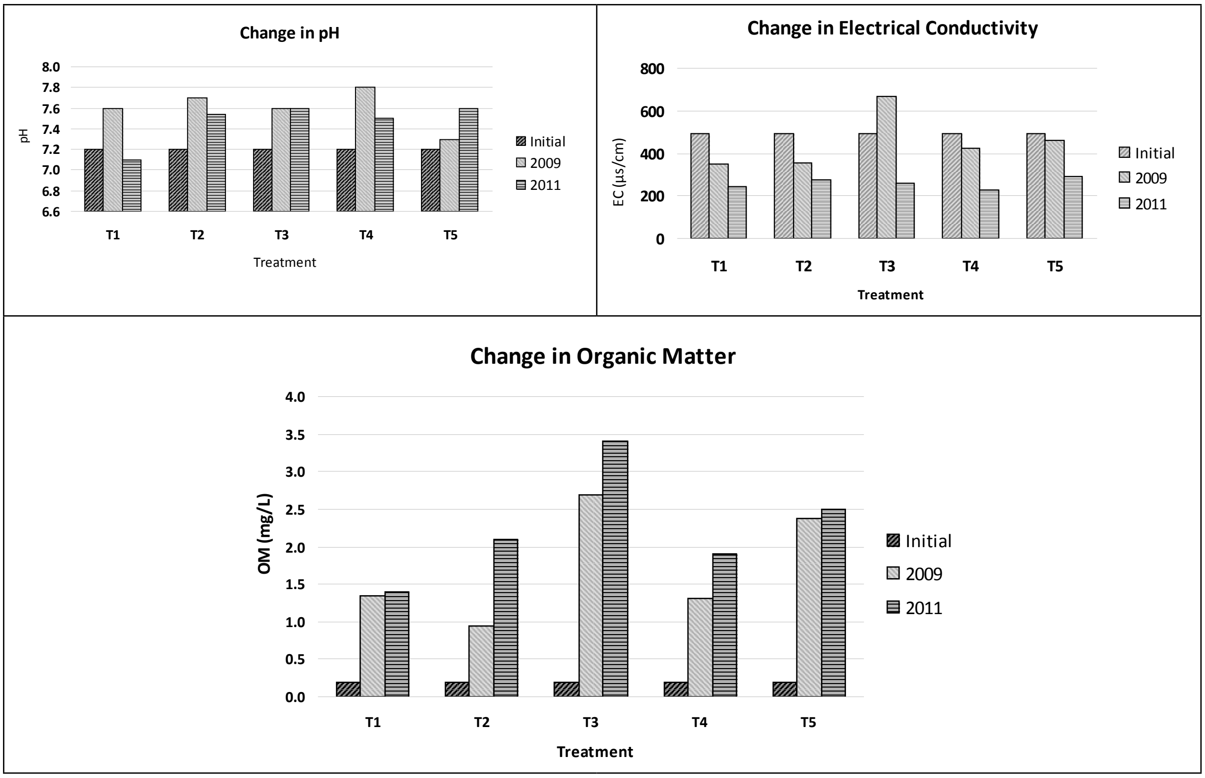
Table 3: Attributes of urine

Parameter	Year		
	2009	2010	2011
Total Nitrogen (mg/L)	2926	5391	7117
Total Phosphorus (mg/L)	308	178	314
Potassium (mg/L)	874	1711	1797
Sodium (mg/L)	-	2774	3526

Results and Discussion

Soil quality

The pH value of soil slightly increased (range 7.2 to 7.9) after first application in all treatments (Table 1). According to FAO (1984), the availability of plant nutrients is high when pH is between 6.5 to 7.5 as soil reaction is highest in the range and breakdown of organic matter and release of nutrients is greatest in intermediate pH levels – around 7 (Thapa, 2013). The organic matter content of the soil increased in all treatments with the highest increase seen in T3 during and after the experiment. EC value decreased in every treatment except in T3 after first harvest. However, the EC values in final year are lower than initial values in all treatments.



Rice and potato yields

According to the results for rice yields under different treatments, the yield in T3 (treatment with human urine and compost) was significantly higher than all other treatments ($p<0.05$). The results also suggest that among different urine application methods, i.e. T1 (two-split), T2 (three-split) and T3 (urine supplemented with compost), T3 was the most effective. The rice yield under T3 is about 20% higher than under other urine treatments (Table 4) possibly due to a higher level of nitrogen in the soil and its uptake by the crops. Earlier research have also reported significant positive rice yield response to application of nitrogen (Singh *et al.,* 2014).

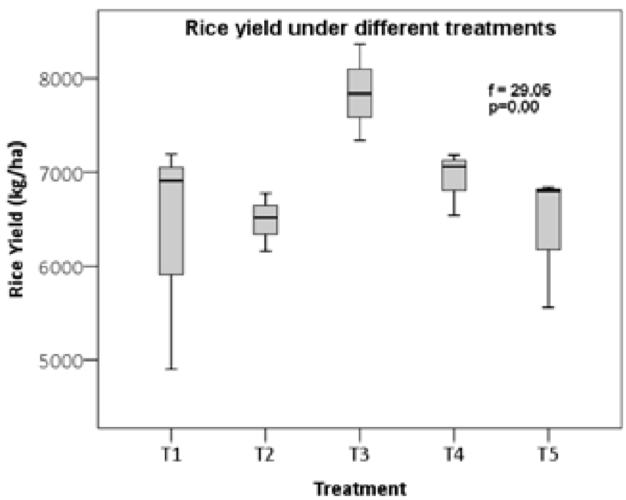
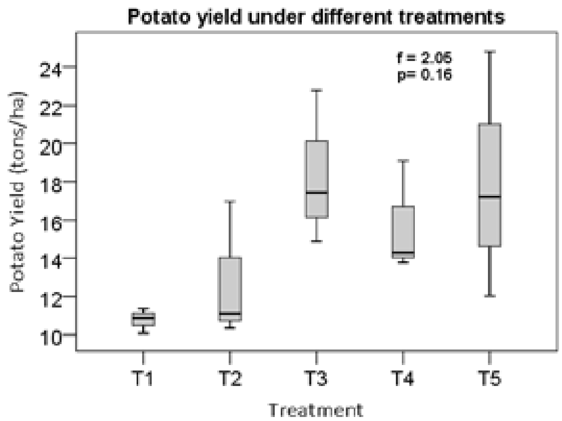


Table 4: Yield of rice and potato production under different treatments in different years

Treatment	Rice Yield (kg/ha)			Tuber Yield (t/ha)		
	2009	2010	2011	2009	2010	2011
T1	6915	7191	4902	10.1	10.9	11.4
T2	6775	6519	6162	10.3	11.1	17.0
T3	8362	7336	7838	14.9	17.4	22.8
T4	7064	7183	6545	14.3	13.8	19.1
T5	6838	6800	5557	12.0	17.2	24.8

Rice production with T3 is 2-20% and 23% higher compared to yield of T4 and T5 respectively. Yield from T4 (chemical fertilizers) was lower than yield from T3, but higher than T1, T2 and T5. The yield from farmer's common practice was consistently lower than those from chemical and two-split urine applications.
In case of potato, highest yield was obtained with T3 (urine supplemented with compost) every year. Though statistical analysis of yields under different treatment methods did not show significant difference in potato yields ($p>0.05$), the general trend indicates a higher yield with T3. Potato yield from T3 is about 50% higher than yieldfrom other urine treatments and about 16% higher compared to chemically treated plots. Unlike in rice, potato yield under T3 was not significantly different from yield under farmer's common practice.Potato yield with farmer's practice was higher than those from chemically treated plots. The plots treated with urine only (T2 and T3) showed lower yields compared to other treatments, which indicate that the nutrients could not be effectively used by plants with these treatments. Similar results were reported by Pradhan *et al.* (2007) who studied the effect of human urine fertilizer on cabbage growth. Another study by Pradhan *et al.* (2009) also found that urine fertilized tomato produce was equal to the produce of mineral fertilized plants which was 4.2 times more than non-fertilized plants (Karak and Bhattacharya, 2011).

The potato yield increased over the years under all treatments. Comparing yields of the first year with that of the third year, the increase in yield is least (12%) under T1 and highest (106%) under farmer's common practice. This could be due to the increase in fertility of the soil for potato production because of the treatment methods applied or the farming.



Conclusions

The research clearly shows significantly higher productivity of rice ($p<0.05$) under T3 (human urine supplemented with compost). Rice yield under farmer's common practice was less than under chemical fertilizers and two-split urine application. The yield of potato was generally higher with T3 although the difference between treatments was not statistically significant ($p>0.05$). Potato yield with farmer's common practice was slightly higher than that with urine alone and with chemical fertilizers. Hence, it can be concluded that urine in combination with compost (T3) can act as a valuable fertilizer and a potential substitute for chemical fertilizer for rice and potato cultivation. Separating urine from sewage and wastewater for use in agriculture can also reduce nutrient load in wastewater streams and save energy and resources necessary for wastewater treatment.

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Co-treatment of faecal sludge with wastewater treatment systems: A systematic review

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Abstract

Co-treatment of faecal sludge with sewer-based wastewater treatment plants could be one solution for treating faecal sludge. The objective of this paper is to systematically review empirical studies of the potential for and impacts of co-treatment of faecal sludge with wastewater treatment systems. Data were obtained from peer-reviewed articles, books and reports. Globally, the practice of faecal sludge co-treatment is very limited, with examples including activated sludge plants, trickling filters, rotating biological contactors, waste stabilization ponds, aerated lagoons, and anaerobic systems. The feasibility of co-treatment largely depends upon solids, organic and nitrogen loadings, shock loadings, faecal sludge characteristics and capacity of treatment plants. One significant challenge is that relatively small volumes of faecal sludge can be co-treated with wastewater treatment plants. Additionally, excessive loadings lead to severe operational problems as a result of the incomplete removal of organics, cessation of nitrification, high sludge generation, presence of inhibitory compounds. Based on this review, the author concludes that co-treatment of faecal sludge with sewer-based wastewater treatment systems is unlikely to be a viable solution in the majority of cases in low-income countries.

Key words: activated sludge plant, co-treatment guideline, FSM, organic loading, septage

Introduction

Proper management of waste and wastewater is a growing issue in urban areas of developing countries. About 90% of wastewater in developing countries is discharged directly into the water bodies without treatment (Corcoran *et al.,* 2010). Over the past few years, promotion and installation of on-site sanitation systems such as pit latrines and septic tanks have increased substantially in both urban and rural areas (Water Research Commission, 2011). Nevertheless, proper planning for faecal sludge management (FSM) is often lacking. As a result, hundreds of thousands of tons of faecal sludge (FS) collected from on-site sanitation systems, most of which is untreated, is disposed of haphazardly into the environment everyday (Strauss and Montangero, 2002). In many cities, FS dumping sites are located close to squatter areas or informally

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inhabited low-income areas where people, particularly children, are at the greatest risk of exposure to hygienically unsafe excreta (Strauss and Montangero, 2002).

There are major problems and challenges associated with each of the components of FSM, including pit/vault emptying, haulage, storage or treatment, and reuse or disposal (Strauss and Montangero, 2002). Although much effort and many resources have been invested in developing both low- and high-cost wastewater treatment technologies over the past decades, very limited field research, technological development and testing have been carried out on sustainable FS treatment and management (Ingallinella *et al.,* 2002).

The practice of disposing FS at centralized wastewater treatment plants (WWTPs) is seen as a feasible option to help to stabilize the sludge from an environmental perspective (Andreadakis, 1992; Heinss and Strauss, 1999; Harrison and Moffe, 2003; Lake, 2010). However, the characteristics of FS and septage can affect the performance and operation of the receiving sewage treatment plants since they are more concentrated than typical sewage flows (Andreadakis, 1992; Harrison and Moffe, 2003). The objective of this paper is to present the review of co-treatment of FS with centralized WWTPs and the issues with co-treatment that should be addressed to avoid failures. The findings from the review of the FS co-treatment with activated sludge plants, trickling filters, rotating biological contactors, waste stabilization ponds, aerated lagoons, and anaerobic systems are presented and discussed in this paper.

Methods

Data were collected by reviewing the existing scientific literature, books and reports related to FS co-treatment with WWTPs. To find the relevant documents, the search was done on the websites of United States Environmental Protection Agency (US EPA), National Service Center for Environmental Publications (https://www.epa.gov/nscep), and Google Scholar (https://scholar.google.com) using the following keywords: "Faecal Sludge" AND "Co-treatment"; "Septage" AND "Co-Treatment"; "Faecal Sludge" AND "Wastewater Treatment Plants"; "Septage" AND "Wastewater Treatment Plants". The systematic review mainly focused on identifying data and information on type and design capacity of WWTPs; co-treatment processes; characteristics and volume of FS added; impacts of FS addition; and procedures to reduce these impacts.

Results and Discussions

FS co-treatment in conventional WWTPs has been practiced in high-income countries, including the United States, and in some middle-income countries. Based on monitoring results, the US EPA (1984) pointed out that the ability of WWTPs to accommodate the addition of FS depends on the plant type, layout & location; design capacity; wastewater flow; effluent limitations; FS pre-treatment facilities; and sludge handling facilities. The quantity of FS that can be added to the WWTP depends on the quantity & characteristics of the FS; nature of flow (slug load or continuous loadings); and aeration capacity, in the case of aeration based WWTP.

Co-treatment in activated sludge wastewater treatment plant

The co-treatment of FS in an activated sludge WWTP can be achieved in two ways: addition in the liquid stream - before bar screening, before primary clarifier and before the aeration tank or trickling filter, and addition in the solid stream - in the sludge thickener, in the sludge digester and in the dewatering facility (US EPA, 1984). FS addition to the WWTP is recommended only after pre-treatment (e.g. screening, degritting and equalization) (US EPA, 1984). Pre-treatment is required to prevent possible shocks to the plant's hydraulic and organic load-carrying capacity. This is further supported by the results of the study conducted by Eikum (1983) in Norway. If pre-treatment is not possible, the US EPA (1984) suggests discharging fecal sludge into a controlled manhole upstream of the plant headworks allowing it to get diluted by the wastewater before entering the plant. However, the addition of FS during low flows is not recommended, since that can exert shock loading, leading to operational problems. The US EPA (1984) recommends evaluating the impact of FS addition to the activated WWTP units, with a focus on such key considerations as: increased hydraulic loading on primary and secondary clarifiers; increased loading on sludge treatment or handling units; increased sludge volume in clarifiers; increased organic loading to the biological process units; scum build up in treatment units; odour and foaming problems in aeration units; and toxic substances present in FS causing inhibition to biological processes and effluent limitations.

Segall *et al.,* (1979) reported that a constant addition of 2% of FS almost doubles the organic input to an aeration basin and doubles the solids loading on a primary clarifier in a conventional activated sludge WWTP. It is possible for conventional activated WWTPs to operate successfully with continuous FS additions (ahead of primary units) of less than 5% of flow volume at loadings of 0.33 to 1.1kg BOD_5/kg MLVSS/d and COD loadings of up to 3kg COD/kg MLVSS/d (US EPA,1984). A field study conducted at the full scale WWTP at Marlborough, Massachusetts concluded that the plant is in operation at a loading of 0.42kg BOD_5/kg MLVSS/d without FS addition, which increased to 0.45 and 0.54kg BOD_5/kg MLVSS/d for respective FS addition rates of 1.25 and 2.14 percent of wastewater flow (Segall *et al.,* 1979). The same study indicated that the FS addition to WWTPs has an average oxygen requirement of 0.7kg O_2/kg of BOD in FS added. The FS added to these plants was pre-treated, and operation & management requirements were carefully planned before the FS addition, which is key for the successful operation of these plants.

Dangol (2013) carried out mathematical modelling of different volumes and strengths of digested and fresh FS combined with wastewater to assess the potential impact on the efficiency of a 100,000 Population Equivalent (P.E.) activated sludge WWTP receiving medium strength wastewater. This simulation study highlighted the detrimental effects of adding FS to an activated sludge WWTP. The aeration capacity of the system was rapidly insufficient and nitrification stopped due to the high TSS, COD and N loading. Further, it found that for low and medium-strength digested sludge, only a small quantity of the total influent flow (max. 0.6 and 0.5% respectively) could be added. For fresh FS, less than 1 promille was acceptable to the plant. The results demonstrated that co-treatment of faecal sludge is a feasible option only for limited amounts of low and medium-strength digested faecal sludge. Before discharging faecal sludge to a WWTP, one must be know whether one is dealing with fresh or digested sludge.

Similarly, a field-based study on two activated sludge WWTPs in South Africa found serious operational problems caused by high loads of organics, nitrogen compounds and suspended solids after adding low volumes of FS into the systems (Wilson and Harrison, 2012). A complete cessation of nitrification process was observed in one of the plants, and excessive overloading of the solids was found in another system (Still and Foxon, 2012). Still and Foxon (2012) concluded that FS co-treatment in activated sludge WWTPs is not sustainable due to severe technical and operational problems. Another study conducted for co-treatment of septic tank sludge in an activated sludge WWTP on Saint Marten, Netherlands Antiles concluded that the plant could handle FS volumes of no more than 2.8% of the influent (Lake *et al.,* 2011). The FS discharged to this system contained high loads of non-biodegradable particulate organic matter and non-biodegradable soluble organic nitrogen, which hindered compliance with the effluent limits after co-treatment.

In Manila, Philippines, an activated sludge plant was found to be able to treat up to 814 m^3/day of FS, mainly because the total volume handled by the plant was only about 40-50% of its design capacity, allowing room for FS addition (Robbins *et al.*,. 2012). In addition, there was adequate operator capacity and competence, and an appropriate management scheme was being implemented for the system.

Germany has developed guidelines for the addition of FS in sewer mains and liquid streams connected to centralized WWTPs (ATV-Regelwerk, 1974). These guidelines include the following key suggestions:

Table 1: Guidelines for FS addition in sewer mains and in liquid stream

FS addition in sewer mains	FS addition in liquid stream in WWTP
The treatment plant must have a biological step with adequate capacity to treat an additional load of FS designed for a minimum of 30,000 persons.	The treatment plant must have a biological step with adequate capacity to treat an additional load of FS designed for a minimum of 10,000 persons.
At the point of discharge, the FS must be diluted at least 10 times with municipal wastewater.	At the point of discharge, the FS must be diluted at least 20 times with municipal wastewater.
FS must only be added at the point specifically set aside for FS addition.	FS must be added upstream from the plant screen.

Co-treatment in Trickling filters:

Data on the performance and design of trickling filters for combined treatment of FS and wastewater is very limited. Rezek *et al.,* (1980) found that the trickling filter plant at Huntington, New York with a capacity of 83.1 L/S treated 1.3 L/S of FS with BOD reductions of 85 to 90%. As high concentrations of suspended solids (1 to 3 %) could cause plugging of the filter media in trickling filter units, it is highly recommended that the mixture of FS & wastewater first go through primary treatment. For an FS addition of 1% of wastewater flow, a low-rate trickling filter would produce about 0.24 kg sludge/m^3 of flow; this would increase to 0.3 kg sludge/ m^3 for high-rate trickling filters. Therefore, besides a requirement for primary treatment, the hydraulic & organic loadings and handling of increased sludge production are the major considerations for FS addition to trickling filters (US EPA 1984).

Co-treatment in Rotating Biological Contactors:

Rotating biological contactors (RBCs) consist of rotating discs where microbial biomass can attach and grow and organic matter is aerobically broken down. RBC systems are largely used in centralized WWTPs in developed countries. There are, however, very few examples of combined treatment of FS and wastewater in systems with RBCs. Combined treatment of FS and wastewater at the Ellsworth, Maine RBC treatment plant was not very successful, as the addition of less than 1% of FS to a wastewater flow of 2,460 m^3/d caused several operation problems (US EPA, 1984). These problems included clogging of roto strainers and high concentrations of BOD & TSS in the final effluent due to high organic and solid contents in FS. Therefore, the organic loading rate is an important factor to be considered if FS co-treatment is to be done in an RBC.

The US EPA (1983) reported that first stage organic loadings of 2.7 kg total BOD_5/d/1,000 ft^2 resulted in an increased frequency of process and mechanical problems at 24 facilities with RBCs. These problems included excessive biofilm thickness, nuisance organism growth, and deterioration of process removal efficiency. As high influent H_2S concentrations can impede RBC performance and accelerate nuisance growths, control of excessive biological growth is very important when FS is added to RBC plants (US EPA 1983).

Co-treatment in anaerobic processes:

The co-treatment of FS and wastewater in anaerobic processes such as up-flow anaerobic sludge blanket reactors (UASBs), anaerobic digesters, and anaerobic ponds could be an alternative for sludge stabilization, volume reduction, and increased dewaterability. Anaerobic processes are particularly attractive due to the production of biogas. However, FS co-treatment in anaerobic processes can be disrupted by overloading of COD, ammonia inhibition, pH variations, and sulfide inhibition (Lopez-Vazquez *et al.,* 2013). Still and Foxon (2012) pointed out that the low concentrations of biodegradable organics in digested FS will lead to low biogas production but high solids accumulation that results in additional operational costs during FS co-treatment in anaerobic treatment systems.

Lopez-Vazquez *et al.,* (2013) conducted mathematical modelling of FS co-treatment in a UASB and concluded that the UASB system designed for 100,000 P.E. can handle only 7.5% of low-strength digested FS and 0.25% of high-strength fresh FS due to high COD content. A UASB could handle low-strength FS but is prone to overloading in the case of addition of high-strength FS. This clearly exhibits that it is important to know the characteristics of FS before addition to such processes. ATV (1985) recommended that feeding that includes FS should be lower than one twentieth of the digester volume for anaerobic co-treatment in the digesters. Therefore, a maximum of 5% FS loading, regardless of its strength, is possible to prevent overloading or any reduction in the Sludge Retention Time (SRT) in anaerobic digesters.

Anaerobic ponds, which are the first stage of treatment in a waste stabilization pond (WSP), are widely used for the treatment of municipal wastewater. With FS co-treatment in anaerobic ponds, ammonia quickly becomes a limiting factor (Strauss *et al.,* 2000; Still and Foxon, 2012). Methanogenic bacteria are the most sensitive to ammonia inhibition, resulting in lower biogas yield even if soluble biodegradable organics are available (Chen *et al.,* 2008; Angelidaki *et al.,* 1993; Chaggu, 2004). Due to high ammonia concentrations and high organic loads & solid content, treating high quantities of FS or treating only FS in WSPs is not recommended (Strauss *et al.,* 2000). Fernandez *et al.,* (2004) suggested the pre-treatment of FS before adding it into a WSP, operated at maximum loading rates of 0.6 kg $BOD_5/m^3/d$. WSP can be used for the co-treatment of wastewater and FS effluent following pre-treatment (solid-liquid separation) in settling-thickening tanks. Kurup *et al.,* (2002) pointed out the possibility of FS co-treatment with landfill leachate in WSPs.

Based on the intensive studies and monitoring of FS addition in centralized WWTPs, Rezek *et al.,* (1980) prepared the chart in Figure 1 below, which shows the amount of FS that can be added to a plant as a function of plant capacity and the ratio of present flow to design flow (Figure 1). The WWTP with 100% wastewater flow will not accommodate FS addition. As per this chart, if the activated sludge plant with primary treatment is in operation with annual wastewater flow of 50%, then FS addition of 1.4% of the plant design capacity can be done. Taking the case of Guheshwori WWTP, which is based on activated sludge with primary treatment and with the design capacity of 17 MLD, if the annual wastewater flow is 50% & 80% then about 238 m^3/d and 102 m^3/d of FS can be added into this system, respectively. While the FS addition seems relatively large, other key factors such as adequate dilution with wastewater, excess aeration capacity, appropriate operation & maintenance, and management capability should be duly considered before the addition of FS into the system.

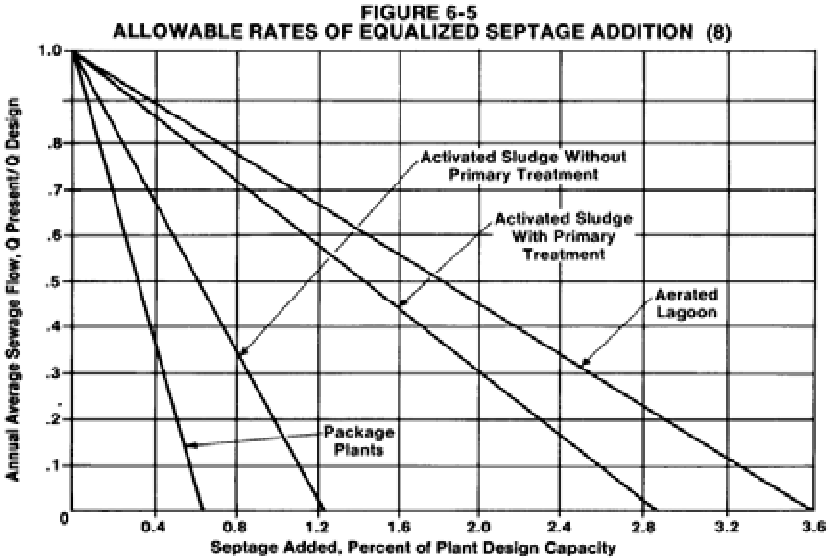

Figure 1: Allowable rates of equalized FS addition in different wastewater treatment systems (Rezek *et al.,* 1980)

Germany has developed guidelines using the chart seen in Figure 2, which shows the recommended volume of FS addition to the WWTP (Figure: 2). As per this chart, a WWTP designed for 100,000 persons with wastewater flow of 50% can accommodate only 5 m^3/day of FS addition. Taking the case of Guheshwori WWTP designed for 75,000 persons, if the annual wastewater flow was 50% & 80% then only 37.5 m^3/d and 15 m^3/d of FS could be added into this system, respectively. Compared to the previous chart, this guideline recommends a relatively low volume of FS addition to the WWTP.

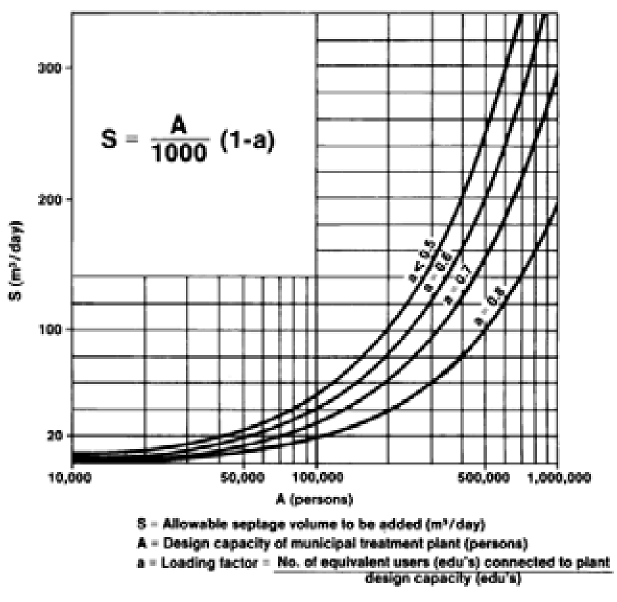

Figure 2: Allowable FS volume to be added to WWTP per German Guidelines (ATV-Regelwerk, 1985)

Conclusion

The feasibility and effectiveness of FS co-treatment with wastewater treatment systems depends on treatment type, capacity of wastewater treatment systems, wastewater flow, FS characteristics, volume of FS added, FS pre-treatment and handling facilities, and effluent standards. The discharge of FS into WWTPs can lead to severe operational problems, which are mainly caused by the higher concentration of FS compared to municipal wastewater. The most common problem is the overloading of solids, COD, and nitrogen compounds. Excessive solids accumulation may lead to high sludge generation that can increase the operational costs. Therefore, FS co-treatment with existing WWTPs is not recommended in low-income countries.

Nevertheless, FS co-treatment in centralized WWTP has been successful in developed countries mainly because of good planning, management, and technical capabilities. If co-treatment is desired, the capacity of the WWTP should be designed to accommodate FS loading, and adequate management and operator capacity should be ensured for the sustainability of the system. Further field-based research on FS co-treatment in WWTP facilities with different operating conditions should be undertaken to generate more evidence.

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Faecal sludge treatment and reuse system in Mahalaxmi Municipality, Nepal

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Abstract

Faecal Sludge Management is growing issue in cities in Nepal. Due to lack of faecal sludge treatment plant, the unsafe disposal of faecal sludge very common in Kathmandu Valley. After the devastating earthquake on April, 2015, many agencies constructed temporary latrines in the campsites and open spaces. As a result, the pits get filled up quickly requiring immediate desludging services. With an aim to treat the faecal sludge generated from the emergency latrines, a faecal sludge treatment plant was established in Lubhu which is first of its kind in Nepal. This article presents the current situation of treatment plant, its performance and scope of replication as being the proven example with successful operation for a year and aided sector learning in context of Nepal. The data were collected from the field visits, interviews, results from laboratory analysis. The efficiency of FSTP in removing organic matters and nutrients was found good. Some operation and maintenance problems were identified and fixed during the monitoring period. Such kind of FSTP can be replicated in other communities in the urban areas in Nepal.

Key words: biogas, compost, desludging, FSM in emergencies, pre-fabricated system

Introduction

In many emergency situations, providing better access to adequate sanitation facilities is important to minimize the risk of widespread of water borne diseases. Besides the provision of good sanitation, faecal sludge management and logistics in emergency settings are always a major challenge for the humanitarian organizations. The development of suitable treatment and disposal methods of large quantities of human excreta in (post) emergency settings has been often neglected due to other priorities. Inappropriate disposal of FS generated from the emergency latrines often result in public health risks and environmental pollution. Thus the proper FSM should be planned while providing emergency sanitation facilities during the emergency settings.

In the aftermath of the devastating earthquakes in 2015, people started residing in number of relief camps in the open spaces for several months. The

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temporary emergency latrines were established to improve the sanitation and safeguard the health conditions of people residing in the relief camps. Lubhu situated in recently Open Defecation Free (ODF) declared Mahalaxmi Municipality of Kathmandu Valley where 10 small relief camps were set for 500 occupants. The intensive use of emergency latrines in the camp setup and settlements resulted the problem of overflowing black water from the pits. The unsafe disposal of faecal sludge (FS) after the desludging, due to lack of appropriate FS treatment system in Kathmandu Valley, was preeminent problem during the emergency situation.

Environment and Public Health Organization (ENPHO) with support from the Municipality, Bremen Overseas Research and Development Association Organization (BORDA) and The Consortium for DEWATS Dissemination (CDD) Society established the Faecal Sludge Treatment Plant (FSTP) in March 2016, primarily to treat FS generated from the camp sites and earthquake affected households. The pre-fabricated treatment plant was constructed within 45 days in 300 m^2 land area provided by the local NGO, Saligram Orphanage. FSTP with design capacity of 6 m^3 per week is based on gravity flow system and have reuse potential in the existing vegetable farmland. Besides FS from emergency latrines, the treatment plant also received FS from the households. The research team have performed regular monitoring, performance evaluation, sampling and laboratory analysis to understand the one-year of performance and efficiency of FSTP. The objective of this paper is to present the status of treatment plant in terms of performance, acceptability and sustainability and to discuss possibility of replication in the context of Nepal.

Methods

Questionnaire Survey

A structured questionnaire for the caretaker of the treatment plant was designed to understand the major O&M requirements and overall perception of caretaker towards FSTP. A questionnaire was also prepared for private tanker collecting sludge to understand the emptying practices, frequency of pit emptying, difficulties during haulage and desludging and protective measures used during emptying of the tank.

Sampling and Analysis of FS

With an aim to understand the performance of treatment plant samples were collected by following grab methodology from different treatment units. Table 1 shows sampling location and volume of sample collected.

Each sample was collected in a sterilized 1L and 250 ml plastic bottle and 500 ml acidified bottle (for sample preservation) provided by the ENPHO laboratory using personal protecting equipment. Bottles were properly labeled in the site to prevent any kind of errors and brought on the same day to ENPHO laboratory for analysis. pH, electrical conductivity, total solids, total volatile solids, total alkalinity as $CaCO_3$, ammonia-nitrogen, nitrate, total phosphorus, total nitrogen, total kjeldahl nitrogen (TKN), chemical oxygen demand (COD), potassium, helminths, total coliform and E. Coli were analyzed following prescribed Standard

Table 1: Sampling Location and Amount of Sample Collected

Treatment units	Exact point of sample collection
Feeding tank (FT)	Inlet of Feeding Tank
Biogas digester (BGD) 1	Expansion chamber of BGD1
Biogas digester (BGD) 2	Expansion chamber of BGD2
Stabilization tank (ST)	Final chamber of ST
Anaerobic baffle reactor (ABR)	Final chamber of ABR
Anaerobic filter (AF)	Final chamber of AF
Planted gravel filter (PGF)	Outlet of PGF

Operating Procedures defined in APHA, AWWA, WEF (2012) in ENPHO laboratory. The sampling for the selected parameters were done and analyzed to know the efficiency of FSTP during pre-monsoon, monsoon and post-monsoon seasons.

Field Observation

Technical team from ENPHO visited the treatment plant for regular supervision of operation and maintenance of the plant and record books. The team performed the maintenance work in the site due to overflowing wastewater in Integrated Settler with ABR and AF and ponding PGF during post-monsoon.

Description of modules of Treatment Plant

The treatment plant has two different treatment systems integrated into one: Liquid Treatment Plant and Solid Treatment Plant. After the desludging truck empties faecal sludge from its tank into the feeding tank through hose pipe, supernatant is conveyed to liquid treatment system and thick sludge is conveyed to solid treatment system, after retention for 3 to 4 hours. Following are the components of two different treatment system with their respective size and functions;

Table 2: Function and Size of Treatment Modules

	Name of Module	Size	Function
	Feeding Tank (FT) (common for both treatment plant)	4 cum	Bar-screen provided within feeding tank separates solid waste; Incoming faecal sludge (FS) is retained for 3-4 hours for solid-liquid separation; After retention, supernatant is discharged to settler with anaerobic baffle reactor (ABR) and anaerobic filter (AF) and sludge into biogas digester.
Sludge Treatment Units	Biogas Digester (BGD) (in series)	6 cum each (2 numbers)	Anaerobic treatment of highly concentrated organic sludge; Produces biogas as the by-product.
	Stabilization Tank (ST)	10 cum	Allow the sludge to get further stabilized, which leads to settlement of solids at the bottom and supernatant to flow into the settler with integrated ABR and AF.
	Planted Sludge Drying Beds (PSDB)	20 sq. m each (3 numbers)	Digest the sludge to reduce the organic activity, thereby reducing the pathogen content. Dehydrates the sludge to produce bio-solids that can be easily transported or handled for reuse applications.
Wastewater Treatment Units	Integrated Settler Anaerobic Baffle Reactor (ABR) with Anaerobic Filters (AF)	10 cum	Wastewater undergoes sludge stabilization with biological treatment in settler (settler); Anaerobic degradation of suspended and dissolved solids while flowing through sludge blanket making use of the pollutants for metabolism by anaerobic bacteria (ABR); Allows the growth of microorganisms to make use of the pollutants for metabolism, degrading the organic material present in the wastewater (AF).
	Planted Gravel Filter (PGF)	15 sq. m	Aerobic tertiary treatment unit where the pollutants (mostly nutrients) present in the wastewater are degraded aerobically.
	Collection Tank	4 cum	Collects treated water.

Results and Discussion

The efficiency of FSTP in removing various parameters is presented in Table 3.

With Solid Loading Rate (SLR) of 210 kg TS/m^2.year, this FSTP showed similar efficiency as observed in the planted sludge draying bed study by Koottatep *et al.* (2004). The efficiency of FSTP in removing the physico-chemical parameters has increased in monsoon but again decreased in post-monsoon. The overflowing of wastewater treatment system was observed during monsoon. Some key technical problems such as leakages in control valve of feeding tank and backflow of faecal sludge from the clearing pipe into the control valve

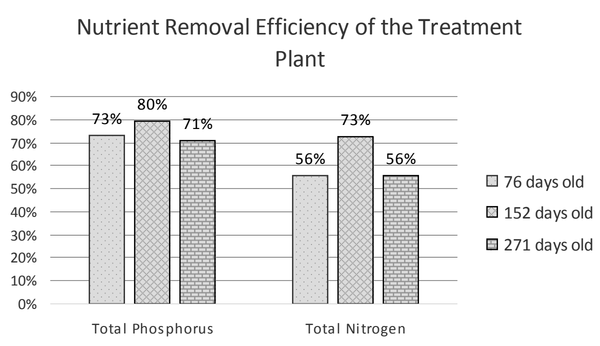
Table 3: Removal Efficiency of Treatment Plant During Pre-monsoon, Monsoon and Post-monsoon

Parameters	Unit	After 76 days of operation	After 152 days of operation	After 271 days of operation
		Pre-monsoon (June)	Monsoon (August)	Post- monsoon (December)
		Removal Efficiency (%)	Removal Efficiency (%)	Removal Efficiency (%)
pH	-	NA	NA	NA
Electrical Conductivity	µS/cm	55.41%	69%	22%
Total Solids	mg/L	71.37%	78%	50%
Volatile Solid	mg/L	75.70%	85%	70%
Total Alkalinity as $CaCO_3$	mg/L	40.43%	91%	26%
Nitrogen-Ammonia	mg/L	53.87%	71%	42%
Nitrate	mg/L	NA	90%	96%
Total Phosphorus	mg/L	72.90%	80%	71%
Total Nitrogen	mg/L	55.78%	73%	56%
Total Kjeldahl Nitrogen (TKN)	mg/L	55.78%	73%	56%
Organic Dry Matter	mg/L	75.70%	85%	70%
Chemical Oxygen Demand (COD)	mg/L	90.62%	91%	86%
Potassium (K)	mg/L	33.11%	65%	-68%
Helminths	Present/ Absent	Absent	Absent	Absent
E. coli	CFU/mL	TNTC	TNTC	TNTC

TNTC: Too Numerous To Count

units increased undesired volume of sludge in each unit of wastewater treatment system. As a result, the efficiency of FSTP in removing nutrient, solid and organic matters slightly decreased during post-monsoon season (Figure 1).

After these results and field observations, the problems observed in FSTP have been fixed. The next round of sampling and analysis will confirm if the efficiency of FSTP improved after fixing the problems. No helminths were found in the effluent. The majority of houses are served by on-site sanitation systems such as septic tanks and unsewered toilets. The faecal sludges (FS) revealed that the bulk of helminths eggs contained in wastewater or in faecal sludge end up in the bio solids generated in treatment schemes (Ingallinella *et al.,* 2002). Thus, bio-



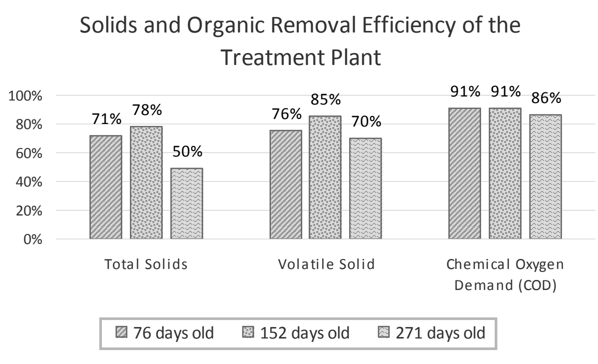


Figure 1: Season-wise nutrient, solids and organic removal efficiency of FSTP

solids that would be obtained from the treatment plant needs to be examined and verified with the proposed guideline value (3-8 eggs/g TS) for bio-solids by Xanthoulis and Strauss (1991). *E. coli* count was found very high in all the time. It indicates the need of hygienic reuse of treated wastewater and sludge. The instructions on hygienic use of treated wastewater and sludge was provided to the caretaker.

Altogether 91 trips of FS, about 320 m^3 of FS have been fed into FSTP, producing around 180 m3 of treated wastewater, which is being used by Saligram orphanage in the farm land. Following the theoretical calculation method used by Lier *et al.* (2011), nearly 507 m^3 biogas has been produced from the system. Nevertheless, the actual recorded data showed that 254 m^3 of biogas have been used for cooking by the caretaker's family.

The calculation showed that use of biogas from the system has saved money for buying about 7 cylinder of LPG gas which accounts for saving of USD 95. In addition, the amount saved due to use of treated wastewater is around USD 200 per year. Besides, financial benefits, the caretaker deemed that the productivity has been increased after the use of treated wastewater in the farm land. This is further supported by the results of treated effluent with high NPK value. It is expected that the used of treated sludge will further increase the financial benefits and productivity.

The private FS tanker operators deemed the safe disposal of FS into FSTP is very good practice and showed willingness to pay for the safe disposal. The demand for the desludging services is around 4-5 times per day. They feel bad disposing FS haphazardly but they don't have any options. Thus, the operators suggested to establish additional FSTP in different locations for easy disposal. It will also minimize transport mileage as suggested by Ingallinella *et al.* (2002). Agyei *et al.* (2011) indicated the need of strong political will for effective and sustained FSM services at local level. The local stakeholders at Lubhu provided their support in identifying the land to establish FSTP and the municipality office has been providing salary to the caretaker of this system. These commitments showed by the local stakeholders is promising for sustainability of this FSTP. In addition, the local stakeholders are proud to showcase this demonstration project which is a good platform for sector learning.

According to Niwagaba and Mbéguéré (2014), the rate of biological degradation increase with warmer temperatures. Thus FSTP can be largely replicated in the Hilly and Terai regions of Nepal, where temperature is relatively high and the practices of onsite sanitation systems is growing. The targeted populations at those regions can be benefitted by the productive use of biogas, treated wastewater and sludge.

Conclusion

Contrary to wastewater management, the development and implementation of strategies and options to cope with faecal sludge (FS) adapted to the conditions prevailing in developing countries has long been neglected. In such situation, the promising results of the treatment efficiency, the emerging demand and the self-sustaining potential of this type of proven treatment plant indicates the relevance and hence the importance of scaling up of these types of systems in the rapid and haphazard urbanization context like of Nepal. Continued research and monitoring in terms of financial, institutional, environmental, technical and social aspects of such treatment plant is essential to scale-up replication in other communities. The findings and evidences from this study can be useful for the policy makers in developing and implementing standards and policies on FS handling, disposal and treatment. The FS desludging and transportation services should be regulated and recognized that will significantly contribute in effective FSM in Nepal.

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Water quality of Bagmati river in Kathmandu valley: 2011-2014

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Abstract

Water quality of Bagmati River within Kathmandu valley was monitored for three seasons (pre-monsoon, monsoon and post-monsoon) at seven sites for four years (2011-2014). Eleven parameters were analyzed. A rapid increase in values of EC, TSS, Cl, Ammonia, Phosphorous, BOD and COD as the river flows downward was observed that indicates severe contamination of the river. Except for the samples from Sundarijal, most other samples showed intensive contamination that increased with river flow. The primary causes of water pollution include direct dumping of sewage, septage, household and industrial effluent and animal waste into the river. The difference in parameter values between years was not significant in most cases. A slight decrease in contamination was observed in 2013 and 2014 data, possibly a positive impact of the "Bagmati River Clean-up" campaign initiated in May 2013.

Key words: BOD, COD, ecosystem, ENPHO, pollution, urbanization

Introduction

Water of many important rivers in Asia is heavily polluted mainly due to human population growth, rapid urbanization, and improper waste disposal from houses, livestock, and factories. Dense urban populations, poor city waste management are common causes of river water pollution in rivers such as the Citarum River in Java (Indonesia), Yamuna River in Delhi (India), Marilao River in Manila (the Philippines), Yangtze River (China) and Buriganga River in Dhaka (Bangladesh) making their water unsuitable for human use (https://backpackerlee.wordpress.com/2014/11/12/top-5-most-polluted-rivers-in-asia/). Likewise, in Nepal most rivers flowing through urban areas are polluted. Kathmandu valley is a living example of how poor waste management and rapid urbanization can affect river water quality. Numerous studies indicate that water in existing wells and aquifers in Kathmandu valley is also polluted (Pandey *et al.,* 2010; Gautam *et al.,* 2013).

The holy river of Bagmati originates from Baghdwar situated at the top of Shivapuri Hill (2690 masl) in the north of Kathmandu valley. The river has 24 tributaries of which six are within the valley. It flows from Kathmandu to the Terai in the south and finally joins the Ganga River in India. Bagmati River contains

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large amounts of untreated sewage, garbage and waste (Davis, 1977). Not only household waste, but most of industrial waste inside Kathmandu valley is discharged untreated into Bagmati River that flows through the valley (ADB/ICIMOD, 2006). The industrial effluent in general contains high levels of detergents, non-biodegradable materials and toxic chemicals hazardous to human health. The tributaries Hanumante, Dhobi, Tukucha and Bishnumati that pass through core city areas are the most polluted (Kannel *et al.,* 2007). A report by Stanley International *et al.* (1994) concludes that water from Bagmati River within the Kathmandu valley is not fit for drinking, recreation and irrigation. The water quality has further deteriorated since then.

Over the last few decades, Kathmandu valley has seen an unprecedented growth in human population. The combined population of three districts (Kathmandu, Lalitpur and Bhaktapur) of Kathmandu valley nearly tripled from 1981 to 2011, a 30-year period (from 766,345 in 1981 to 2,517,023 in 2011 (Countrymeters, 2015) with a population growth of 4.63% per annum. The population density of Kathmandu district in 2011 reached 4416 persons per km^2; while the average for the whole valley was 2800 persons per km^2 (derived from CBS, 2011). The actual figures are probably much higher (unofficial estimate is over 4 million people) due to a large number of floating population. The high population and density in the valley is exerting immense pressure on existing water resources, sanitation facilities and waste disposal.

The on-going "Bagmati River Clean-up" campaign, a joint initiative of various government and non-government organizations started in May 2013. It is a collaborative effort to clean Bagmati River by removing solid waste from the river banks every Saturday (government holiday) and discouraging waste dumping in the river. More than 140 groups are involved in the campaign.

Method

Water samples from Bagmati River were collected from the seven sample sites for three seasons: pre-monsoon (Mar-Apr), monsoon (Jul-Aug) and post monsoon (Oct-Nov) for four years (2011 to 2014) to determine the seasonal and spatial impact of human and other activities within Kathmandu valley. Seven sample sites (Table 1, Figure 1) along the river within the valley were selected to represent changing population density and landscape.

The average rainfall (1981-2010) for Kathmandu valley is 1455 mm per year (https://en.wikipedia.org/wiki/Kathmandu#cite_ref-DHM_28-0), with nearly 78% of annual rainfall falling within four months (Jun-Sep). The heavy downpour during the monsoon season increases river flow that dilutes contamination in the river.

Collected samples were kept in acid washed bottles for physico-chemical parameters and in sterilized glass bottles for bacteriological parameters. All

Table 1: Description of sampling sites

Sample sites	Co-ordinates		Code	Remarks
Sundarijal	27.76381	85.42395	A	Upper portion of river, just outside the national park, minimum human influence
Gokarna	27.7391	85.38796	B	Mixing of seasonal rivers and some sewerage pipes; dense human settlement
Pashupati	27.71312	85.34994	C	Religious site; human and industrial waste mixed along with sewerage (wastewater treatment plant just above sampling site)
Minbhawan	27.68571	85.3433	D	Settlement of squatters, sewages and garbage dumping into river
Thapathali	27.69261	85.30448	E	After joining of Manohara, Hanumante, Dhobi, Tukuchha Khola
Sundarighat	27.67464	85.2932	F	Lower stretch of the river after junctions of Bishnumati and Balkhu Khola
Chovar	27.65807	85.29349	G	End point of Bagmati River inside Kathmandu valley

Figure 1: Map of Kathmandu valley with sampling points along Bagmati River

samples were stored in insulated cooler containing ice (to maintain temperature at 4°C as suggested by Kazi *et al.* (2009) and delivered on the same day to ENPHO that has a government accredited laboratory for bacteriological and physico-chemical tests. The tested parameters, their units and test methods are provided in Table 2. The tested parameters include key indicator parameters to quantify water pollution caused by human and industrial effluent.

Table 2: Water quality parameters and test methods

Parameter	Unit	Method used
pH	-	APHA, AWWA, WEF(2012), 4500-HB
Electrical Conductivity (EC)	µS/cm	APHA, AWWA, WEF(2012), 2510 B
Total Suspended Solids (TSS)	mg/L	APHA, AWWA, WEF(2012),2540 D
Chloride (Cl)	mg/L	APHA, AWWA, WEF(2012), 4500- Cl-B
Ammonia (NH_3)	mg/L	APHA, AWWA, WEF(2012), 4500-NH3F
Nitrate (NO_3)	mg/L	APHA, AWWA, WEF(2012), 4500-NO_3B
Total Phosphorous (P)	mg/L	APHA, AWWA, WEF(2012), 4500 PF
Biochemical Oxygen Demand (BOD)	mg/L	APHA, AWWA, WEF(2012),5210B
Chemical Oxygen Demand (COD)	mg/L	APHA, AWWA, WEF(2012), 5220B
Faecal coliform	CFU/mL	APHA, AWWA, WEF(2012),90.222H

Results

General observations

The water quality data from seven sites and three seasons were analyzed. Faecal coliform was observed in all samples, including those from Sundarijal where it was assumed to be little affected by human activities. As Bagmati River flows through the Shivapuri Nagarjun National Park, the flowing water may have received faecal contamination from wild animals or human settlements (Okhreni, Chilaune and Mulkharka) located within the Shivapuri water catchment area.

ANOVA of data using season as an independent variable indicated significant difference ($p<0.05$) between seasons for most test parameters except nitrate and faecal coliform counts. Likewise, site differences were significant except in case of pH, nitrate and faecal coliform. ANOVA of annual data did not indicate significant influence, but indicated a general increasing trend in contamination levels; the 2014 data showed slight reduction in contamination compared to 2013 data.

Seasonal variation

Signficant differences were seen in season means (Table 3). The values for all parameters, except TSS, were highest during pre-monsoon, decreased to a minimum in monsoon and then again increases in the post-monsoon season. For most parameters (except for TSS), the monsoon values were significantly lower compared to those of pre and and post-monsoon seasons. This is most likely due to the dilution effect of increased river flow during the rainy season. For TSS, the highest value (642 mg/L) was seen during the monsoon season, possibly debris and other suspended particles carried with the rain water.

Data of some parameters are repeated in Figures 2 to 5 to show the dip in parameter values during the rainy season.

Table 3: Seasonal means of tested parameters

Parameter	Unit	Pre-monsoon	Monsoon	Post-monsoon	Mean
pH	-	7.6	7.1	7.3	7.3
EC	µS/cm	861.9	144.0	373.7	459.9
TSS	mg/L	208.8	642.2	99.1	316.7
Chloride	mg/L	65.2	10.7	32.3	36.1
Ammonia	mg/L	64.7	6.6	20.5	30.6
Nitrate	mg/L	1.4	1.0	1.3	1.2
Phosphorous	mg/L	5.8	0.8	2.3	3.0
BOD	mg/L	200.0	28.8	98.4	109.1
COD	mg/L	426.0	70.1	211.5	235.9
Faecal coliform	CFU/mL	622,893	29,034	14,943	222,290

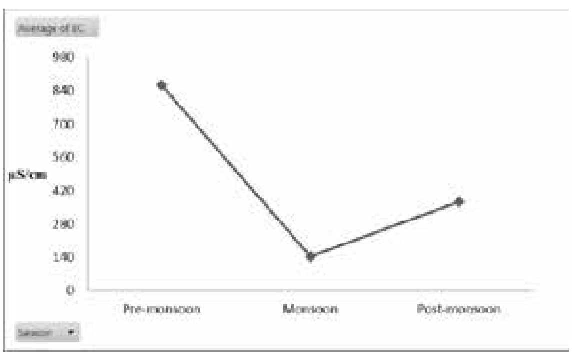

Figure 2: Seasonal means of Electrical Conductivity

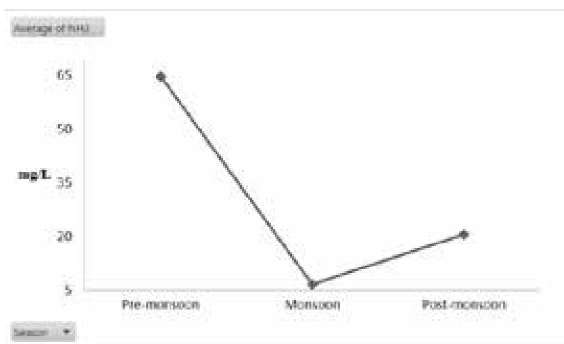

Figure 3: Seasonal means of Ammonia

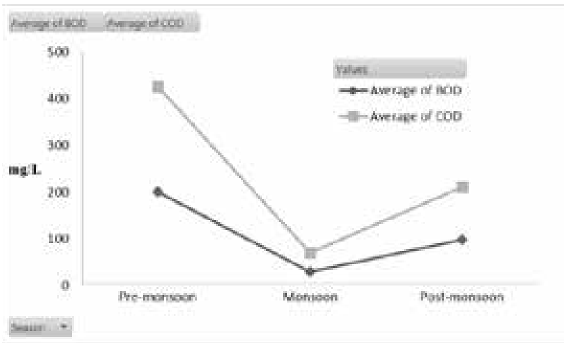

Figure 4: Seasonal means of BOD and COD

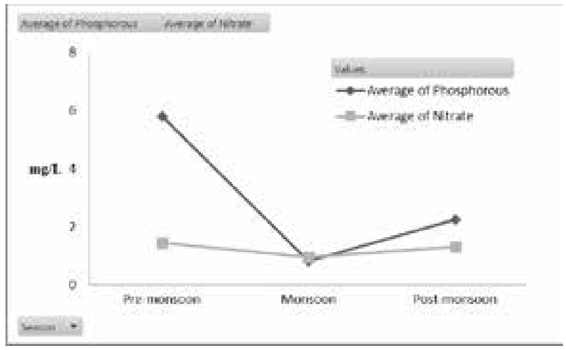

Figure 5: Seasonal means of Phosphorous and Nitrate

Site variation

The averaged site-wise data are presented in Table 4. The general trend for most parameters is a gradual rise in contaminants from site A (Sundarijal) to site F (Sundarighat) and then a slight decrease at site G (Chovar). There is a steep rise in the value of most parameters from site C (Pashupati) to site D (Minbhawan) indicating highest contamination stretch of Bagmati River.

Faecal coliform count increased almost 10 folds from one site to the next. The count was lowest in site A (Sundarijal) and highest in site F (Sundarighat). There was slight decrease from site F to site G (Chovar).

Figures 6 and 7 are presented as examples to highlight significant change (rise) in contaminants across the sites as Bagmati River flows downstream. A slight decrease in the parameters was observed at the final site just before the river leaves the valley.

Yearly analysis

Although annual variations in the means of tested parameters were mostly statistically insignificant, they indicate some interesting trends. The values of chloride and COD gradually increased from 2011 to 2013. Values of TSS and BOD increased from 2011 to 2012 but dipped down in 2013 and further in 2014 (Figures 8 and 9). This may

Table 4: Site means of tested parameters

		Sites							
Parameter	**Unit**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**Mean**
pH	-	7.3	7.3	7.2	7.2	7.3	7.5	7.6	7.3
EC	μS/cm	36.6	117.3	175.8	600.2	709.7	805.3	774.3	459.9
TSS	mg/L	14.5	158.4	160.3	302.6	432.2	617.6	531.3	316.7
Chloride	mg/L	1.1	6.9	12.4	50.1	57.8	64.8	57.3	36.1
Ammonia	mg/L	0.2	3.3	6.6	43.3	53.1	55.5	52.1	30.6
Nitrate	mg/L	0.9	1.0	1.1	1.2	1.7	1.4	1.3	1.2
Phosphorous	mg/L	0.1	0.4	0.8	4.0	4.6	5.9	4.9	3.0
BOD	mg/L	0.9	13.1	31.8	225.6	172.7	157.2	162.2	109.1
COD	mg/L	5.8	34.3	57.8	481.6	412.3	361.5	297.9	235.9
Faecal coliform	CFU/mL	117	948	10,958	104,830	94,955	1,285,744	58,477	222,290

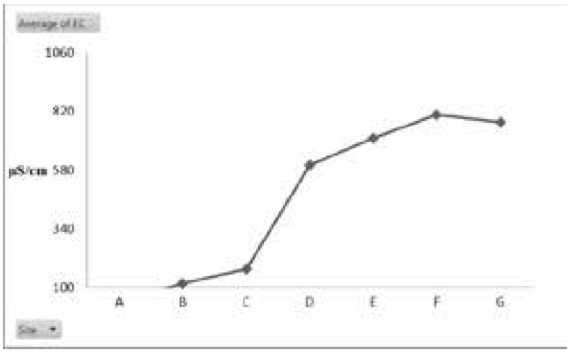

Figure 6: Site-wise means of Electrical Conductivity

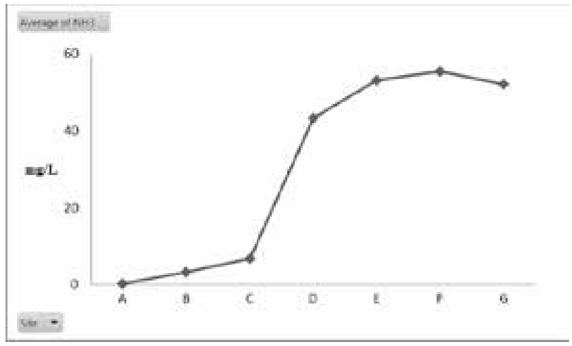

Figure 7: Site-wise means of Ammonia

Table 5: Site-wise means of annual data

Parameter	Unit	2011	2012	2013	2014	Mean
pH	-	7.3	7.4	7.4	7.3	7.3
EC	µS/cm	453.0	414.4	462.7	509.3	459.9
TSS	mg/L	180.8	443.0	428.2	214.9	316.7
Chloride	mg/L	27.4	34.6	41.6	40.5	36.1
Ammonia	mg/L	28.6	32.4	29.9	31.6	30.6
Nitrate	mg/L	1.5	0.3	1.6	1.4	1.2
Phosphorous	mg/L	3.3	2.5	3.7	2.3	3.0
BOD	mg/L	101.2	125.7	118.0	91.4	109.1
COD	mg/L	206.3	259.0	266.6	211.6	235.9
Faecal coliform	CFU/1mL	699,482	2,643	21,672	165,363	222,290

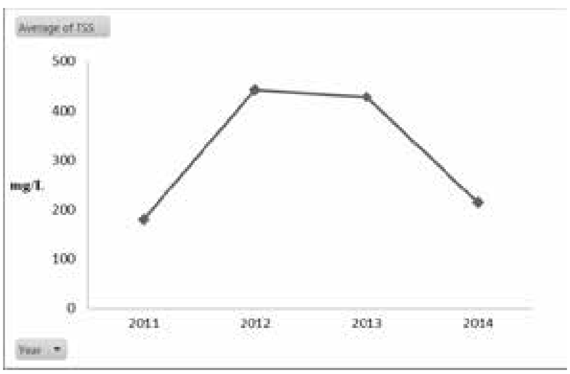

Figure 8: Yearly means of TSS

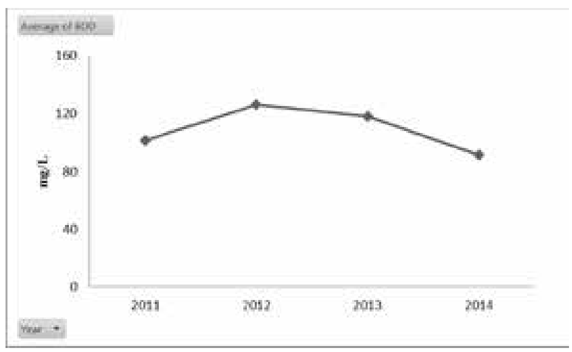

Figure 9: Yearly means of BOD

be an indication of positive change in river water quality due to weekly cleaning efforts made under the "Bagmati River Clean-up" campaign that started in May 2013.

Discussion and conclusion

Many studies in the past have analyzed the physical makeup and biological indicators of the Bagmati River. Over 68 factories and nearly 2 million people pour industrial effluent and human waste directly into the Bagmati River which has religious, cultural and social values (Pandey, 2006).

With rapid urbanization and lack of control of river pollution, water of Bagmati River has been deteriorating for many years. The rapid increase of pollutants, as indicated by this study, provide good evidence of the intensity of contamination as the river flows through Kathmandu valley. Similar findings have been reported by (Moog and Sharma, 2005; Kaprimo, 2007; Milner *et al.,* 2015). A range of human activities contribute to river contamination. The direct dumping of untreated human and industrial waste into the river, throwing remains from funeral pyres and ashes into the river, bathing and washing, illegal sewage dumping along the river stretch are some primary causes of river pollution.

Nepal Water Quality Guideline (CBS, 2008) states a pH range of 6.5-8.5 for drinking and irrigation; pH values of water samples fall within this range. Likewise, the nitrate value of sampled water all fall within the maximum 50 mg/L limit. However, all ammonia values, except for samples from site A (Sundarijal) are above the specified limit. Ammonia value above 0.23 mg/L indicates possible contamination with decaying organic matter, excreta of humans and animals, fertilizers; this may also affect aquatic ecosystem.

Nepal Water Quality Guideline (CBS, 2008) also specifies a maximum TSS value of 50 mg/L in water used for irrigation. Except for site A (Sundarijal), TSS level was much higher in all water samples, indicating unsuitability of water for irrigation. High TSS value indicates sewage and other biological contamination.

Presence of phosphorous in water at the stretch of the river indicates water contamination most likely due to animal waste (sewage), industrial waste, soil erosion, and fertilizers that may lead to eutrophication and negative impact on aquaculture. The COD and BOD values of water samples from site C (Pashupati) and below far exceed the guideline values of 40 mg/L for aquaculture. This is a strong evidence of heavy contamination from industrial effluent and organic waste making the river water unsuitable even for aquaculture (BBWMSIP, 1994). Desirable BOD level for drinking is 4mg/L and 10mg/L for bathing and agriculture. Except for site A (Sundarijal), BOD values of all other sites were much higher.

Chloride values of all water samples remained below the guideline specified range between 100-700 mg/L for irrigation and 600 mg/L for aquaculture. Presence of chloride indicates contamination from sewage from other waste. EC guideline limit for chloride is 40 mS/m for irrigation. The high chloride values indicate that the water from lower half of the river, starting from site D, i.e. Minbhawan, is unsuitable even for irrigation.

The biological contamination is a major indicator of water quality for human consumption. Only two samples from site A (Sundarijal) were free of faecal coliforms. Water samples from lower stretches had very high levels of faecal contamination. Kannel *et al.,* (2007) concluded that the Bagmati River water quality in the rural areas was increasingly affected from untreated human sewage and chemical fertilizers. Results of the current study concur with earlier studies and provide an alarming load of faecal contamination in Bagmati River with major risk to human health. Likewise, high levels of EC, TSS, Cl^-, NH_3 (aq), NO_3^-, Phosphorous, BOD and COD clearly indicate extremely poor status of water in

Bagmati River within Kathmandu valley.
The Government and Nepal and general public in Kathmandu are well aware of the deteriorating quality of river water. Rules and regulations (such as the Water Resources Act 2049, Aquatic Animal Protection Act 2017, Environment Protection Act 1996) have been developed to curb pollution of Bagmati River. Enforcement of the rules and regulations is poor and ineffective.

Overall, the present study of spatial and temporal variation of quality of water in Bagmati River in Kathmandu provided convincing evidence of the poor state of the sacred Bagmati River. The lower stretches of the river are worse that indicates heavy contamination within Kathmandu valley due to poor waste management.

Recommendations

The study clearly shows rapidly increasing contamination of water in Bagmati River as it flows downstream. A multitude of causes exist and impact of each cause may vary with site. A targeted yet coordinated approach to controlling river pollution will be required to identify and address the root causes of pollution at source. Regular cleaning of regular and campaigns alone will not suffice. Effective enforcement of rules and regulations will be required to prevent dumping of solid and liquid waste into the river.

A number of organizations have collected data on water quality in Kathmandu. The data collection appears to be uncoordinated and irregular; sample sites, sampling frequency are inconsistent and often unavailable; and data from multiple studies incomparable. There is an urgent need to standardize test methods to allow comparison between different studies and to co-ordinate regular monitoring system for its restoration.

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