Environmental Engineering and Management Journal

February 2021, Vol.20, No. 2, 257-266
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

“Gheorghe Asachi” Technical University of Iasi, Romania

WASTEWATER AND BIOGAS PRODUCTION IN KATHMANDU VALLEY, NEPAL: CHALLENGES AND OPPORTUNITIES

Pradeep Ramtel[1], Thakur Tamang[1], Nishan Pokhrel[2], Bandita Mainali[3], Shukra Raj Paudel[1,4*]

[1]Department of Civil Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University, Pulchowk, Lalitpur, Nepal
[2]Department of Civil and Environmental Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA
[3]School of Engineering and Mathematical Sciences, La Trobe University, Bendigo, VIC 3550, Australia
[4]Department of Environmental Engineering, College of Science and Technology, Korea University, Sejong, Republic of Korea

Abstract

Kathmandu valley, the country’s most urbanized city, is expected to deal with an estimated 200 million liters per day (MLD) of wastewater at the completion of the Melamchi Water Supply Project. In this paper, we review the history, present, and future prospects of the wastewater treatment plants (WWTPs) as well as estimate the total biogas potential of the expected wastewater through anaerobic digestion using the chemical oxygen demand (COD) mass balance approach. The total biogas potential from the expected 200 MLD wastewater with an average COD concentration of 1000±225 mg/L, was estimated to be 23105±5185Nm^3/day which is equivalent to a total electricity potential of 3.35±0.76 megawatt (MW). Thus produced bioenergy can be utilized to supply the energy demand of the treatment plants, support the plants to be less dependent on the grid energy-thereby helping to achieve energy self-sufficiency, achieve cleaner urban rivers, and possibly also reduce greenhouse gas emissions from the plants. This study also encourages timely construction and completion of energy self-sufficient treatment plants around the country.

Key words: bioenergy, biogas, chemical oxygen demand (COD), Kathmandu Valley, wastewater

Received: May, 2020; Revised final: July, 2020; Accepted: September, 2020; Published in final edited form: February, 2021

1. Introduction

Wastewater has become a global concern with fast-growing populations, rapid economic growth, industrialization, and an increase in technical and institutional capacity (Boretti and Rosa, 2019; UNESCO, 2017). Globally, billions of litres of wastewater are produced every day and the fate of thus produced wastewater is different depending on how it is handled locally (Mateo-Sagasta et al., 2015). The wastewater treatment can be strongly correlated with the countries' income, for instance: an average of 70% of municipal and industrial wastewater is treated in high-income countries whereas, in low-income countries, it just averages around 8% (Mateo-Sagasta et al., 2015). Nepal, one of the least developed countries in the world with a low income and Human Development Index (HDI) of 0.574 (UNDP, 2018), is a good case in point with only 12% of its wastewater being treated. The country has been considered as having the lowest levels of wastewater treatment in the Asia-Pacific Region in 2013 (UNESCO, 2017), while also being the top fifth-fastest urbanizing countries for the years 1990 to 2018 (UN, 2019). Statistically, two-thirds of households in the country have had no access to sewage facilities; dominantly in urban and poorest quantile groups (CBS, 2016). Kathmandu valley is a highly urbanized and densely populated city in the country with about 6.5 % population growth rate (Kathmandu Population, 2020) and comparatively has

---

[*] Author to whom all correspondence should be addressed: e-mail: srpaudel@ioe.edu.np; Phone: +977-9851220184; Fax: +977-1-5525830

more sewerage coverage with treatment facilities. The centralized wastewater treatment plants (WWTPs) are mainly limited to the valley whereas in urban and peri-urban with low-income areas, decentralized wastewater treatment system (DEWATS) is mainly adopted (GON, 2015).

Kathmandu valley includes five major cities: Kathmandu, Lalitpur, Bhaktapur, Kirtipur and Madhyapur Thimi. As of 2011, the valley had a population of more than 2.51 million that produced an estimated 69.012 MLD wastewater, out of which only 34.506 MLD was collected (Regmi, 2013). The fate of this collected wastewater is not exceptional though as all existing WWTPs being non-functional or only partially functional, has led to the direct discharge of wastewater into the Bagmati River system (ADB, 2019; Regmi, 2013). Moreover, with the completion of the Melamchi Water Supply Project, there will be an estimated additional 125 MLD wastewater production, which will eventually have the same future considering the current affairs (ADB, 2012). Therefore, Kathmandu Valley Wastewater Management Project (KVWMP) was proposed to rehabilitate, modernize, and expand sewerage networks along with the existing WWTPs, and finally to improve overall wastewater management in the valley (KUKL, 2018a).

Kathmandu Valley had five major WWTPs: Guheshwori, Dhobighat, Sallaghari, Hanumanghat, and Kodku WWTP, with other many small DEWATS installed around the valley. All of these major plants have been run-down; mainly the lack of expertise, management, and capability to supply the energy demand has caused the failure of these plants (Regmi, 2013). The energy demand can be considered as the dominant reason because a typical domestic WWTP employing aerobic activated sludge treatment and anaerobic sludge digestion requires 0.6 kWh/m^3 energy (McCarty et al., 2011). To put this in perspective, per capita consumption of electric energy in Nepal averages around just 0.486 kWh per day (World Data, 2019). Nepal's net energy imports have risen from 1.0 Mtoe in 1994 to 3.0 Mtoe in 2017 (IEA, 2017), demonstrating its increasing dependency on imported energy sources (Surendra et al., 2011). Thus, the country has not been able to address the fundamental energy demands of the treatment plants. On the other side, some researchers have documented that municipal wastewater contains ten times as much energy as is required for the treatment of wastewater to meet the effluent standards (Shen et al., 2015). Extracting the absolute energy potential of wastewater is an unrealistic endeavour-for now, but making the plants energy self-sufficient is a grounded and viable resolution of the problem.

Energy from wastewater can be extracted in different forms using various processes. Among them, capturing biogas energy during the anaerobic sludge digestion-a proven technology-is highly prevalent globally. Thus produced biogas can be used to generate electricity and heat simultaneously in the plants, which helps turn them from an energy consumer into a producer (Bachmann et al., 2015; Shen et al., 2015). Development of energy-efficient wastewater treatment methods is an extremely important part of keeping our environment safe and cleans (Wang et al., 2020). In tropical/subtropical rural areas of Nepal, even though biogas has been produced from biogas digesters to provide energy for lighting and cooking (Gautam et al., 2009), biogas generation from wastewater in a considerable scale itself has not been fully practised yet. But, the proposed KVWMP has started including biogas generation facilities in its plants (KUKL, 2018a). This project can be an outlet for wastewater treatment with energy viability from biogas production in Nepal and promote self-sufficient WWTPs that collect and utilize the energy present in wastewater which will eventually help clean the polluted river systems and reduce potential greenhouse gas, especially; carbon dioxide and methane.

This paper aims to present the history, present, and future prospects including challenges and opportunities of biogas production from WWTPs in Kathmandu valley, and to estimate the energy potential of the expected wastewater-irrespective of operational and environmental conditions, and reactors' type-in the form of biogas (methane) by exploiting the available data from the WWTPs in the valley. This study focuses to promote the development of self-sufficient WWTPs in the country by conducting a comprehensive case study of the Kathmandu valley.

2. Overview of wastewater treatment plants

2.1. Historical perspective

In ancient times during Lichhavi Periods (300-879AD), the water was supplied to the valley by constructing stone spouts (Dhunge Dhara) fed by the groundwater (Roka et al., 2016). With the provision of water supply, the requisite sewer system was constructed. The oldest sewer was made during the Malla Dynasty (1200-1768) as a combined sewer for domestic and surface drainage, which had their outfalls located in open fields (Roka et al., 2016). During the Rana dynasty (1898-1950 AD) the sewerage was further developed and Pani Goshowara Adda was established for the development and management of wastewater systems (Nyachhyon, 2006; Roka et al., 2016). The main sewer made with bricks, initially constructed in Kathmandu (44 km) and Patan (11 km) only for storm water, latter was reformed into a combined sewer system (Nyachhyon, 2006). Likewise, about 232 km long concrete piped sewer system was developed to provide sewer facility to 40% of the valley population (Nyachhyon, 2006; Shukla et al., 2012).

In 1972, the Department of Water Supply and Sewerage (DWSS) was established with the aim of providing safe water and sanitation to people; however, substantial efforts were come to be effective only after the United Nations (UN) declaration of the

International Decade of Drinking Water Supply and Sanitation (GON, 2011). With the growing population, water supply and wastewater management became crucial, resulting in the investment of wastewater treatment plants (Shukla et al., 2012). In 1977, Hanumanghat WWTP, an aerated lagoon of capacity 0.5 MLD, located in Bhaktapur was the first installment (KUKL, 2013). The major wastewater treatment plants in the valley with their establishment date and the initial capacity is presented in Table 1.

2.2. Current status of WWTPs in Kathmandu Valley

Kathmandu Valley has had five major WWTPs, all of which has been either non-operational or had treatment below design intentions. Thus, Kathmandu Valley Wastewater Management Project (KVWMP) was proposed to improve the appalling status of wastewater services in the valley and reinforce the plants for the upcoming increase in wastewater after the completion of the Melamchi Water Supply Project (MWSP) (KUKL, 2013). KVWMP was initiated in 2013 with the Asian Development Bank (ADB) as finance agency, Ministry of Water Supply (MoWS) as top-level planning agency, and Kathmandu Upatyaka Khanepani Limited (KUKL) as the implementing agency in the partnership with Government of Nepal (GON) (KUKL, 2013). The objective behind the project has been to collect wastewater systematically and resurrect the river system, by releasing treated wastewater within tolerable range into the water bodies (KUKL, 2013). KVWMP works mainly to rehabilitate and expand treatment plants, sewerage networks, pumping stations, and interceptors along the rivers within the valley. There are six WWTPs under this project, with all the previously mentioned five major WWTPs, and Gokarna WWTP, which is a small treatment plant in Gokarneshwor. Gokarna WWTP with a total area of 0.925 ha originally designed as a reed bed treatment system (RBTS) will have a treatment capacity of 0.6 MLD after the construction, serving an estimated population of 7,200 (KUKL, 2013). All the WWTPs are being reconstructed/ rehabilitated in the pre-existing site whereas Hanumanghat WWTP will be closed because of its small size and the wastewater will be diverted to Sallaghari WWTP (KUKL, 2013) (Table 1).

This project with five new WWTPs at Kodku, Sallaghari, Dhobighat, Guheshwori, and Gokarna (Table 1) will have a combined capacity of 90.5 MLD serving estimated 1.96 million populations with an energy generation of 910KW through sludge digestion and gasification (ADB, 2013; KUKL, 2013). The present status of implementation of the major WWTPs with their treatment capacity after the reconstruction is also presented in Table 1.

Table 1. Major wastewater treatment plants in Kathmandu Valley with their characteristics (ADB, 2019; KUKL, 2013, 2018a, 2018b;)

WWTP	*Hanumanghat*	*Sallaghari*	*Kodku*	*Dhobhighat*	*Guheshwori*	*Khokana**
Establishment date	1975	1983	1982	1982	2002	Proposed
Geographical Coordinate	-	27°40'26.3"N 85°24'33"E	27°40'27"N 85°20'13"E	27°40'36"N 85°17' 55"E	27°42'45.3"N 85°21'25.6"E	
Original supporting agency	GTZ/Germany	GTZ/Germany	IDA, Engineering Science/ USA	IDA, Engineering Science/ USA	GON	
Nominal Capacity (MLD)	0.5	2	1.1	15.4	16.4	
Type of Plant Originally installed	Aerated Lagoon	Aerated Lagoon	Waste stabilization pond	Waste stabilization pond	Oxidation pond	
WWTP Area Available (ha)	0.35	3.4	6.5	30	5	38.5
Treatment Technology	Activated Sludge		Activated Sludge	Activated Sludge	Activated Sludge	Activated Sludge
Wastewater Treatment Capacity in 2020 (MLD)	13.1		7	39.2	30.6	
Wastewater Treatment Capacity in 2030 (MLD)*	13.1		11.2	39.2	30.6	245
Approximate Gas engine (KW)	130*		160*	330	300	
Status of Implementation progress	Design Phase		Design Phase	Design Phase	Ongoing Construction	

**indicates, a future project, MLD= Millions of litres per day, ha= hectare, KW=Kilowatt*

2.3. Future expansion of WWTPs in Kathmandu Valley

With the continuous increase in wastewater alongside population, the constructed WWTPs would be insufficient to treat the wastewater produced from the valley, which leads to the necessity of the expansion of the wastewater treatment system. Therefore, KVWMP has planned the expansion of existing WWTPs and construction of additional treatment plants by 2030. In this context, the government has initiated the acquisition of 40 hectares of land at Khokana for future construction of the treatment plant with 245 MLD capacities (KUKL, 2013). Likewise, Kodku WWTP will be expanded to increase its treatment capacity from 7 MLD to 11.2 MLD. The expansion and treatment capacity of WWTPs is also summarized in Table 1, and the diagrammatic layout of major WWTPs in Kathmandu Valley under KVWMP is presented in Fig. 1.

3. Wastewater and biogas estimation

3.1. Wastewater treatment technologies used in KVWMP

KVWMP has emphasized on Activated Sludge Process (ASP) with technologies like Sequencing Batch Reactor (SBR), Moving Bed Biofilm Reactor (MBBR), Oxidation Ditch, etc. in all the major plants, in order to enhance operational efficiency and reduce undesirable odor (KUKL, 2013; KUKL, 2018b). The main components of the plants used in the Valley (Fig. 2) are Screening and Grit chambers, Primary Sedimentation Tanks, Activated Sludge Tanks, Secondary Sedimentation Tanks, Tertiary Treatment Facility, Disinfection Facility, Sludge Thickening Facility, Anaerobic Sludge Digester, Bio-Gas Generation Facilities, Sludge Dewatering machines, etc. (KUKL, 2018a, 2018b). These components are designed so as to ensure the effluent is within the permissible standard, making it suitable for irrigational reuse or river discharge.

For biogas generation, the sewage sludge from the primary and secondary tank is sieved, thickened, and collected for digestion (KUKL, 2018a). A completely mixed type anaerobic digester, with 20 days of retention time maintained at mesophilic temperature (35°C) is used for this process (KUKL, 2018a). Breakdown of organic particles present in the sludge produces biogas, which is then treated for moisture removal and desulfurization, and used for electricity production through a generator. The schematics of unit operations and processes are illustrated in Fig. 2.

3.2. Fundamentals of anaerobic digestion

Anaerobic digestion (AD) is a sequential biological and chemical process for the breakdown of organic materials by microbial organisms in the absence of free oxygen. It is an application of a series of processes that use a diverse population of bacteria for the degradation of complex organic matters (Chynoweth et al., 2011; Chen and Neibling, 2014). The AD process is mainly subdivided into the four phases (Fig. 3) and these processes help to reduce the volume of waste while transforming non-soluble organic matters to gas, soluble form such as; organic acid, acetate, hydrogen and carbon dioxide as intermediate products. Eventually, the intermediate products are biologically transformed to methane gas via methanogens is process, with the production of digestate which can be used as fertilizers (Asadi et al., 2020; Bakraoui et al., 2019b; Ersahin et al., 2011; Reith et al., 2003).

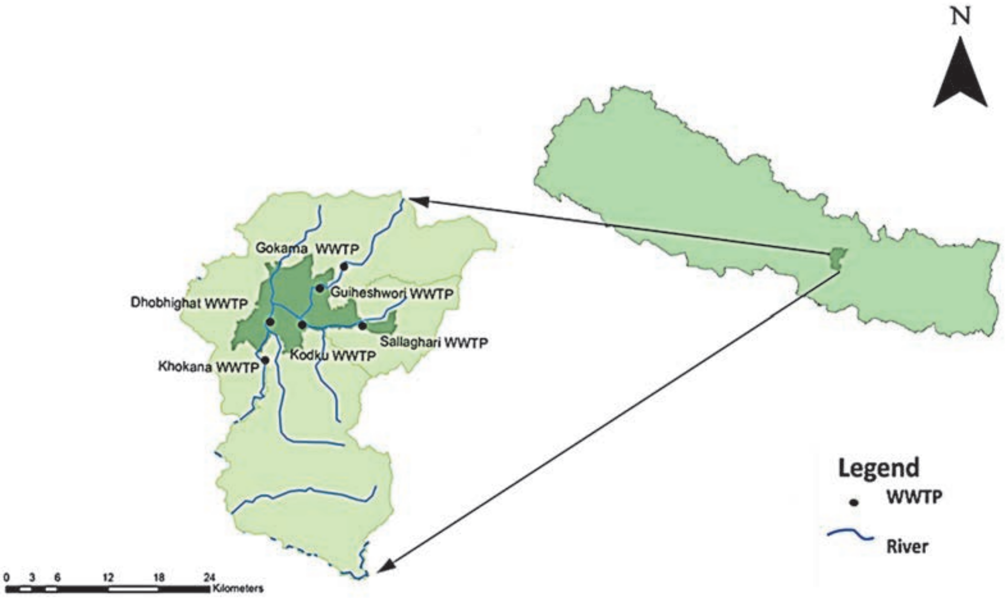

Fig. 1. Diagrammatic layout of major WWTPs in Kathmandu Valley under KVWMP

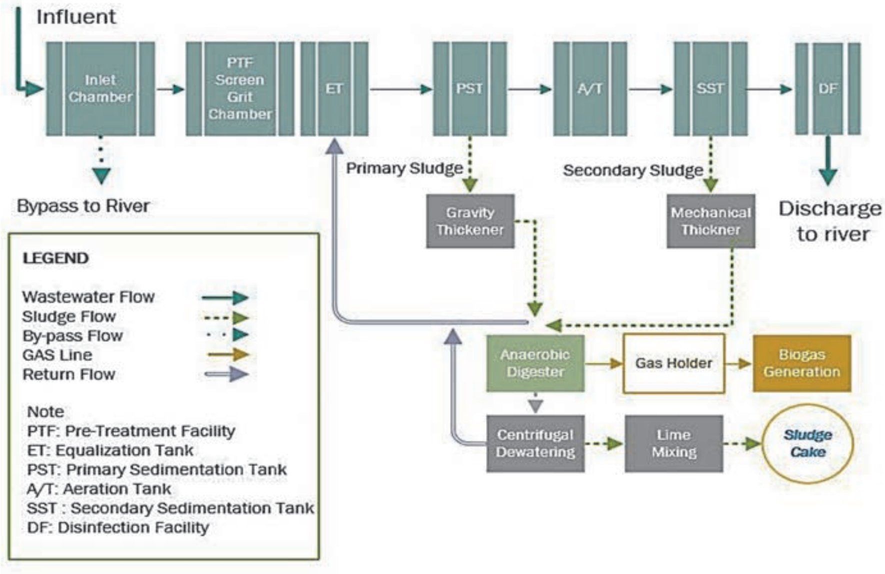

Fig. 2. Wastewater treatment units operations and processes in KVWMP (KUKL, 2018c)

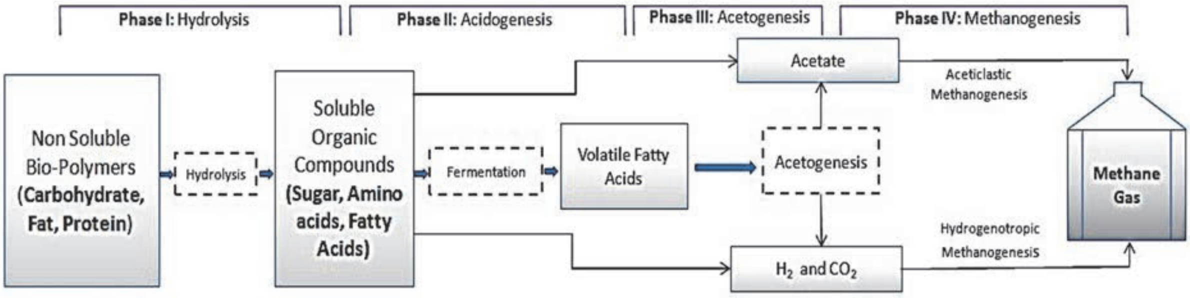

Fig. 3. Schematic diagram of four phases in the anaerobic digestion process

The mechanism of digestion is affected by different parameters like temperature, pH, alkalinity, organic fractions, volatile fatty acid, toxicity, inflow rate, total solids, and hydrolysis rate of the substrate (Bakraoui et al., 2020a, 2020b, 2020c; Reith et al., 2003) whereas the composition of biogas is mainly determined by the type of substrate. General range of percentage proportion of biogas is 40-75% CH_4, 25-40 % CO_2, 0.5- 2.5% N, 0.1-1 % O, and other gases (Arthur and Brew-Hammond, 2010). The energy value of thus produced biogas depends upon their composition, volume of methane and their relative densities (Bakraoui et al., 2020b). Biogas from sewage sludge has a comparatively higher methane content of 63 to 67 % compared to other feedstock (Bachmann et al., 2015).

3.3. Potential biogas estimation

Biogas yield from wastewater depends upon different water and treatment characteristics: the biological oxygen demand (BOD), volatile suspended solids (VSS), digestibility of the organic matter, microbial activity, humidity, retention time, the temperature in the digester, etc. These parameters determine the feasible gas yield from the wastewater, and by controlling these parameters the gas yield can be optimized (Demirbas et al., 2016; Reith et al., 2003;). Among these, chemical oxygen demand (COD), representing the organic carbon present in the wastewater, is a key parameter which can be used to estimate the potential biogas production (Baquero-Rodriguez et al., 2016; Pasztor et al., 2009; Reith et al., 2003). This COD can be divided into biodegradable COD, non-biodegradable COD, and active biomass COD (Pasztor et al., 2009). If the biomass COD is not considered, the fractionation can be simplified as presented in Fig. 4.

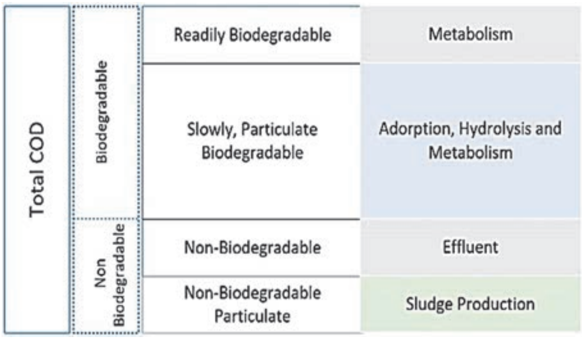

Fig. 4. COD fractionation in a conventional wastewater treatment plant

The overall microbial growth governs the exploitation of degradable substrate, where the biodegradable COD (bCOD) is used to express the amount of organic compound present in the wastewater.

On further fractionation of COD, the biodegradable soluble (bsCOD) of wastewater relates to the stoichiometry of substrate oxidized for cell growth as it can be metabolized readily by a microorganism (Baquero-Rodriguez et al., 2016; Tchobanoglous et al., 2003). So, this fraction of total COD, biodegradable soluble COD (bsCOD) is used to estimate the biogas potential of the wastewater. While considering this bsCOD, both the readily and slowly soluble biodegradable COD should be accounted (Reith et al., 2003; Tchobanoglous et al., 2003).

The COD mass balance technique, based on the Law of Conservation of Mass, was applied to consider for the change in COD during fermentation, where the COD loss is accounted for the methane production (Tchobanoglous et al., 2003). A steady-state mass balance equation for COD, as presented by Tchobanoglous et al., 2003, was employed to estimate the amount of the influent COD converted to methane as described in Eq. (1-3).

$$COD_{\inf} = COD_{eff} + COD_{VSS} + COD_{methane} \tag{1}$$

$$COD_{eff} = 0.01 \times (100 - \eta)\, COD_{\inf} \tag{2}$$

$$\begin{aligned} COD_{VSS} &= (Bacterial\ biomass) \times (Net\ biomass\ Synthesis\ Yield) \times \\ &\times 0.01 \times \eta\ COD_{\inf} \end{aligned} \tag{3}$$

where: COD_{inf}= Influent COD; COD_{eff}= Portion of COD influent in effluent;COD_{VSS}= Influent COD converted to cell tissues; $COD_{methane}$= Influent COD converted to methane; ή= Efficiency of COD removal.

The above (Eq. 1) can be used to estimate the methane generation equivalent to COD, whereas the COD_{eff} and COD_{VSS} are determined using Eq. (2-3). Mathematically, the COD equivalent of methane is defined as amount of oxygen required to oxidize methane into carbon dioxide and water (Tchobanoglous et al., 2003).

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \tag{4}$$

From the above balanced (Eq. 4), the COD per mole of methane is obtained as 64g O_2/mole. The volume of methane per mole at standard temperature and pressure is 22.4 L, so the CH_4 equivalent of COD converted under anaerobic condition is 0.35L CH_4/g COD (Tchobanoglous et al., 2003). In other words, each gram of COD in the above reaction of (Eq.4) generates 0.35 liters of methane in the system.

For the estimation of biogas from Kathmandu Valley, we considered the projected wastewater (200 MLD) generated at the end of the MWSP. Albeit, the characteristics of wastewater produced depends upon the source, waste feedstock, geographical location, and different factors (Demirbas et al., 2016), an average uniform value (1000 mg/L) of COD for the valley is considered, as the governing factors for wastewater production is more or less identical in the study area. Furthermore, owing to the limited availability of influent COD data in WWTPs around the valley, the valley's wastewater COD was considered to be identical to that collected in Guheshwori WWTP of 1000±224.4mg/L (Regmi, 2013). According to Mogen Henze, 1992 and Baquero et al. 2016, the biodegradable soluble fraction is most likely to be around 35-40% of the total COD (Baquero- Rodriguez et al., 2016; Henze, 1992). Considering 40% of the total COD to be biologically degradable, the bsCOD of wastewater is found to be 400±90 mg/L. Assuming all wastewater undergoes anaerobic treatment, with 90% COD removal efficiency, the total daily estimated biomass is $4.089\text{x}10^6$ $\pm 9.2\text{x}10^5$ g/d whereas $COD_{methane}$ is $6.79\text{x}10^7 \pm 1.524\text{x}10^7$g/d. In an ideal condition of 100% efficiency of COD capture in a treatment process, the total daily produced biogas considering the baseline data tabulated (Table 2) is 41791.02± 9378Nm^3/d. Thus produced biogas has the electric potential of 6.10±1.36MW considering the baseline data (Table 2).

This estimated theoretical value is solely based on COD mass balance (Fig. 5) of the expected wastewater and bsCOD present in it which may differ from the empirical value. Percentage of bsCOD might vary on feedstock and type of settlement area, while actual COD of wastewater collected through all the plants around the valley may also be highly variable-spatially as well as temporally-unlike our study consideration.

Table 2. Baseline data for biogas estimation from Kathmandu valley (KUKL, 2018b; Regmi, 2013; Tchobanoglous et al., 2003)

Parameters	***Value***	***Parameters***	***Value***
Wastewater Produced (MLD)	200	Biogas methane (%)	65
COD (mg/L)	670-1350	Net biomass Synthesis Yield (g VSS/g bsCOD)	0.04
Average COD (mg/L)	1000	Bacterial Biomass (gCOD/g VSS)	1.42
bsCOD/COD	40%	Calorific value of Biogas (kcal/Nm3)	8560
Efficiency of COD removal(η)	90%	Calorific value of electricity (kcal/kWh)	860
COD capture efficiency (η_a)	60%	Gas engine efficiency (η_p) (%)	35

Therefore, to consider the feasible biogas production, all the myriad factors such as COD capture efficiency of the treatment process, digester type, hydraulic retention time, environmental conditions, feedstock, toxic content etc. of the treatment plants should also be accounted, which are the limitations of our approach. Despite these limitations, our estimation demonstrates the tentative energy potential of expected wastewater in Kathmandu Valley.

Nevertheless, for further accuracy, we consider the COD capture efficiency (Fig. 5 and Table 2) of the technology used in treatment plants in Kathmandu Valley. ASP, as emphasized in KVWMP, despite being advanced, has been noted to have low efficiency in capturing COD before the biological oxidation (Pluciennik-Koropczuk and Myszograj, 2019). After we considered the COD capture efficiency of the ASP of 60% (Khanal, 2011) and used (Fig. 5 and Table 2) for calculation, the daily estimate biomass is estimated to be $2.45 \times 10^6 \pm 5.52 \times 10^5$ g/d whereas the potential biogas production is found to be $23105 \pm 5185 Nm^3$/day which is equivalent to a total electricity potential of 3.35±0.76MW. The presented estimation is a tentative evaluation of the energy potential of wastewater produced within Kathmandu valley. In reality, characteristics of wastewater considerably depend upon the type and source of wastewater, and environmental and operational conditions. Therefore, subsequent optimizations of the biogas production should be prioritized based on suitable and relevant anaerobic process. The design of any treatment plant's components like reactor and digester type should consider the characteristic of waste, economical, and environmental conditions (Mir et al., 2016). This viable energy from the wastewater treatment plant in the form of heat and electricity can reduce the dependency on the energy grid, inevitably resolving the interference for the efficient and sustainable operation of the treatment plant.

4. Challenges of WWTPs and biogas production

The initial project completion date of KVWMP was mid-2018, however recent study and field visits have reported the works to be still fragmentary with most of the plant's work still in the design phase (ADB, 2019; KUKL, 2013). At present, KVWMP should be given a high priority by the government and relevant organizations as its successful completion is a major step towards the reclamation of wastewater and improvement of river water environment in the valley. The project has been delayed from the proposed plan long enough to probably necessitate recalibrations in its design considerations, therefore, enforcement systems should be provided for its streamlined progression that can meet the requirements of the changing scenario of Kathmandu valley.

Many countries have developed tremendous technologies in wastewater treatment and reuse with substantial physical and research works, while in Nepal, such efforts have been based on small scale survey, study, and research which hinder effective design, planning, implementation, and smooth operation of the projects. Further, the technology used in the plants, ASP, has a major disadvantage in terms of energy consumption, alongside the need to treat waste sludge before disposal (Wan et al., 2016). Moreover, this process requires excessive mechanizations, along with huge construction and operational costs, need of specialized technical staffs, inadequate payback from biogas with irregular energy outage, thus making the project more demanding (Regmi, 2013; Shen et al., 2015).

Considering the low operational efficiency of the ASP; the adoption of innovative treatment configurations, and evolving technologies should also be considered as a viable option, where an improved energy recovery can be obtained by efficient capture of COD (Shen et al., 2015; Wan et al., 2016).

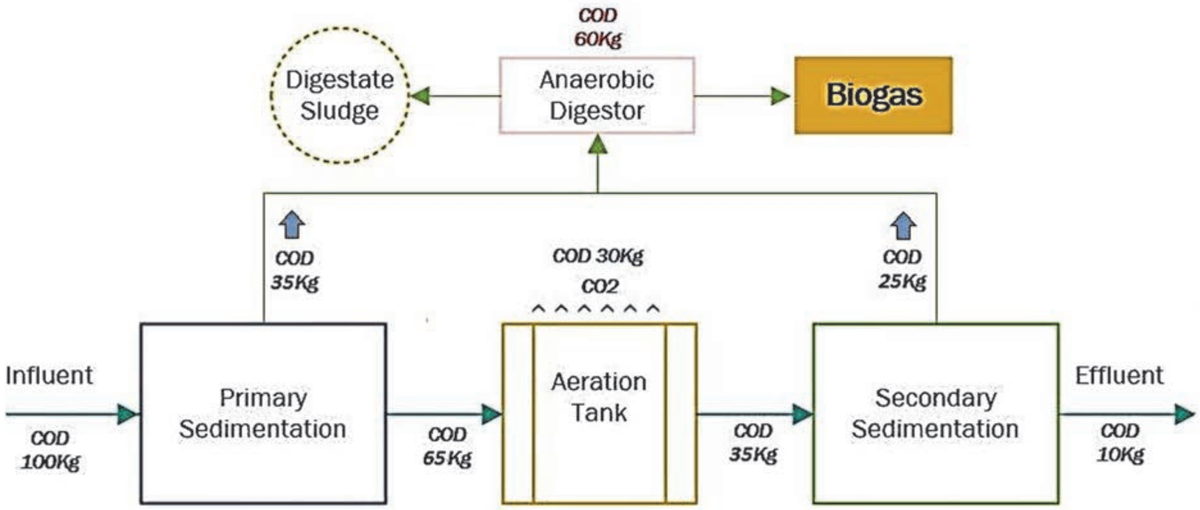

Fig. 5. COD mass-balance through a conventional wastewater treatment plant

Anaerobic digestion is sensitive to toxicants: the presence of toxicants in the influent, as well as toxic by-products in the digester, can generate instability, decreases methane production, and in extreme conditions, cause failure of methane production (Chen et al., 2014). Understanding the different parameters of wastewater like organic loading, pH, presence of inhibitory toxic content, etc. that can contribute to instability in the anaerobic digestion should be studied and properly optimized to increase the efficiency (Chen et al., 2014). This can be carried out with proper and systematic research to understand the microbial metabolism, biochemistry and the overall treatment process relevant to the nature, composition and biodegradability of waste which depend on the influence area (Bakraoui et al., 2019a, 2020c).

WWTPs are also a source of anthropogenic emissions like methane, nitrogen oxides, carbon dioxide, and other gases produced during the conversion of organic and nitrogenous matters, which, if not properly operated and managed, contributes to the escalating climate crisis (Campos et al., 2016). The ratio of gases produced during anaerobic digestion depends upon various parameters, which can be altered to achieve high methane production by modifying the operational conditions and using efficient equipment and configuration optimization (Campos et al., 2016; McCarty et al., 2011). Furthermore, even after the capturing of biogas, contaminants clean up in the final products remains one of the technical barriers, which is a costly process if required strict standards and quality specifications to be met (Shen et al., 2015).

5. Conclusions

This paper reviewed the past, present and future scenarios of wastewater treatment services in the Kathmandu Valley, focusing on the endeavor of KVWMP. At the end of the project, KVWMP, the general scenario of the plants can be considerably transformed, energy perspective of which is presented in the paper. The study estimated the potential and feasible biogas production using COD mass balance and efficiency of the activated sludge process with its electricity potential from the estimated wastewater production.

Although the estimated biogas production and electricity generation was theoretically approached-values likely being different from the actual production-this cursory estimation can surely provide a tentative idea of the energy potential of wastewater in Kathmandu Valley. The energy generated from biogas in the wastewater can decrease energy dependency and provide a platform to showcase and advertise the possibility and sustainability of renewable energy for energy-sufficient treatment plants. Also, in Nepal, this can be a precedent to provide a perspective to see wastewater-broadly waste-more than just a problem but as an opportunity to generate energy in an environment-friendly way, and also help reducing greenhouse gas emission from wastewater treatment plants. This paper thus suggests promoting biogas production as an efficient and sustainable source of supplemental energy for the operation of WWTPs.

Acknowledgements

Authors would like to extend their sincere gratitude towards Department of Civil Engineering, Pulchowk Campus, Tribhuvan University, Nepal; and School of Engineering and Mathematical Sciences, La Trobe University, Bendigo, Australia. The corresponding author is mostly responsible for all kind of expenses during this study. We would like to thank Aakriti Khadka for her help while initially drafting the manuscript. The authors are grateful to anonymous reviewers for their critical comments which are useful to enhance manuscript quality.

References

ADB, (2012), Project administration manual Nepal: Kathmandu Valley wastewater management project, Asian Development Bank, Online at https://www.adb.org/sites/default/files/project-document/76315/43524-014-nep-pam.pdf.

ADB, (2013), Proposed loan and grant and administration of loan and grant for Kathmandu Valley wastewater management project, Asian Development Bank, On line at: https://www.adb.org/sites/default/files/project-document/76314/43524-014-nep-rrp.pdf.

ADB, (2019), Nepal: Kathmandu valley wastewater management project, Asian Development Bank, On line at: https://www.adb.org/sites/default/files/project-documents/4352/43524-014-emr-en_2.pdf.

Arthur R., Brew-Hammond A., (2010), Potential biogas production from sewage sludge: A case study of the sewage treatment plant at Kwame Nkrumah University of science and technology, Ghana, *International Journal of Energy and Environment*, **6**, 1009-1015.

Asadi M., Guo H., Mc Phedran K., (2020), Biogas production estimation using data-driven approaches for cold region municipal wastewater anaerobic digestion, *Journal of Environmental Management*, **253**, 109708, http://doi.org/10.1016/j.jenvman.2019.109708.

Bachmann N., LaCour Jansen J., Bochmann G.,Montpart N., (2015), Sustainable Biogas Production in Municipal Wastewater Treatment Plant, IEA Bioenergy, On line at: https://www.nachhaltigwirtschaften.at/resources/iea_pdf/reports/iea_bioenergy_task37_wastewater_biogas_grey.pdf.

Bakraoui M., Hazzi M., karouach F., Ouhammou B., EI Bari H., (2019a), Experimental biogas production from recycled pulp and paper wastewater by biofilm technology, *Biotechnology Letters*, **42**, 1299-1307.

Bakraoui M., Karouach, F., Ouhammou B., Aggour M., Essamri A., El Bari H., (2019b), Kinetics study of the methane production from experimental recycled pulp and paper sludge by CSTR technology, *Journal of Material Cycles and Waste Management*, **21**, 1426-1436.

Bakraoui M., Karouach F., Ouhammou B., Aggour M., Essamri A., El Bari H., (2020a), Biogas production from recycled paper mill wastewater by UASB digester: Optimal and mesophilic conditions, *Biotechnology Reports*, **25**, 00402, http://doi.org/10.1016/j.btre.2019.e00402.

Bakraoui M., El Gnaoui Y., Lahboubi N., Karouach F., El Bari H., (2020b), Kinetic study and experimental productions of methane production from UASB reactor treating wastewater from recycled pulp and paper for the continuous test, *Biomass and Bioenergy*, **139**, 105604, http://doi.org/10.1016/j.biombioe.2020.105604.

Bakraoui M., Karouach, F., Ouhammou B., Lahboubi N., EI Gnauoi Y., Aggour M., EL Bari H., (2020c), Kinetics study of methane production from anaerobic digestion of sludge and wastewater recycled pulp and paper by different models simulation, *International journal of Smart Grid and Clean Energy*, **9**, 170-179.

Baquero-Rodriguez G.A., Lara-Borrero J.A., Martelo J., (2016), A simplified method of estimating chemical oxygen demand (COD), *Water Practice and Technology*, **11**, 838-848.

Boretti A., Rosa L, (2019), Reassessing the projections of the world water development report, *NPJ Clean Water*, **2**, 15, http://doi.org/10.1038/s41545-019-0039-9

Campos J.L., Valenzuela-Heredia D., Pedrouso A., Val del Rio A., Belmonte M., Mosquera-Corral A., (2016), Greenhouse gases emission from wastewater treatment plant: minimization, treatment, and prevention, *Journal of Chemistry*, **2016**,1-12.

CBS, (2016), Annual household survey 2015/16, Central Bureau of Statistics-National planning commission secretariat, Government of Nepal, On line at: https://nada.cbs.gov.np/index.php/catalog/85.

Chen J.L., Ortiz R., Steele T.W.J., Stockey D.C., (2014), Toxicants inhibiting anaerobic digestion: A review, *Biotechnology and Advances*, **32**, 1523-1534.

Chen L., Neibling H., (2014), Anaerobic digestion basics, University of Idaho Extension, CIS 1215, 1-6, On line at: https://www.extension.uidaho.edu/publishing/pdf/CIS/CIS1215.pdf

Chynoweth D.P., Owens J.M., Legrand R., (2001), Renewable methane from anaerobic digestion of biomass, *Renewable Energy*, **22**,1-8.

Demirbas A., Taylon O., Kaya D., (2016), Biogas production from municipal sewage sludge (MSS). *Energy Sources*, *Part A*: *Recovery Utilization and Environmental Effects*, **38**, 3027-3033.

Ersahin M.E., Ozgun H., Dereli R.K., Oztork L., (2011), *Anaerobic Treatment of Industrial Effluents*: *An Overview and Applications*, In: *Wastewater Treatment and Reutilization*, Gracia- Einschlag F.S. (Ed.), In Tech, Rijeka, Croatia, 9-13.

Gautam R., Baral S., Herat S., (2009), Biogas as a sustainable energy source in Nepal: present status and future challenges, *Renewable and Sustainable Energy Reviews*, **13**, 248-252.

GON, (2011), Sanitation and hygiene master plan, Steering Committee for National Sanitation Action 2011, Government of Nepal, On line at: http://washinschoolsmapping.com/wengine/wp-content/uploads/2015/10/Nepal-Government-Sanitation-and-Hygiene-Master-Plan.pdf.

GON, (2015), Nepal water supply, Sanitation and Hygiene Sector Development Plan (2016–2030), Government of Nepal ministry of water supply and sanitation, sector efficiency improvement unit, On line at: https://drive.google.com/file/d/1WeJJIbjtJVgqy0rBx9lt_ks6eLRshqrh/view?usp=sharing.

Henze M., (1992), Characterization of wastewater for modelling of activated sludge process, *Water Science and Technology*, **25**, 1-15.

IEA, (2017), Data and statistics for Nepal, International Energy Agency, On line at: https://www.iea.org/data-and-statistics?country=NEPAL&fuel=Imports%2Fexports&indicator=Net%20energy%20imports.

Kathmandu Population, (2020), World Population Review, On line at: http://worldpopulationreview.com/world-cities/kathmandu-population/.

Khanal S.K., (2011), *Anaerobic Biotechnology for Bioenergy Production: Principal and Application,* John Wiley& Sons, Manoa, 161-186.

KUKL, (2013), NEP: Kathmandu Valley Wastewater Management Project, Draft Initial Environmental Examination Report, Kathmandu, Kathmandu Upatyaka Khanepani Limited, On line at: https://www.adb.org/sites/default/files/project-document/75409/43524-014-nep-iee.pdf.

KUKL, (2018a), Nepal: Kathmandu valley wastewater management project –Guheshwori Package No: KUKL/WW/TP-02, Initial Environmental Examination Report, Kathmandu Upatyaka Khanepani Limited, On line at: http://www.kuklpid.org.np/kukl/Content/Upload/document/safeguard/43524-014-iee-en_1.pdf.

KUKL, (2018b), Nepal: Kathmandu valley wastewater management project –Guheshwori Package No: KUKL/WW/TP-01, Initial Environmental Examination Report, Kathmandu UpatyakaKhanepani Limited, On line at http://www.kuklpid.org.np/kukl/Content/Upload/document/safeguard/43524-014-iee-en_3.pdf.

KUKL, (2018c), Nepal: Kathmandu valley wastewater management project, Semi-Annual Environmental Monitoring Report, Kathmandu UpatyakaKhanepani Limited, On line at: http://www.kuklpid.org.np/kukl/Content/Upload/document/safeguard/13.1SAEMR-%20KVWWMP,%20January-June%202018.pdfl.

Mateo-Sagasta J., Raschid-Sally L., Thebo A., (2015), *Global Wastewater and Sludge Production*, *Treatment and Use*, In: *Wastewater*, DrechselP.,Quadir M., Wichelns D. (Eds.), Springer, Dordrecht, Netherlands,15-38.

McCarty P.L., Bae J., Kim J., (2011), Domestic wastewater treatment as a net energy produced –can this be achieved?, *Journal of Environmental Science and Technology*, **6**, 7100-7106.

Mir M.A., Hussain A., Verma C., (2016), Design considerations and operational performance of anaerobic digester: A review, *Cogent Engineering*, **3**, 1181696, http://doi.org/10.1080/23311916.2016.1181696.

Nyachhyon B.L., (2006), Service Enhancement and Development of Sanitary Sewage System in Urban and Semi-Urban Setting in Nepal, prepared for economic policy network - Government of Nepal and ADB Nepal resident mission, On line at: https://www.academia.edu/21280143/economic_policy_network_service_enhancement_and_development_of_sanitary_sewerage_system_in_urban_and_semi_urban_setting_in_nepal.

Pasztor L., Thury P., Pulai J., (2009), Chemical oxygen demand fraction of municipal wastewater for modelling of wastewater treatment, *International Journal of Environmental Science and Technology*, **6**,51-56.

Pluciennik-Koropczuk E., Myszograj S., (2019), New approach in COD fractionation methods, *Water*, **11**, 1484-1496.

Regmi S., (2013), *Wastewater treatment in Kathmandu: management treatment and alternative*, Bachelor Thesis, Mikkeli University of Applied Science, Finland.

Reith J.H., Wijffels R.H., Barten H., (2003), *Bio-methane and Bio-hydrogen: Status and Perspective of Biological Methane and Hydrogen Production*, Dutch Biological Hydrogen Foundation Publisher, Netherland, 1-165.

Roka R.B., Dongol R., Kalavrouziotis L.K., (2016), *Historical Development of Wastewater Management in Kathmandu Valley*, Proc. of 4th IWA Int. Symp., On Water and Wastewater Technologies in Ancient Civilization, Coimbra Portugal.

Shen Y., Linville J.L., Urgun-Demirtas M., Mintz M.M., Snyder S.W., (2015), An overview of biogas production and utilization at full-scale wastewater treatment plants (WWTPs) in the United States: challenges and opportunities towards energy-neutral WWTPs, *Renewable and Sustainable Energy Reviews*, **50**, 346-362.

Shukla A., Timilsina U.R., Jha B.C., (2012), *Wastewater Production, Treatment and Use in Nepal*, Proc. of.2nd Int Regional Workshop for South, West and Central Asia, India.

Surendra K.C, Khanal S.K., Shrestha P., Lamsal B., (2011), Current status of renewable energy in Nepal: opportunities and challenges, *Renewable and Sustainable Energy Reviews*, **15**, 4107-4117.

Tchobanoglous G., Burton F.L., Stensel H.D., (2003), *Wastewater Engineering, Treatment and Reuse,* 4th Edition, Metcalf & Eddy Inc., Boston.

UN, (2019), World urbanization prospects: the 2018 Revision, United Nation, On line at: https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf.

UNDP, (2018), Human development indices and indicators: 2018 statistical update, Human Development Report for United Nation Development Program, On line at: http://hdr.undp.org/sites/default/files/2018_summary_human_development_statistical_update_en.pdf.

UNESCO, (2017), The United Nation World Water Development Report 2017, The United Nation, Education, Scientific and Cultural Organization, On line at: http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2017-wastewater-the-untapped-resource/.

Wan J., Gu J., Zhao Q., Liu Y., (2016), COD capture: a feasible option for energy self –sufficient domestic wastewater treatment, *Scientific Reports*, **6**, 1-9.

Wang P., Peng H., Adhikari S., Higgins B., Roy P., Dai W., Shi X., (2020), Enhancement of biogas production from wastewater sludge via anaerobic digestion assisted with biochar amendment, *Bioresource Technology*, **309**, 123368.

World Data, (2019), Energy Consumption in Nepal, On line at: https://www.worlddata.info/asia/nepal/energy-consumption.php.