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Wastewater Treatment Technologies in Nepal

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Abstract

Mostly in urban centers of low-income countries including Nepal, wastewater management is an emerging issue. This review emphasizes on the state of wastewater production and treatment technologies in Nepal. It is found that in urban centres of the country, the theoretical estimation of the total domestic wastewater production is 867 MLD. Nearly 70% of the total urban wastewater production is collected in on-site sanitation system and 30% is collected by sewers. It is also observed that only 7% (i.e., 20.1 MLD) of wastewater is treated in Nepal. The conventional centralized approaches to wastewater management have failed in addressing the wastewater problem is revealed in Nepal. The major causes of failure are high capital investment, high operational and maintenance costs, lack of expertise and expensive spare parts. This review discusses opportunities for implementing wastewater management systems based on decentralized approach for wastewater reuse and resource recovery as well as improvements in local environmental health conditions. The prospects of sustainable decentralized wastewater treatment systems such as constructed wetland in Nepal is also considered in this review. The cost-effective, environmental friendly wastewater treatment plants that are suitable for the condition in Nepal such as climate, topography and socio-economic conditions are suggested. The design example of wastewater treatment plants – a CEPT alone or a combined CEPT -WSPs or CWs and a combined WSPs - CWs, the most suitable wastewater treatment plants in Nepal are presented. Finally, this review also tries to present the existing policy guidelines and regulatory frameworks and the institutional arrangements in addressing the development and management of infrastructure and services on wastewater management in the country. In general, it reveals that the existing policies, legislations and regulatory provisions are adequate to address the problems of wastewater management whereas the gaps are noted at the level of institutional development and in internalizing the problem of wastewater management. Further, it reveals that the despite being blessed with an abundance of water throughout the country, the Kathmandu Valley has become a victim of water shortage from a long time and the reasons behind it are tried to explain. Also, obviously, this review shows that the current status of wastewater management is poor although, the existing legislations for wastewater management are adequate for protection of water sources and public health.

Keywords: *Wastewater production; Wastewater treatment; Urbanization; Decentralized system;Constructed wetlands; Waste stabilization Ponds; Policies and Legislations; Institution; Kathmandu; Nepal*

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List of Abbreviations

%	percentage
&	and
∴	therefore
A.D.	*Anno Domini*
ADB	Asian Development Bank
AIPS	Advanced Integrated Pond System
B.S.	Bikram Samvat
BOD	Biological Oxygen Demand
CEPT	Chemically Enhanced Primary Treatment
COD	Chemical Oxygen Demand
CW	Constructed Wetland
DEWATS	Decentralized Wastewater Treatment System
DO	Dissolved Oxygen
E	East
ENPHO	Environment and Public Health Organization
Etc	Et cetera
GDP	Gross Domestic Product
GoN	Government of Nepal
HDI	Human Development Index
HFB	Horizontal Flow Bed;
HPCIDBC	High Powered Committee for Integrated Development
ha	hectare
hr	hour

HRT	Hydraulic Retention Time
i.e.	that is
IDA	International Development Assistance
km	kilometre
km^2	square kilometre
KUKL	Kathmandu Upatyaka Khanepani Limited
kWh	kilowatt hour
lpcd	litres per capita per day
m	metre
m^2	Square metre
m^3	Cubic metre
m^3/capita/year	Cubic metre per capita per year
m^3/d	Cubic metre per day
m^3/s	Cubic metre per second
m^3/year	Cubic metre per year
mg/l	milligram per litre
MDGs	Millennium Development Goals
MLD	Million Litres per Day
MMHEPS	Middle Marsyangdi Hydro-electric Power Station
Mt.	Mountain
N	Nitrogen
N	North
n.d.	no date
N^2	Nitrogen gas

O & M	Operation and Maintenance of Bagmati Civilization
Ph.D.	Doctorate of Philosophy
Q	Flow rate
R & D	Research and Development
S.T.	Settlement Tank
SDB	Sludge Drying Bed
TSS	Total Suspended Solids
USA	United States of America
USD	United States Dollar
VDCs	Village Development Committees
VFB	Vertical Flow Bed
WASH	Water, Sanitation and Hygiene
WSPs	Waste Stabilization Ponds
WW	Wastewater
WWP	Wastewater Production
WWTP	Wastewater Treatment Plant

1. Motivation and Objective

Interest in environmental issues and knowledge in the same field led me to think clearly about the environmental condition of Nepal. Wastewater, solid waste and potable water supply being the major environmental problem of Nepal. I decided to focus on the wastewater condition of Nepal. Traditionally, rivers have high value for cultural and religious beliefs and practices of Nepalese, citizens of Nepal. But, due to lack of proper management and awareness have deteriorated the quality of river water which can easily be seen still in the Bagmati River, the main river in the Kathmandu (the capital city of Nepal). The state of pollution in river has even caused frequent cases of water borne diseases such as diarrhea, dysentery, cholera, and skin diseases among people living in riverside areas.

The knowledge that I gained in the University of Stavanger motivated me with the main objective to present the current status of wastewater management in Nepal and to suggest appropriate methods of wastewater treatment. This overview reveals the reasons behind the poor wastewater treatment plants in the country. The objective is also to suggest an environmental friendly and economical wastewater treatment plants that are suitable for the condition in Nepal such as climate, topography and socio-economic conditions.

2. The Country Overview

Nepal is a landlocked, predominantly mountainous country situated in South Asia, surrounded by two giant neighbours the People's Republic of China to the north and the Republic of India to the South, East and West (Acharya, 2008; Shrestha & Aryal, 2011). It extends from 80°4' E to 88°12' E longitude and 26°22' N to 30°27' N latitudes, along the Southern slopes of the Himalayas (snow peaks) (WESC, 2004; Shrestha & Aryal, 2011; Department of Hydrology and Meteorology, 2015).The elevation ranges from 60 m above the sea level to 8,848 m at the summit of Mt. Everest, within a span of 200 km (Department of Hydrology and Meteorology, 2015). Mt. Everest, the highest peak in the world with an altitude of 8,848 m (Subedi, 2004; Shrestha & Aryal, 2011; Central Bureau of Statistics, 2015).

Geographically, the country is divided into three East-West ecological belt: the Northern Range – Mountain (35.2% of area), the Mid-Range - Hill (41.8% of area) and the Southern Range - Terai (flat land of 23% of area) (ADB, 2014; Central Bureau of Statistics, 2015). On an average, Nepal extends 885 km from East to West direction and non-uniform mean width of 193 km from North to South with total area of 147,181 km^2 (Central Bureau of Statistics, 2015; Acharya, 2008; Mahat & Koirala, 2004). This area is about 0.03% of the world and 0.3% of the Asia (Central Bureau of Statistics, 2015). According to the census 2011, the total population of the country is about 26.5 million with the annual growth rate of 1.35 % (Central Bureau of Statistics, 2012). Kathmandu is the capital of the country that is located in the central part of Nepal an altitude of about 1,300 m above the sea level and has an area of approximately 650 km^2 (Basnyat et al., 2001; Gurung et al., 2007).

Nepal's economy is largely based on agriculture, which contributes to nearly 40% of GDP (Ministry of Population and Environment; 2004; WESC, 2011; Dudwick et al., 2011; Green et al., 2003; Shukla et al., 2012) and provides employment to two-thirds of the population (Shukla et. al., 2012; WESC, 2011). In the country, with 25.4% of the population living below the national poverty (NPC & UNDP, 2010), which is far less than the global USD 1.25 a day standard (Pokharel, 2015). Figure 2.1 shows the location of Nepal in the South East Asia (in the inset) and also with major river basins.

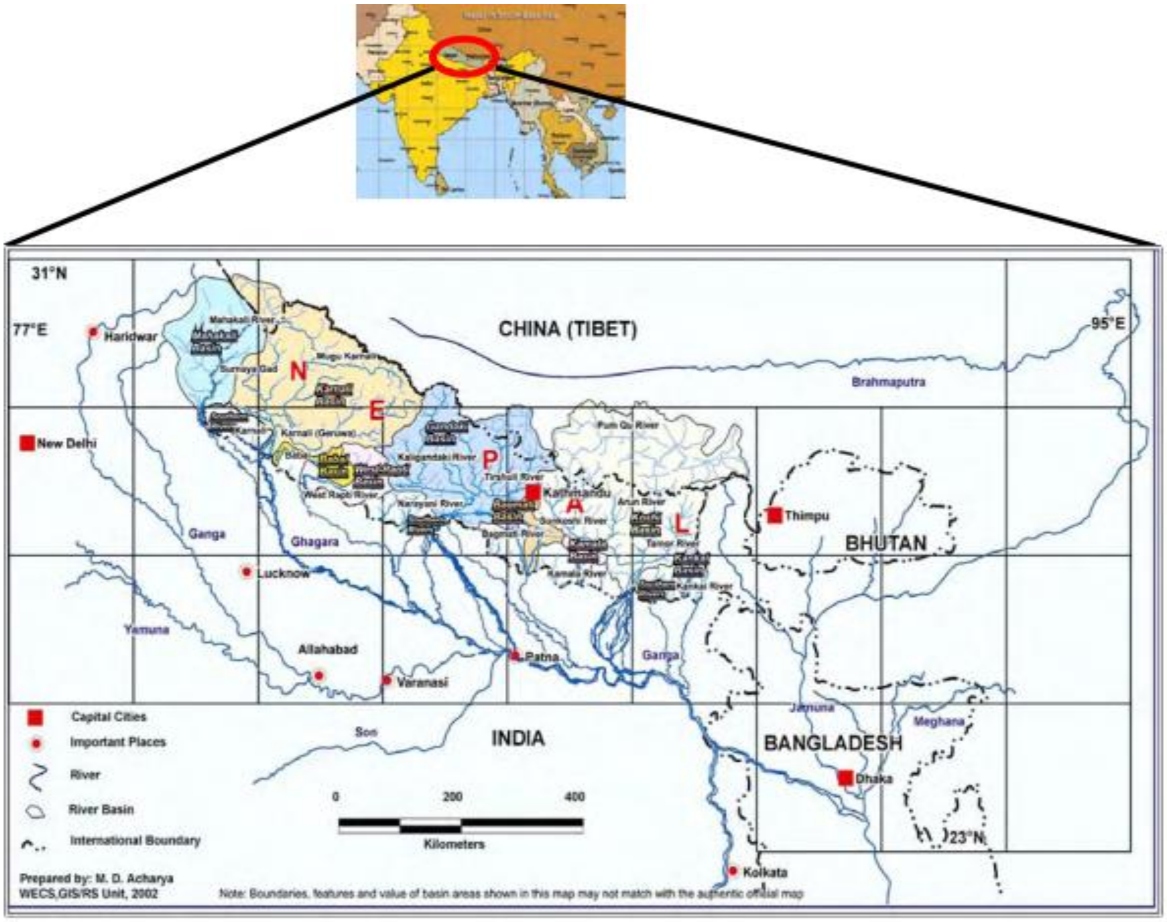

Figure 2.1 Location Map of Nepal in South East Asia (WECS, 2004)

3. Wastewater Production and Treatment Systems

3.1 Water Resources Availability

Nepal is the second richest country in inland water resources in the world, possessing about 2.27 % of the world water resource (Rai, 2008; Bhatt, 2017). The major sources of water are: glaciers, snowmelt from Himalayas, rainfall and groundwater (Rai, 2008.; Bhatt, 2017). It is estimated that there are altogether 6,000 rivers (including rivulets and tributaries) having about 45,000 km length (Shilpakar et al., 2008; Rai, 2008; Shukla et al., 2012; Bhatt, 2017). Of these different forms of water resources in the country, rivers are the most important running surface sources water in terms of volume and potential for utilization in wide ranging economic activities, involving irrigation, hydropower generation, water supply and sanitation and Navigation (Shukla et al., 2012). Koshi, Gandaki and Karnali are the main river systems getting major part of their water supply (Khatiwada, 2014; Bhatt, 2017).

In the country, the per capita availability of water resources is estimated to be 8,900 m^3/capital/year, is at least five times higher than the threshold of 1,700 m^3/capital/year to meet all water needs in agriculture, water supply and sanitation, energy and environment (UNDP, 2006, cited in Shukla et al., 2012 and TU-CDES & ICIMOD, 2017). Here, m^3/capital/year is stated but, m^3/capital/year does not give sense to the statement. It should be m^3/capita/year to the statement which really does give sense. Table 3.1 shows the water resources availability and use in Nepal over the period 1991-2011.

Table 3.1 Water Resources Availability and Use in Nepal (1991-2011)

Particulars	1991	2001	2011	Remarks
Annual Renewable Surface Water (billion m3)	225	225	225	Including the catchments outside Nepal
Annual Renewable Groundwater (billion m3)	12	12	12	
Total Population (approx.) Million	18.49	23.15	26.49	(CBS, 2011)
Per Capita Renewable Surface and Groundwater ('000 m3/year)	12.81	10.23	8.90	
Total Annual Withdrawal (billion m3)	12.95	16.70	23.70*	
Per Capita Withdrawal ('000 m3/year)	0.69	0.72	0.89	
Sectoral Withdrawal as % of Total Withdrawal*:				
Domestic	3.97	3.68	3.43	
Industrial	0.34	0.41	0.41	
Agricultural	95.69	95.91	96.16	

Source: TU-CDES & ICIMOD, 2017; UNEP, 2001, cited in Shukla et al., 2012

****Estimated value based on % annual increment 1991-2001***

3.2 State and Sources of Wastewater Production

Considering the need of better wastewater management, there is a need for updated data and information on wastewater generation and treatment (Sato et al., 2013; Shrestha et al., 2017). In recent years, the volume of wastewater produced in urban areas has been increasing, commensurate with rapidly growing population, economic development as well as changes in water consumption behavior (Gurung & Oh, 2012; Sato et al., 2013; Mishra et al., 2017).

3.2.1 Urbanization Trend

For the period 2014-2050, Nepal will remain amongst the top ten fastest urbanizing countries in the world with a projected annual urbanization rate of 1.9% (Bakrania, 2015). In urban areas of Nepal, the population increased from 6.4% in 1981 to 42.5% in 2015 (Central Bureau of Statistics, 2016, cited in Shrestha et al., 2017) is shown in Figure 3.1. Kathmandu Valley is the most populated (one of the fastest-growing urban agglomerations in South Asia, (Muzzini & Apericio, 2013; Ministry of Urban Development, 2015)), which has five municipalities (Kathmandu, Lalitpur, Bhaktapur, Kirtipur, and Madhyapur Thimi) and constitutes the country largest urban economy (Gurung et al., 2007). In 2015, the valley had approximately 3.2 million population (MoUD & JICA, 2016) which accounted for 24% of the total urban population (i.e., 17% of the total population, Central Bureau of Statistics, 2012) (Ministry of Urban Development, 2015). With the increased urban population, the wastewater generation in urban Nepal is increasing (Shrestha et al., 2017)

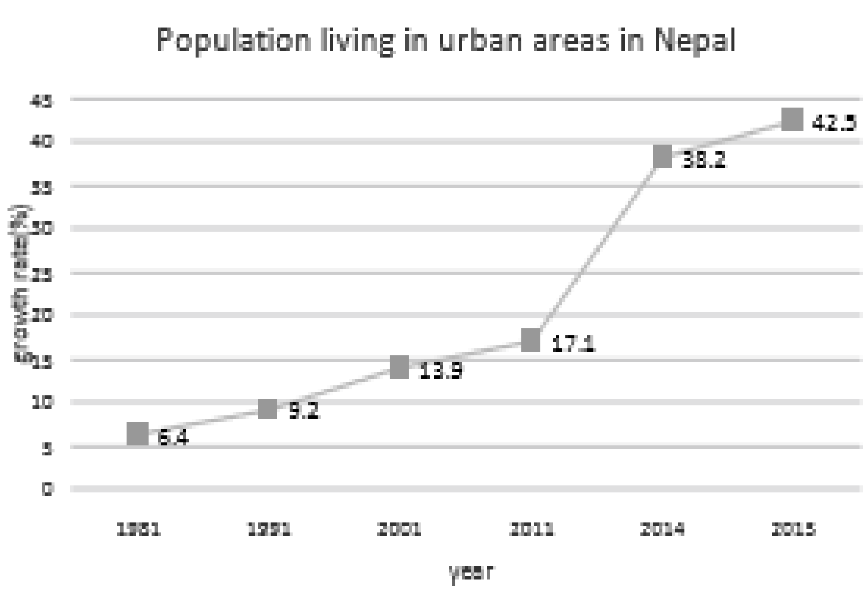

Figure 3.1 Urbanization trend in Nepal (Shrestha et al., 2017)

3.2.2 Sources and Compositions

The sources of wastewater in Nepal are mostly domestic and commercial (washing and other sanitary activities) with addition of industrial wastewater in urban areas (Rutkowiski et al., 2007; Jha & Bajracharya, 2014; Shrestha et al., 2017; TU-CDES & ICIMOD, 2017). The domestic waste includes grey and black water (ICIMOD, MOEST/GON & UNEP, 2007). This wastewater mainly contains discharge from the toilets (containing urine, faeces, soap, detergents, etc) and from the kitchen (containing foodstuff, fats, oils, etc.) (ICIMOD, MOEST/GON & UNEP, 2007; TU-CDES & ICIMOD, 2017). The composition of wastewater generated by commercial activities varies according to the type of activity; for instance, dry cleaning and photograph development use different chemicals generating wastewater of completely different compositions (ICIMOD, MOEST/GON & UNEP, 2007). The significant amount of wastewater produced from industries which include brewery and distillery, cigarette and tobacco, cement, animal feed, sugar and leather tanning, oil and vegetable ghee, jute, paper and pulp, iron and steel, rosin and turpentine, soap and chemical solvent (Sah, 2002; Jha & Bajracharya, 2014; Shukla et al., 2012; ; TU-CDES & ICIMOD, 2017).

3.2.3 Wastewater Production and Sewer System

The development of sewer system started in Nepal only towards 1920s that include a 55 km long brick channel to collect and dispose combined sewerage and rainwater runoff in Kathmandu and Patan (Nyachhyon, 2006). During 1970s and 1980s centralized wastewater treatment plants were developed in many parts of Kathmandu valley though planned development of infrastructures and services for wastewater management in other urban areas of the country was started in much later in time (Shukla et al., 2012; TU-CDES & ICIMOD, 2017). In 2008, KUKL was established which is responsible for operating and managing the water supply and wastewater services in the Kathmandu Valley through a public-private partnership (ADB, 2013).

In urban areas of Nepal, the data on wastewater management including production and treatment is very limited (Shrestha et al., 2017). ICIMOD, MOEST/GON and UNEP (2007) observed that in the five major cities of Kathmandu, approximately 93 % of the total wastewater generated is domestic and remaining 7 % is industrial wastewater, is provided in Table 3.2. In urban areas of the country, 60% of population have access to on-site sanitation facilities (septic tanks and pit latrines), 9% are deprived from even basic sanitation access (and 30% are sewer connected (Central Bureau of Statistics, 2012, cited in ENPHO, 2017).

On the based on census data of 2011, Shrestha, Shrestha and Dangol (2017) estimated the population of the country in 2016 to be 28.3 million with the growth rate of 1.35 % per annum out of which 12 million as urban population (i.e., 42.4% of the total population). They considered that 100 lpcd of water demand for urban areas and 80 % of it turned into WW. Hence, theoretically, they estimated the domestic WW generation about 867 MLD in urban areas of the country (Shrestha et al., 2017).

But, the corrected theoretical estimated domestic wastewater generation in urban areas of the country by using the considered wastewater production (i.e., 0.80 *100 lpcd) and estimated population (i.e., 12 million) is: $0.80 * 100\ lpcd * 12\ Million\ = 960\ MLD$. As above mentioned, 30 % of urban wastewater generated are connected to sewer network which is 288 MLD (0.3 * 960 MLD) of wastewater of total estimated volume is conveyed through the sewer network. Their calculation showed that the nearly 7 % (i.e., 20.1 MLD) out of 288 MLD is being treated through the existing functional centralized and decentralized wastewater treatment plants and the remaining 93 % wastewater that is not connected to sewer, is disposed into the nearby rivers without treatment is shown in Figure 3.5.

Table 3.2 Wastewater Production in Kathmandu Valley's Municipalities

Description	Municipalities					Total (%)
	Kathmandu	Lalitpur	Bhaktapur	Kirtipur	Madhyapur Thimi	
Total Domestic Wastewater Generated (MLD	64,497	15,647	5,971	3,920	3, ,069	93,104 (nearly 93% of the total WWP)
Total Industrial Wastewater Generated (MLD	4,515	1,095	418	274	215	6, ,517 (nearly 7% of the total WWP)
Total Wastewater Production ((MLD)	69,012	16,742	6,389	4,195	3,284	99,621

Source: ICIMOD, MOEST/GON & UNEP, 2007

3.3 State of Treatment and Management Services of Wastewater

3.3.1 Wastewater Management Practices

In most urban areas in developing nations, excess wastewater is disposed of directly, or without effective treatment, into surface water bodies, resulting in their severe degradation; despite the adoption of countermeasures (Ismail & Abed, 2013 and Purandara et al., 2011, cited in Mishra et al., 2017).

Ellingsen (2010) observed that the wastewater of all kinds including grey water, landfill leachate and septage of septic tanks is released straightforwardly in Bagmati, Bishnumati and Dhobikhola rivers with no proper treatment through sewer system in the Kathmandu valley where these rivers are close to the society or urban center. Likewise, GoN/UNDP (2013) observed that the most of the domestic wastewater generated in cities is discharged into the Bagmati river system without any treatment. According to ICIMOD, MOEST/GON & UNEP (2007) that the industrial wastewater was discharged without pre-treatment or neutralization either to municipal sewers that flow into rivers or directly into rivers without pre-treatment or neutralization

In an attempt to assess public understanding, regarding wastewater management, ENPHO conducted Knowledge, Attitude and Practice (KAP) survey. Data from 4,958 random pedestrians was collected from 34 strategic locations within Kathmandu Valley. Majority of the respondents identified that the major sources of wastewater generation is the 'toilet flush'. About 62% responded that wastewater goes into the sewerage pipeline immediately after flushing (Figure 3.2) and a huge majority of the people, about 77% percent, said that the toilet flush ultimately ends up in the rivers as shown in Figure 3.3 (ENPHO, 2017)

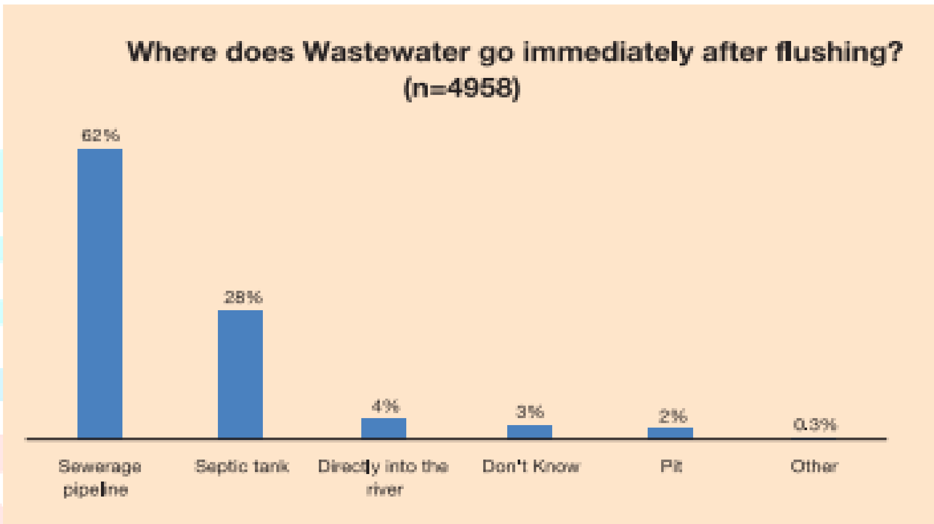

Figure 3.2 Where does Wastewater go immediately after flushing? (ENPHO, 2017)

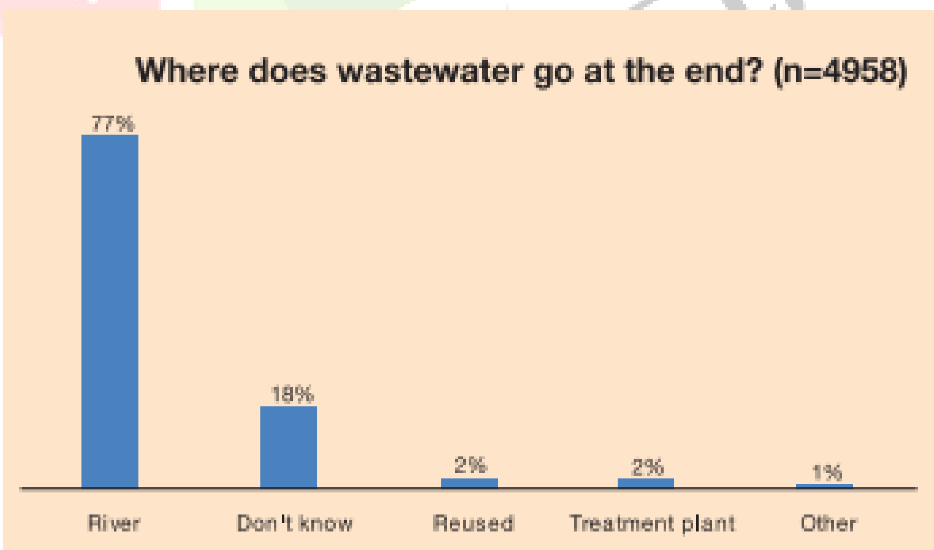

Figure 3.3 Where does wastewater go at the end? (ENPHO, 2017)

3.3.2 Existing Centralized Wastewater treatment

According to Corcoran, Nellemann, Baker, Bos, Osborn and Savelli (2010) it is now clear that future water demands cannot be met unless wastewater management is efficient. The acute shortage of water supply can be reduced by treating the domestic waters and industrial effluents in the wastewater treatment plants (Kivaisi, 2001, cited in Bartaula, 2016).

Normally, as in the case of Nepal, Jha and Bajracharya (2014) observed that in the absence of waste treatment technologies and transmission of water-borne diseases, the environmental damage costs to the society works out to be more than the financial costs. In the county, for the first time, in 1975, modern technologies of wastewater treatment system was introduced with the establishment of wastewater treatment plant at Hanumaghat (KUKL, 2013, cited in Shrestha et al., 2017). In early 1980s wastewater treatment plants were established at Kodku, Dhobighat, and Sallaghari (ADB, 2013; Shrestha et al., 2015). In 2001, the first activated sludge wastewater treatment plant is constructed at Guheshwori, Kathmandu to avoid the pollution in the Bagmati River (Jha & Bajracharya, 2014). Although, these treatment plants are technically very simple with no mechanized parts, they are not effective in treating wastewaters in the valley (Green et al., 2003). Among the five centralized systems, Guheshwori wastewater treatment plant (17.3 MLD) was observed partially functioning in February 2013 due to power cut-off (about 7 hr), but the plant was in operation status in 2003 (ADB, 2013; Regmi, 2013). Figure 3.4 shows the locations of these five wastewater treatment plants. The existing centralized wastewater treatment plants with their capacity and operational status are summarized in Table 3.3.

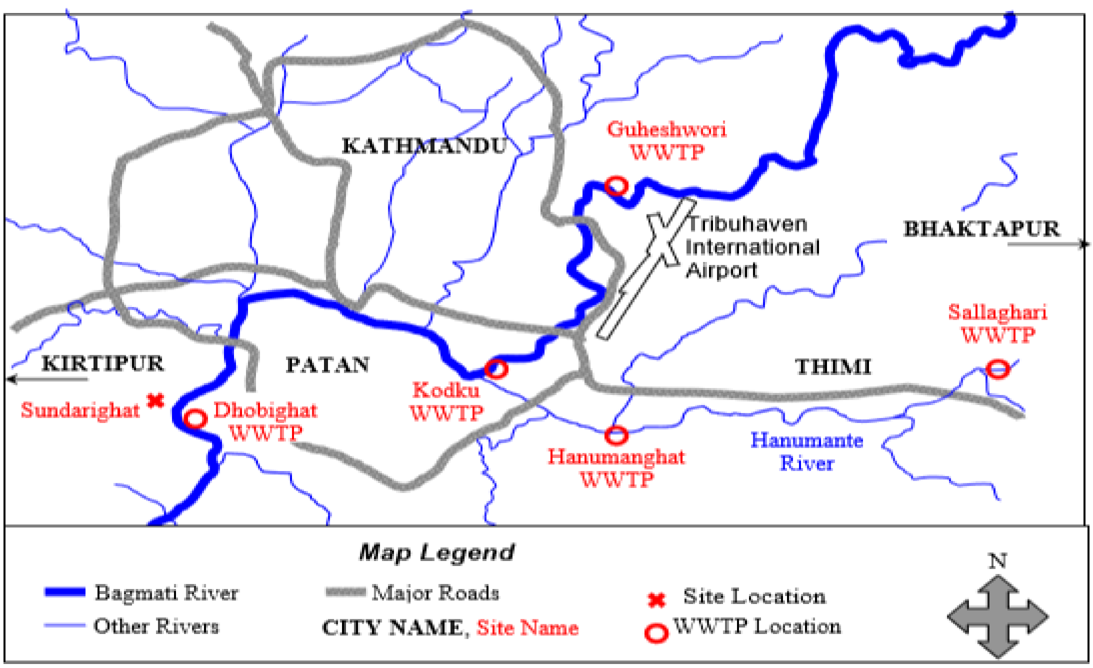

Figure 3.4 Map of Wastewater Treatment Plants in Kathmandu Valley (ADB, 2000)

The Kodku WWTP (1.1 MLD) lies along the Bagmati River in the city of Patan as shown in Figure 3.4. Tetsuji Arata of MIT Nepal Project team stated after observing Kodku WWTP, observed in January 2003 that the performance of the facility was doubtful, as effluent discharged into the Bagmati River "was bubbling" and smelled "just like that of sewer water" (Arata, 2003, cited in Green et al., 2003).

In Figure 3.4, the Dhobighat WWTP (15.4 MLD) facility is positioned downstream from Kodku, in the southwest area of Kathmandu Valley. In this plant, gravity-driven sewage flows to a sump well at Sundarighat as shown in Figure 3.4, where it was pumped to the plant at Dhobighat. The pump station at Sundarighat, the pump main and the interceptors along the Bagmati and Bishnumati rivers were all broken in places, so untreated wastewater drains directly into the rivers (Darnal, 2002, cited in Green et al., 2003). The treatment plant was used for different farming, recreation and informal purposes as well as being used by KUKL as a storage area for sewer pipes (ADB, 2013).

The Sallaghari and Hanumanghat WWTP's both lie along the Hanumante River in Bhaktapur, upstream from its junction with the Bagmati river near Kodku (Figure 3.4). Since the shutdown of the plant, local farmers had removed the pump from the northern main and plugged the southern main so that inflowing, untreated wastewater could be used for irrigation purposes (Arata, 2003 cited in Green et al., 2003).

Table 3.3 Existing Centralized Wastewater Treatment Plants in Kathmandu Valley with some details.

WWT Plant	**Established Year**	**Capacity (MLD)**	**Type of Plant originally Installed**	**Original Supporting Agency**	**Existing Operation Status**
Hanumanghat	1975	0.5	Aerated lagoon	GTZ/Germany	Not in operation
Kodku	1982	1.1	Oxidation Pond: 2 primary anaerobic ponds, 1 secondary facultative pond, 1 tertiary pond	IDA, Engineering Science/USA	Not in operation
Dhobighat	1982	15.4	Oxidation Pond: 2 primary anaerobic ponds, 1 secondary	IDA, Engineering Science/USA	Not in operation, out of operation almost since

			facultative pond, 1 tertiary aerobic pond		construction. Problem began with pumping wastewater and conveying through under-river sewer.
Sallaghari	1983	2.0	Originally designed as an aerated lagoon system using diffused aeration equipment. The plant is now converted to a non- aerated lagoon	GTZ/Germany	Not in operation
Guheshwori	2001	17.3	Activated sludge oxidation ditch.	GoN (Government of Nepal)	In partial operation. High O&M cost.

Source: ADB, 2000; Shukla et al., 2012; ADB, 2013; Jha & Bajacharya., 2014; Shrestha et al., 2015.

3.3.3 Failure Reasons of Existing Centralized Wastewater Treatment Plants

Sah (2006), cited in Shrestha et al. (2015), stated that the major technical difficulty of Guheshwori plant is Foaming in an aeration tank. WaterAid (2008) and WASH (2011) found that poor operation and maintenance, and lack of expertise are some of the important reasons. Similarly, Jha and Bajracharya (2014) found electricity expenses, expensive spare parts, high prices of chemical additives, short of skilled human resources and complex operation and maintenance were reasons for poor plant operation and performance. Likewise, Shukla, Timilsina and Jha (2012) noted that higher cost of operation and maintenance and, also Green, Poh and Richards (2003) found lack of financial capability is often associated with poor or no plant operation.

3.3.4 CW: An Alternative To Centralized Wastewater Treatment Plants

Amory and Magliaro (2004) defines decentralized systems as an alternative to conventional, centralized systems. In general, centralized wastewater treatment plants are not the most cost-effective, require sophisticated technologies and skilled manpower as well as have huge O&M costs (Singh et al., 2009). Moreover, centralized wastewater treatment systems are also not environmentally friendly and consume more energy (Singh et al., 2009).

The DEWATS is widely used not only in developing countries, but in developed countries as well (Singh et al., 2009). In Georgia, United States, about 40% of the residents rely on decentralized systems (Sheehan, 2011, cited in Chirisa et al., 2017). In Oslo, Norway, the Klosterenga ecological housing project succeed where all grey water from 35 apartments is treated in a small and decentralized treatment system, Constructed Wetland (Jenssen, 2005). CWs have proved useful worldwide in treatment of municipal, industrial, storm water and agricultural wastewater (Bruch et al., 2011 and Korkusuz et al., 2004, cited in Alagbe & Alalade, 2013). The DEWATS is mostly implemented with natural (extensive) systems in the developing countries although a variety of intensive systems like membrane filtration, sequencing batch reactor, etc. are also used in the developed countries. The major advantages of the DEWATS with extensive systems are as follows (Sasse, 1998 and Brissaud, 2007; cited in Singh et al., 2009):

- Reliable, robust and buffer shock loads.
- No (or very little) energy is required.
- Limited sludge production.
- O&M does not require highly skilled personnel.
- Very low O&M cost.
- Reduces the risks associated with system failure.
- Increases wastewater reuse opportunities

The DEWATS is not the best solution everywhere. However, where skilled and responsible O&M cannot be guaranteed, the DEWATS is undoubtedly the best choice available (Sasse, 1998, cited in Singh et al., 2009).In Nepal, a pilot scale wastewater treatment plant based on CW was constructed in 1997 at Dhulikhel Hospital by the ENPHO with the technical support from a Nepali Ph.D Scholar from University of Natural Resource and Applied Life Sciences, Vienna, Austria (Shrestha, 1999, cited in WaterAid, 2008).

After its successful operation, DEWATS were being promoted by the development organizations involved in the public health and environmental issues, such as UN-Habitat, ENPHO, Municipalities and Community Groups (Tuladhar et al., 2008). Out of 67 DEWATS constructed in Nepal by 2016, about 52 % (i.e., 35 DEWATS) were in Kathmandu Valley (Shrestha, 2017, cited in Uprety, 2017). However, only 53 % of the DEWATS were properly used and maintained while nearly 24 % were not in use at all (Uprety, 2017; ENPHO, 2017, cited in Shrestha et al., 2017) is shown in Figure 3.6. Some of DEWATS are listed in Table 3.4.

Table 3.4 List of Some Constructed Wetlands in Nepal

Location	Date of Operation	Q (m^3/d)	WW Type	CW Configuration	Size of the CW
Dhulikhel hospital	1997	40	Hospital	HFB followed by VFB	S.T.-10 m^3, HFB-140m^2, VFB-121m^2
Private house, Kathmandu	1998	0.5	Grey Water	VFB	S.T.-0.5 m^3, VFB-6 m^2
Kathmandu Metropolitan city	1998	40	Septage	SDB followed by VFB	S.T.-40 m^3, SDB-225 m^2, VFB-362 m^2
Malpi International school	2000	25	Institutional	HFB followed by VFB	S.T.-25 m^3, HFB-136 m^2, VFB-231 m^2
SKM P.R.S Hospital	2000	15	Hospital	HFB followed by VFB	S.T-10 m^3, HFB-72 m^2, VFB-69 m^2
Kathmandu University	2001	40	Institutional	HFB followed by VFB	S.T-40 m^3, HFB-290 m^2, VFB-338 m^2

Staff Quarter of MMHEPS	2002	26	Domestic	HFB followed by VFB	S.T-13 m^3, HFB-148 m^2, VFB-150 m^2
ENPHO Laboratory	2002	1.5	Domestic and Laboratory	VFB	S.T-500 L, HFB-18 m^2
Kapan Monastery	2003	17	Institutional	HFB followed by VFB	S.T-7 m^3, HFB-50 m^2, VFB-150 m^2
Private house, Kathmandu	2002	0.5		VFB	S.T-0.5 m^3, VFB-6 m^2
Shuvatara school	2004			VFB	S.T-4 m^3, VFB-95 m^2
Sunga, Thimi	2005	25	Municipal	HFB followed by VFB	S.T-42 m^3, HFB-150 m^2, VFB-150 m^2, SDB-70 m^2

Source: Shrestha & Shrestha, 2004; UN-HABITAT, 2008; WaterAid, 2008

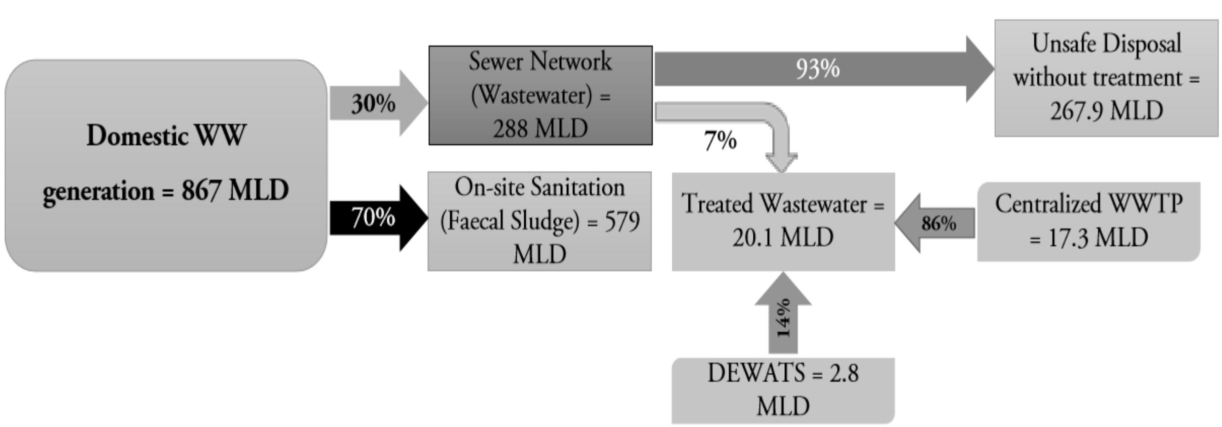

Figure 3.5 Domestic wastewater flow diagram of urban areas in Nepal (Shrestha et al., 2017)

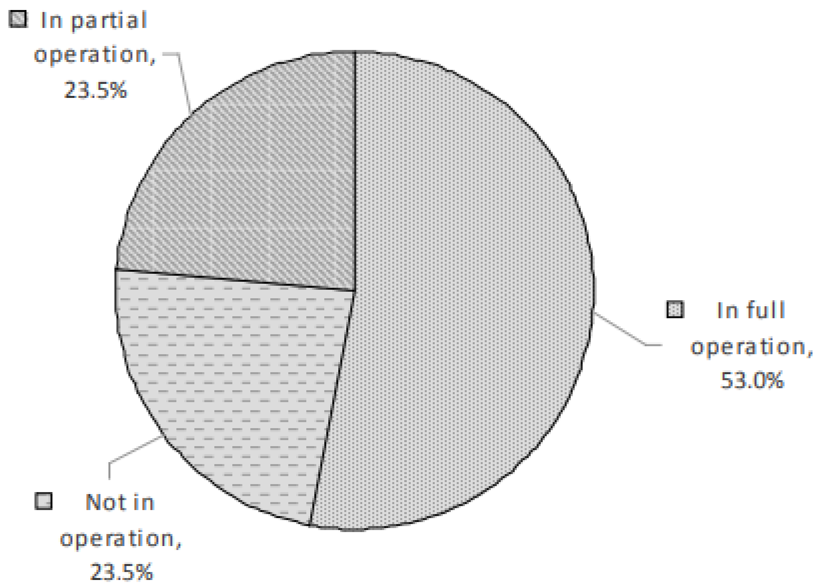

Figure 3.6 Existing operation status of DEWATS (ENPHO, 2017 adopted from Shrestha et al., 2017)

Despite efforts, the agencies involved in public health and environmental management, including municipal bodies, including those in Kathmandu valley, have failed to manage the growing volume of wastewater **(**Jha & Bajracharya, 2014**)**. Due to higher volume of wastewater (i.e., 267.9 MLD) disposal in nearby rivers, the receiving rivers are being polluted and their protection has also been a challenge (Shrestha et al., 2017).

Mishra et al. (2017) carried out a systematic case study on the Bagmati river pollution in Kathmandu Valley by using WEAP model to simulate of year 2014 and future (year 2020 and 2030) river water quality conditions based on the two important indicators: DO and BOD. They observed that the water quality of the Bagmati River is relatively better during monsoon season due to higher river flow in comparison to the dry season. The simulated DO and BOD values for 2020 and 2030 with 2014 values were compared and found that the water quality of the Bagmati River within Kathmandu Valley will not significantly improve as a result of the planned wastewater treatment plants requiring additional countermeasures. They also pointed out the inefficiencies of the current practice of discharging untreated sewage into the surface water and causing largely in the river water and unsuitability of river (Mishra et al, 2017)

Shrestha, Lamsal, Regmi and Krishan, (2015) also carried out a case study to assess the existing urban water environment of the Kathmandu Valley through urban water quality modeling for the sustainable urban water environment of the valley in future. They observed that the urban water quality in Kathmandu valley is not good enough to sustain healthy water ecosystem. Instead of sustaining life, they have become the carrier of diseases and pollution. Deteriorating quality of river water has even caused frequent cases of water borne diseases such as diarrhea, dysentery, cholera, and skin diseases among people living in riverside areas. They also observed that it reduced the religious, recreational and aesthetic value of rivers (Shrestha et al., 2015)

3.3.5 Prospects of CWs for Sustainable Wastewater Treatment in Nepal

As already mentioned that the CW is simple in construction and operation as well as cost-effective and environmentally friendly as compared to centralized wastewater treatment systems (Singh et al., 2009) and has an enormous potential to be successful in low-income countries like Nepal (Shrestha et al., 2001, cited in Jha & Bajracharya, 2014).

Gurung and Oh (2012) stated that CWs can be applied in both cold and warm climates. Almost all types of climates, subtropical to alpine/artic encountered in Nepal (Department of Hydrology and Meteorology. 2015). Nepal is one of the least developed countries in the world with per capita GDP at USD 762 for the year 2014/15(CBS, 2015). Nepal has a HDI of 0.558, and was ranked 144th out of 188 countries (UNDP, 2016) and with 25.4% of the population living below the national poverty (NPC & UNDP, 2010), which is far less than the global 1.25 USD a day standard (Pokharel, 2015). Thus, from an economic perspective CWs are viable option for treating wastewater as compared to centralized wastewater treatments in Nepal (Shrestha & Maharjan, 2009). An economical comparison was done in Mexcio by Seyring and Kuschk (2005), reviewed in ElZein et al., 2016, between Activated Sludge Systems (ASS) and CWs. It was found that both the investment and O&M costs of the ASS are very high compared to that of CW. The investment and O&M costs of CWs were about 58% and 20% of the costs of that ASS respectively. This makes clear that CWs is more economic that the traditional ASS (Seyring & Kuschk, 2005, cited in ElZein et al., 2016). In Nepal, the total cost invested for the construction of CWs in Nepal is shown in Table 3.5.

As also already mentioned, for the period 2014-2050, Nepal will remain amongst the top ten fastest urbanizing countries in the world with a projected annual urbanization rate of 1.9% (Bakrania, 2015). In Kathmandu valley, the population has increased from 0.41 million in 1952 to about 3.2 million in 2015 (MoUD & JICA, 2016). Due to rapid urbanization, there is high demand of water and the average demand of drinking water in the Valley is about 370 MLD in which only 144 MLD of water is being supplied in the wet season and about 86 MLD during the dry season (MoUD & JICA, 2016). The growing imbalance between water supply and demand can only be maintained if the wastewaters are being treated and reused for agricultural and other purposes (Bruch et al., 2011 and Kivaisi, 2001, cited in Gurung & Oh, 2012). In urban areas of Nepal, it is estimated that approximately 867 MLD of wastewaters produced (Shrestha et al., 2017) in which 256 MLD is generated from the Kathmandu

Valley alone of which estimated population is 3.2 million (MoUD & JICA, 2016) with 80 lpcd WW produced (Shrestha & Maharjan, 2009; Shrestha et al., 2017). However, the installed capacity of wastewater treatment plants is only 36.3 MLD is shown in Table 2.3. Moreover, the existing plants are not in operation in regular basis and nearly 7% of wastewater (i.e., 20.1 MLD) is treated out of which about 86% (i.e., 17.3 MLD) is contributed by centralized wastewater treatment system and approximately 14% (i.e., 2.8 MLD) by DEWATS is shown in Figure 3.5. In Nepal, the CW technology is already proved to be effective in removing organic pollutants and inorganic contaminants (Shrestha & Shrestha, 2004). Although the prospective for the usage of constructed wetlands in Nepal is huge, the dissemination of the CW is unsatisfactory (Jha & Bajracharya, 2014). The reason for this could be lack of awareness, information and familiarity (Shrestha & Shrestha, 2004; WaterAid, 2008; Jha & Bajracharya, 2014). Hence, advocacy, training and policies might play vital roles for its development. However, its construction, design, operation and maintenance is simple, requirement of a large land area may limit its usage (Sasse, 1998 and Brissaud, 2007, cited in Gurung & Oh, 2012; Jha & Bajracharya, 2014).

Table 3.5 Summary of cost considerations for CW in Nepal

CW plant	**Total construction cost (USD)**	**Per m^2 (USD)**	**Operation and maintenance cost/year (USD)**
Dhulikhel hospital	16,000	60	150
ENPHO laboratory	570	40	
Kathmandu University	26,000	40	290
Sunga, Thimi	31,500	85	520
Private house, Kathmandu	520	85	
Pokhara sub-Municipality	85,000	20	

Source: UN-HABITAT, 2008

3.4 Challenges of water and wastewater management in Nepal

Despite being blessed with an abundance of water throughout the country, the Kathmandu Valley has become a victim of water shortage from a long time, which is primarily due to the growth in population (Thapa et al., 2017; http://thewaterchannel.tv/thewaterblog/437-water-scarcity-as-a-business-in-kathmandu-valley). According to The World Bank in 2013, Kathmandu Valley with a population of 2.5 million, growing at 4% per year, one of the fastest-growing metropolitan areas in South Asia, and the first region in Nepal to face the unprecedented challenges of rapid urbanization and modernization at a metropolitan scale (https://www.worldbank.org/en/news/feature/2013/04/01/managing-nepals-urban-transition). The current growth of the Kathmandu Valley is not only rapid but also uncontrolled, and has resulted in haphazard development of new urban areas (ICIMOD, MOEST/GON & UNEP, 2007). Migration (about 42 % of population living in the valley, in 2001) appeared to have contributed largely to the rise of population of the Kathmandu Valley as compared to the natural growth (Thapa et al., 2008). According to ICIMOD, MOEST/GON & UNEP (2007), the migrating population increased significantly in the last decade due to the nation's ongoing conflict and political instability. Several other pull factors such as electricity, water supply and sanitation, telecommunication, education, road and transportation services are better developed in the valley compared to rest of Nepal. In addition, better job opportunities occur here because most governmental, academic and financial institutions as well as health care facilities are located (ICIMOD, MOEST/GON & UNEP, 2007).

In Kathmandu Valley, the traditional water system are stone spouts, dug wells, tanks and ponds that were built at different times in the ancient period (http://www.globalwaterforum.org/2017/12/04/inequities-in-household-water-consumption-in-kathmandu-nepal/). While there were once 389 functioning stone spouts situated as a comprehensive water distribution network across the Kathmandu Valley, 45 no longer exist and 68 have run dry. Of the remaining stone spouts, 43 (illegally) connect to city supply lines and 233 still flow naturally serving as independent water sources catering to approximately 10% of Kathmandu's population (https://medium.com/the-sustainability-graduate-programs/kathmandu-valleys-ancient-stone-spouts-8cb70c85887f)

The Kathmandu Valley had a demand of 370 MLD but, Kathmandu Upatyaka Khanepani Limited (KUKL), the utility responsible for water supply in the valley, supplies only 115 MLD during the wet season and 69 MLD during the dry season, and the deficit is met through groundwater pumping, traditional water spouts, wells, supplies from private water vendors (which was estimated at more than 450 tankers operating in 2009; Shrestha & Shukla, 2010, cited in Thapa et al., 2017; 23 trucks ferry 90 tankers of water to various dry areas in the Capital for free; Rauniyar, 2011, cited in http://development-topics.blogspot.no/2011/12/drinking-water-shortage-in-kathmandu.html) , and bottled water companies (Thapa et al., 2017; Kathmandu Upatyaka Khanepani Limited, 2015). The leakage percentage is 40%, as reported by the utility company (Kathmandu Upatyaka Khanepani Limited, 2015).

To address the issue of water scarcity in Kathmandu, the government of Nepal proposed a project of inter-basin transfer of water from Melamchi River located 40 km north–east of the Kathmandu Valley (Khadka & Khanal, 2007). According to Rachael Buckland, in March 2017, an intern with the Lowy Institute's Migration and Border Policy project, mentioned that almost 20 years ago, the Melamchi Water Supply Project (MWSP) was designed to address the rapidly growing demand for water in the Valley. Despite ambitious promises, 19 years after it was announced the MWSP is incomplete. To many this is unsurprising in the face of ongoing political instability, constitutional debates, ineffective government institutions, corruption allegations, and the devastating 2015 Gorkha Earthquake. As time passes, the Kathmandu Valley continues to struggle, facing declining water quality, increasing water scarcity, and the troubling emergence and expansion of groundwater entrepreneurs (https://www.lowyinstitute.org/the-interpreter/water-access-kathmandu-valley-robbing-peter-pay-paul). Also, the blog, http://development-topics.blogspot.no/2011/12/drinking-water-shortage-in-kathmandu.html , dedicated in to discuss topics relevant to Development Studies : Drinking Water Shortage in Kathmandu Valley discussed in December 2011, had discussed that the Melamchi Project was the only hope of Kathmandu's people which will fulfill its resident's water needs, promising enormous relief, yet it remained a distant dream. The first phase was supposed to be completed by 2014, which will provide 170 million litres of water per day, and the whole project should be completed by 2025, which will supply 510 MLD. By the time Melamchi project will be completed, Kathmandu resident's demand for water might be doubled due to population growth and the water shortage problem will still exist then.

According to National Planning Commission (2015) that a Gorkha Earthquake of magnitude of 7.8 M hitted Nepal on 25 April 2015 (and 300 aftershocks greater than magnitude 4.0 until 7 June 2015) took the lives of about 9,000 people, as well as causing nearly 22,500 injuries which caused damage and losses to the water and sanitation sector that were reported to cost USD 106 million (National Planning Commission., 2015). An approximate 40% reduction of supplied water by KUKL was also reported, affecting 0.15 and 0.24 million people during the dry and wet seasons, respectively (Thapa et al., 2016)

These clearly reveal that Kathmandu is going through a serious problem of water shortage but the major causes behind the existing water shortage was still not clear which is also due to poor supply system, and misuse of water but, there are other reasons too such as the availability of water could decrease in the dry season and increase in the wet season due to climate change, resulting in an increase in annual water availability (Babel et al., 2013, cited in Thapa et al., 2017) , change in flood patterns (Sharma & Shakya, 2006, cited in Thapa et al, 2017) and sand extraction (NTNC, 2008 cited in Thapa et al., 2017) have greatly influenced the hydrological responses and water resource planning in the valley, resulting in water shortages, inter-sectoral water conflicts (Shukla et al., 2010, cited in Thapa et al., 2017).

All of these scenarios have created insecurity in the potable water supply in the Kathmandu Valley.

4. Alternative Wastewater Treatment Options

4.1 Chemically Enhanced Primary Treatment (CEPT)

Analyzing the existing status/failure reasons of wastewater treatment plants in Nepal assures that the current condition is lacking the wastewater management and natural environment protection. So, an alternative and viable wastewater treatment technology for Nepal is Chemically Enhanced Primary Treatment (CEPT).

Harleman and Murcott (2001) promoted CEPT as an effective first step of pollution control, particularly in large urban areas that have evolved with sewage systems, but without centralized wastewater treatment and that have limited financial resources for more complete but capital-intensive biological treatment options such as activated sludge systems. Urban areas may also not have the area available for appropriate technology options, such as stabilization pond processes. Harleman and Murcott (2001) concluded that CEPT, while not a complete treatment, is far better than no treatment. After implementing chemical treatment as an initial stage, biological polishing of some sort can be added later for soluble BOD removal and nitrogen conversion, if required, as funds become available (Mouri et al., 2013).

CEPT is a relatively simple technology with low-cost and provide effective treatment compared to the traditional biological (primary treatment plus activated sludge) wastewater treatment plant (Harleman & Murcott, 2001; Harleman et al., 2002; Chagnon & Harleman, 2004; Mahmoud, 2009). In Mexico City, it was estimated that capital and O & M costs for CEPT was about 55% of the costs of conventional primary and secondary biological treatment, including sludge handling (Harleman et al., 2002; Harleman & Murcott, 2001). As already mentioned, urbanization, industrial and commercial etc. in Nepal lead to the higher influent rate to the treatment plant (Gurung & Oh, 2012; Sato et al., 2013). The CEPT can normally handle such higher rates compared to the biological treatment plant (Chagnon & Harleman, 2004) such as Gueshwori wastewater treatment plant in Kathmandu (Design flow rate: 0.19 m3/s) requires less residence time of which HRT is 15.2 hr (Bartaula, 2016). Thus, CEPT plant reduces the basin size and as a result, the construction costs are reduced. In addition, CEPT known as the appropriate first step in urban wastewater management (Harleman & Murcott, 2001). Although the chemical cost for CEPT may be high which is offset by the high energy cost for biological treatment (Harleman & Murcott, 2001). This is a bonus in Nepal, where energy can be scarce (Shrestha, 2010; Koirala, 2016). Yet, the removal efficiencies show CEPTs superiority, as discussed in the following below sub-section: Efficiency of CEPT (Chagnon & Harleman, 2004; Murcott & Harleman, 2002 cited in Bourke, 2002). CEPT may be implemented using a dedicated "CEPT tank" (i.e., a settling tank specially designed for CEPT), or by retrofitting a conventional primary treatment facility (Chagnon & Harleman, 2004). Figure 4.1 shows a simple flow diagram of a CEPT process.

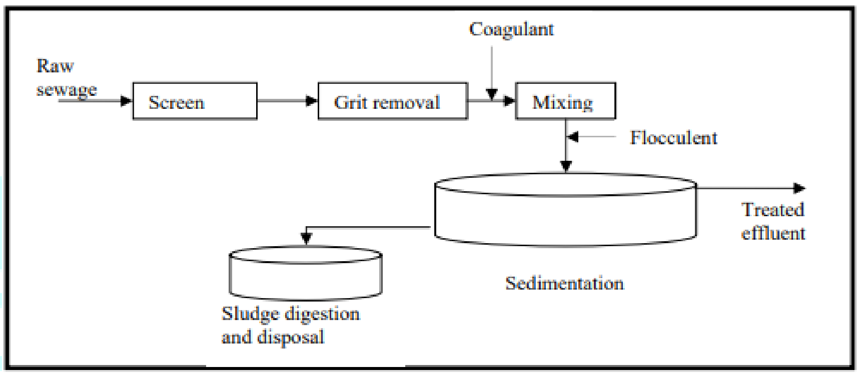

Figure 4.1 Simple Flow Diagram of a CEPT Process (Nema and Tare, n.d.)

A conventional primary treatment process consists of bar screens, a grit removal chamber, and a sedimentation basin (or primary clarifier) (Figure 4.1). To upgrade a conventional primary treatment facility to a CEPT facility, all that is needed is the addition of a chemical coagulant (and optionally a flocculent) as shown in Figure 4.1 (Chagnon & Harleman, 2004). The governing principle behind CEPT is the enhancement of the primary settling process through the addition of low dosages of metal salts and extremely small amounts of an anionic polymer (Bourke, 2002). A coagulant, typically metal salt is added to primary sedimentation basin. A coagulant attaches to suspended solids, forming denser particles and a flocculent, a polymer in the form of organic polyelectrolytes, is then added, allowing coagulated solids to combine to form even larger particles. These particles are allowed to settle and form a sludge, thereby enhancing treatment efficiency (Chagnon & Harleman, 2004; Mahmoud, 2009). Jar test and coliform test must be performed to analyze how effective CEPT could be at removing debilitating parasites found in wastewater (Green et al., 2003). Table 4.1 illustrates the removal efficiencies of CEPT compared to other technologies.

Efficiency of CEPT

Table 4.1 Removal Efficiencies of CEPT compared to different technologies

% Removals	**CEPT**	**Conventional Primary Treatment**	**Conventional Primary + Biological Secondary Treatment**
Total Suspended Solids (TSS)	75 – 85 %	*55 %	*91 %
BOD_5	55 – 65 %	30 %	*85 %
Phosphorus (P)	55 – 85 %	30 %	
Nitrogen (N)	30 %	30 %	

Source**:** Murcott & Harleman, 2002 cited in Bourke, 2002; *Chagnon & Harleman, 2004

The Table 4.1 shows that, by CEPT, the removal efficiencies of TSS, BOD_5 and P are much more improved in comparison to the conventional primary treatment alone. But, the removal efficiencies of TSS and BOD_5 by conventional primary plus biological treatment are higher than that of CEPT. So, a combination of CEPT and a pond or constructed wetland will be much more efficient and economical than the traditional activated sludge that requires a lot of energy for aeration is suggested for wastewater treatment in the country. Alone CEPT or a combined CEPT and a pond/CW is designed depending on climate, topography and socio-economic conditions of Nepal. The design of a CEPT is presented in section: Design of a CEPT, below and a pond/CW design is presented in Chapter 5.

Design of a CEPT

It is observed that the Kathmandu is mainly facing the problem of wastewater management and results pollution in the Bagmati River. From Table 3.3, out of five WWTP, I take, design influent flow rate of Guheshwori WWTP (the highest design capacity, 17.3 MLD i.e., 17,300 m^3/d) which is serving Kathmandu. The data of influent flow rate is of 2001 and designed accordingly, a CEPT to solve the problems. The following design approach is same but, should be done depending on required data of near future.

a) Calculations of required surface area for the CEPT (A_{CEPT})

Influent flow rate (Q) = 17,300 m^3/d

The design overflow rate for primary settling tank is 30 – 60 m/d. A single rectangular basin will cost more than a circular basin of the same size. However, if numerous tanks are required, then the rectangular tanks can be constructed with common walls and be the most economical. The depth (d_{CEPT}), width and length of the rectangular sedimentation tank ranges are 3 to 5 m, 3 - 24 m and 15 – 90 m respectively. (http://mimoza.marmara.edu.tr/~bilge.alpaslan/enve301/Lectures/Chp_10.pdf).

Assuming overflow rate = 40 m/d and d_{CEPT} = 3.5 m. The required surface area of the CEPT (rectangular) is

$A_{CEPT} = \frac{Q\ (\frac{m3}{d})}{overflow\ rate\ (\frac{m}{d})} = \frac{17{,}300\ m3/d}{40\ m/d}$ = 432.5 m^2 = 450 m^2 and, the tank volume (V_{CEPT}) is

VCEPT = $A_{CEPT} * d_{CEPT}$ = 432.5 m^2 * 3.5 m = 1513.75 m^3 = 1,550 m^3

b) Dimension required of the CEPT tank

Assuming width = 5 m. Thus, the total required length of the CEPT tank is

Length (l) = $\frac{VCEPT}{dCEPT*5m} = \frac{1513.75\ m3}{3.5\ m*5\ m}$ = 86.5 m = 87 m which is also in a design range as mentioned above.

Checking detention time: Detention time (T) = $\frac{VCEPT}{Q} = \frac{1{,}513.75\ m3}{1{,}7300\ m3/d}$ = 2.1 hr, which is in the design range of 2 – 2.5 hr (http://nptel.ac.in/courses/105104102/22)

c) Estimation of sludge production in CEPT

Influent Total Suspended Solids (TSS_{in}) of Guheshwori WWTP = 216 mg/l (ADB, 2013)

From Table 4.1, assuming, TSS removed by CEPT alone = 85 %

Concentration of TSS removed = 0.85 * TSS_{in} = 0.85 * 216 mg/l =183.6 mg/l

Mass of TSS removed = Concentration of TSS removed * Q = 183.6 mg/l * 17,300 m^3/d = 3,176.28 kg/d = 3,200 kg/d

d) Estimation of sludge production in Conventional primary treatment process

From Table 4.1, TSS removed = 55 %

Concentration of TSS removed = 0.55 * TSS_{in} = 0.55 * 216 mg/l =118.8 mg/l = 118 mg/l

Mass of TSS removed = Concentration of TSS removed * Q = 118 mg/l * 17,300 m^3/d = 2,041.4 kg/d = 2,100 kg/d

The mass of sludge produced from CEPT and conventional primary treatment are 3,200 kg/d and 2,100 kg/d respectively. This shows CEPT increases the primary sludge production compared to conventional primary treatment. Thus, the additional sludge production needs to be considered in the capacity of existing or new sludge treatment units.

4.2 Advanced Integrated Pond System (AIPS)

Another alternative wastewater treatment system is the advanced integrated pond system (AIPS) containing an anaerobic pit underneath an oxygenated, aerobic bioreactor.

The capital and O & M costs for AIPS plant is about 37% of the costs of conventional treatment plant (EERE, 1993). Similarly, U.S. Environmental Protection Agency (2011) reported that AIPS technology are reliable treatment, much reduced need for sludge disposal, lower energy and land requirements, which result in considerable cost reduction for operation and maintenance and also adsorb toxic materials, and convert organic N into N_2.

The AIP systems are the reuse of treated wastewater for irrigation, small amount of sludge they produce. Further, AIP plants are better than conventional plants at removing nutrients such as nitrogen and phosphorus that can damage aquatic ecosystems in which effluent may be discharged (EERE, 1993)

This wastewater technology is apt in state of common wastewater stream as well as extremely inconsistent flow rates and organic loading rates, particularly in cases of inadequate industrial pretreatment and in the existence of toxic materials and heavy metals (Swanson, 2002 cited in Jha & Bajracharya, 2014).

In this system, wastewater passes through an anaerobic pit towards the aerobic reactor, thereby settling heavy solids by gravity and by removing some organic materials due to formation of dense sludge blanket by settled heavy solids. Further, in an aerobic reactor, soluble organic materials in the wastewater are decomposed by bacteria and algae. The oxygen levels in the aerobic reactor are controlled with horizontal surface aerators as well as natural aeration and algal photosynthesis. If the pits are very deep, the solids are fully decomposed. A benefit of such a design is that no sludge needs to be removed or wasted (Green et al., 2003).

5. WWTP in Nepal: A Combined Waste Stabilization Ponds (WSPs) and Constructed Wetlands (CWs)

Taking into an account local conditions such as land, often available at reasonable opportunity cost, skilled labor is in short supply and climate & resources (economy and energy). A combined waste stabilization ponds (anaerobic and facultative ponds) and constructed wetlands system is also suggested for future wastewater treatment in the country. This combination, WSPs-CWs, have proven to be effective alternatives for treating wastewater, and the construction of low energy-consuming ecosystems that use natural processes, in contrast to complex high-maintenance treatment systems, will hopefully lead to more ecologically-sustainable wastewater treatment in the future (Kayombo et al., 2004).

5.1 Design Criteria and Process in WSPs

Anaerobic Ponds

Typically, anaerobic ponds are designed to have a depth of 2–5 m, with a retention time less than one day should not be used (Kayombo et al., 2004)., an optimum P^H less than 6.2, temperatures greater than 15°C (40% removal of BOD at 10°C, and more than 60% at 20°C and an organic loading rate of 3000kg/ha/day for a depth of 3 m (Kayombo et al., 2004). The anaerobic ponds exclude oxygen and encourage the growth of bacterial which break down the organic matter in the effluent, which release carbon dioxide and methane (Biogas). The sludge is taken to the bottom of the pond by the sedimentation process (Quiroga, 2011). This biogas produced can be captured and used for energy production (heat or electricity). These anaerobic ponds are then incorporated alongside facultative ponds.

Facultative Ponds

Facultative ponds (1-2 m deep) are of two types: Primary facultative ponds that receive raw wastewater, and secondary facultative ponds that receive particle-free wastewater (from anaerobic ponds, and primary facultative ponds). The process of oxidation of organic matter by aerobic bacteria is usually dominant in primary facultative ponds or secondary facultative ponds (Kayombo et al., 2004).

The processes in anaerobic and secondary facultative ponds occur simultaneously in primary facultative ponds. It is estimated that about 30% of the influent BOD leaves the primary facultative pond in the form of methane . A high proportion of the BOD that does not leave the pond as methane ends up in algae. This process requires more time, more land area. In the secondary facultative pond (and the upper layers of primary facultative ponds), sewage BOD is converted into "Algal BOD," and has implications for effluent quality requirements. About 70 – 90% of the BOD of the final effluent from a series of well-designed WSPs is related to the algae they contain (Kayombo et al., 2004).

5.2 Design Model and Criteria of Anaerobic pond

The anaerobic ponds are designed on the basis of volumetric loading (λv) **(**Kayombo et al. 2004; Quiroga, 2011), which is given by:

$$\lambda v = \frac{Si*Q}{Va} \quad (\frac{g}{m3.d}) \text{ ……………………1}$$

where, S_i is influent BOD (mg/l), Q is flow rate (m^3 /day), and V_a is anaerobic pond volume (m^3).

It is recommended that the loading should be between 100 – 400 g/m^3/day, in order to maintain anaerobic conditions (Meiring et al., 1998; cited in Kayombo et al. 2004). Once the organic load is selected, the volume of the pond is then determined with the Equation 1. The HRT is calculated, using Equation 2.

$HRT = \frac{Va}{Q}$ (d)…………………………..2

Table 5.1 Design value of permissible volumetric BOD loadings on, and percentage BOD removal in, anaerobic ponds at various temperatures (Mara and Pearson, 1986 and Mara et al. 1997, cited in Kayombo et al. 2004 and Quiroga, 2011)

Temperature (°C)	Volumetric loading (g/m³.day)	BOD removal (%)
< 10	100	40
10 - 20	20T – 100	2T+20
20-25	10T+100	2T+20
>25	350	70

For the physical design, it is recommended that the length-to-breadth of 2:1 to 3:1, and the effluent take off levels are 300 cm below the surface. This type of pond works extremely well in warm climates and can attain 60-80% of BOD removal (Quiroga, 2011)

5.3 Design Model and Criteria of Facultative pond

According to Mara (1997), cited in Sperling (2007, p. 20), the facultative ponds should be designed on the basis of surface loading rate (Ls) which is given by Equation 3.

Ls = 350 x $(1.1.07 – 0.002 \times T)^{(T-25)}$…………..3

The design for BOD removal on the basis of a relatively low surface loading (100 – 400 $kgBOD_5$/ha/d), in order to allow for the development of a healthy algal population, since the oxygen for BOD removal by the pond bacteria is generated primarily via algal photosynthesis (Kayombo et al., 2004). Also, the recommended surface loading rate should be limited to a maximum value of 350 $kgBOD_5$/ha/d for a design purpose (Sperling, 2007).

For facultative pond, the Effluent standard adopted by (D Mara, 1972, cited in Abdullahi et al., 2014) is 50 – 70 $mgBOD_5$/l.

5.4 Design Model and Criteria of Constructed Wetland

Constructed wetlands (CWs) are planned system designed and constructed to employ wetland vegetation to assist in treating wastewater in a more controlled environment than occurs in natural wetlands. CWs for wastewater treatment can be categorized as either Free Water Surface (FWS) or Subsurface Flow (SSF) systems. In FWS system, the flow of water is above the ground, and plants are rooted in the sediment layer at the base of water column whereas in SSF system, water flows through a porous media such as gravels or aggregates, in which the plants are rooted. FWS systems are very appropriate for polishing secondary and tertiary effluents, and for providing habitat (Kayombo et al., 2004).

A properly operating constructed wetland system should produce an effluent with less than 30 mgBOD_5/l , less than 25 mg/l total suspended solids and less than 10,000 cfu/100ml, fecal coliform bacteria (David et al., 2002 , cited in Farooqi et al., 2007).

Reed's method for the design of CWs

There are several design models based on first order plug flow kinetic models. One of the methods is Reed method to calculate the area of a free water surface CW (A_{cw}). The design Reed et al. (1995) equation is the following:

$$Acw = A = \frac{Q\ln\left(\frac{Ci}{Co}\right)}{(KT)ny} \text{ and } K_T = K_{20}\theta^{(Tw-20)}$$

where, Q the influent wastewater flow (m^3/d), Ci the influent pollutant concentration at wetland inlet (mg/l), Co the effluent pollutant concentration at wetland outlet (mg/l), y the water depth in wetland (m), n porosity (percent, expressed as decimal fraction), K_T the rate constant corresponding to water temperature in wetland (d^{-1}), K_{20} the rate constant at 20ºC reference temperature (d^{-1}), T_w the wetland temperature (ºC) and θ is the temperature coefficient for rate constant. The first-order kinetic constant values at 20ºC (K_{20}) and the temperature coefficient (θ) depends on the pollutant removal. For BOD removal K_{20} = 0.678 d^{-1} and θ = 1.06. Wetland temperature *T*w is a fundamental parameter for the designer because the removal of BOD and the various nitrogen forms are temperature dependent (Kayombo et al., 2004).

5.5 Design of a combined WSPs and CWs

As mentioned in sub-section: Design of a CEPT in section 4.1, the design influent flow rate of Guheshwori WWTP (the highest design capacity, 17.3 MLD) which is serving Kathmandu is taken. The data of influent flow rate and BOD_5 concentration is of 2001 and designed accordingly, a combined WSPs and CWs to solve the problems. The following design approach is same but, should be done depending on required data of near future.

A. Design Calculations

Influent flow rate (Q) = 17,300 m^3/d

Influent BOD_5 concentration of Guheshwori WWTP (S_i) = 270 mg BOD_5/l (ADB, 2013)

Mean air temperature in the coldest month of Kathmandu (T) = 10.8°C, over a year: 2016-2017 (http://mfd.gov.np/)

Total load (L) = S_i * Q = 270 mg BOD_5/l * 17,300 m^3/d = 4,671 kg BOD_5/d

(a) <u>Design of the anaerobic pond</u>

From Table 5.1, at 10.8°C, the anaerobic ponds designed using volumetric loading

(λv) = 20 (10.8^0) - 100 = 116 gBOD_5/m^3/d, which is the range of 100 – 400 g/m^3/day, as mentioned in Section 5.2.

(i) Required volume of anaerobic pond (Va) = $\frac{L}{\lambda v} = \frac{4{,}671\ kgBOD5/d}{116\ \frac{gBOD5}{m3.d}}$ = 40,268 m^3

$HRT = \frac{Va}{Q} = \frac{40{,}268\ m3}{17{,}300\ m3/d}$ = 2.33 d. A retention time less than one day should not be used; if it occurs, however, a retention time of one day should be used, and the volume of the pond should be recalculated (Kayombo et al., 2004). Here, 2.33 days is not less than 1 day. So, no recalculated of the volume is required.

(ii) Required area and dimensions

Assuming the depth of pond (d_a) = 4 m (Design depth: 2 – 5 m, which is mentioned in Section

5.1)

Area of anaerobic pond (A_a) = $\frac{Va}{da} = \frac{40{,}268\ m3}{4\ m}$ = 10,067 m^2 = 10,100 m^2

Using 3 anaerobic units

Area of each pond = $\frac{10{,}067\ m2}{3}$ = 3,355.67 m^2 = 3,400 m^2

Applying length to breadth ratio is 2:1 as mentioned in Section 5.2.

Dimension of each pond

If breadth =b, then length (l) = 2b.

Area = 2b * b = 3,355.67 m^2

b = 40.96 m = 41 m

l = 2b = 2* 40.96 m = 81.92 m = 82 m

(iii) Concentration of effluent BOD_5

From Table 5.1, at 10.8° C, the BOD_5 removal efficiency (E) is = 2T + 20 = 2 (10.8°) + 20 = 41.6 % and is given by:

$$E = \frac{Si-(BOD)eff,a}{Si} * 100\%$$

Where, $(BOD)_{eff,\,a}$ is the effluent BOD_5 concentration of anaerobic pond ($mgBOD_5/l$)

$(BOD)eff,a = (1 - \frac{E}{100}) * Si = (1 - \frac{41.6}{100})$ * 270 $mgBOD_5/l$ = 157.68 $mgBOD_5/l$

From the anaerobic pond, the energy generation potential can be estimated (World Bank Group, 2015). Of all wastewater characteristic parameters, Chemical Oxygen Demand (COD) is the most general parameter to estimate potential methane production (Lohani et al., 2013). It measures how much oxygen is required to oxidize all organic and inorganic matter found in water. However, BOD is always equal to the organic fraction of the COD (Lohani et al., 2013). The COD –to-BOD_5 ratio is typically 2:1 for raw domestic wastewater (Abdalla & Hammam, 2014). This ratio is taken for the estimation of energy generation potential.

We have, BOD_5 influent concentration (Si) = 270 mg BOD_5/l

∴ COD influent concentration (COD_{in}) = 2 * Si = 2 * 270 mg/l = 540 mg COD/l

Assuming COD removal % = 50 % (The COD removal % is in the range of 41 – 63 %, World Bank Group, 2015).

∴ COD removed = 50 % of COD_{in} = 0.5*540 mg/l = 270 mg COD/l

COD removed in kg COD/d = Q * COD removal = 17,300 m3/d * 270 mg/l = 4,671 kg COD/d

The COD removal in an anaerobic pond means an opportunity to tap biogas production during the process (Lohani et al., 2013). Biogas typically contains about 60–65 % methane, which is a valuable energy resource

(Zhang et al., 2017). 1 kg COD destroyed produces 0.35 m^3 methane gas at standard temperature and pressure (Zhang et al., 2017)

Assuming, 60 % of the sludge is converted to biogas based on 4,671 kg COD/d sludge production. Then, the total volume of methane produced is: $V_{methane}$ = 0.6 * 4,671kg COD/d * 0.35 m^3methane/kg COD = 980.91 m^3 methane/d = 980 m^3 methane/d.

A typical normal 1 m^3 of methane has a calorific value of around 10 kWh (SGC, 2012). So, the energy produced is = 980 m^3 methane/d * 10 kWh/m^3 methane = 9,800 kWh/d. This energy can be used for operating the treatment plant (pumps, mixers etc.)

(b) Design of the facultative pond

(i) Influent load to the facultative pond

The effluent load from the anaerobic pond is the influent load to the facultative pond. That is:

Load in facultative pond (L_f) = (BOD)eff,a * Q = (BOD)in,f * Q = 157.68 $mgBOD_5$/l * 17,300 m^3/d = 2,727.86 $kgBOD_5$/d

At 10.8°C, surface loading rate (Ls), that is Equation 3 becomes:

Ls = 350 x $(1.1.07 – 0.002 \text{ x } T)^{(T-25)}$ = 350 x $(1.107 – 0.002 \text{ x}10.8)^{(10.8-25)}$ = 109.31 $kgBOD_5$/ha/d, which is in design range (100 – 400 $kgBOD_5$/ha/d) as mentioned in Section 5.3.

(ii) Required area of facultative pond (A_f) = $\frac{Lf}{Ls} = \frac{2{,}727.86\ kgBOD5/d}{109.31\ \frac{kgBOD5}{ha}/d}$ = 24.9553 ha. =

249,553 m^2 = 250,000 m^2 = 25 ha.

Using 5 ponds

Area of each pond (A) = 249,553 m^2/5 = 49,910.6 m^2 = 50,000 m^2 = 5 ha.

(iii) Dimensions of each pond

Applying length to breadth is 2:1. If the breadth = b, then length (l) = 2b.

A = l * b = 2b * b = 49,910.6 m^2

b = 157.98 m = 160 m; l = 2b =2* 157.98 m = 315.96 m = 316 m

(iv) Required volume of pond (V_f)

Assuming depth of pond (d_f) = 1.5 m, which is in the range 1-2 m, as mentioned in Section 5.1.

$V_f = A_f * d_f = 249{,}553\ m^2 * 1.5\ m = 374{,}329.5\ m^3 = 375{,}000\ m^3$

Checking HRT: HRT = $\frac{Vf}{Q} = \frac{374{,}329.5\ m3}{17{,}300\ m3/d}$ = 21.64 d, which meets design criteria (A minimum retention time value of 5 days should be adopted for temperatures below 20^{o}C, and 4 days for temperature above 20^{o}C. This is to minimize hydraulic short-circuiting, and to give algae sufficient time to multiply (Kayombo et al., 2004)). The evaporation is excluded for the simplicity of design.

For facultative pond, the effluent BOD_5 standard adopted by (D Mara, 1972, cited in Abdullahi et al., 2014) is 50 – 70 mgBOD_5/l.

So, assuming (BOD)eff,f = 60 mgBOOD_5/l

The removal BOD_5 efficiency for facultative pond (E_f) is given by following Equation.

$$E = \frac{(BOD)in,f-(BOD)eff,f}{(BOD)in,f} * 100\% = \frac{(157.68-60)mgBOD5/l}{157.68\ mgBOD5/l} * 100\% = 61.94\ \%$$

(v) BOD_5 removal efficiency of anaerobic – facultative pond (E_{af})

$$E_{af} = E = \frac{Si-(BOD)eff,f}{Si} * 100\% = \frac{(270-60)mgBOD5/l}{270\ mgBOD5/l} * 100\% = 77.78\ \%$$

(c) Design of Constructed Wetlands (CWs)

(i) Influent load to CW

The effluent load from the facultative pond is the influent load to the constructed wetland. That is:

Load in constructed wetland (L_{Cw}) = (BOD)eff,f * Q = (BOD)in,CW * Q = 60 mgBOD_5/l * 17,300 m^3/d = 1,038 kgBOD_5/d

Since 'Q' is same. Thus, (BOD)in,CW = (BOD)eff,f = 60 mg/l = Ci

Assuming the effluent BOD_5 at CW (Co) = 20 mgBOD_5/l (because a properly operating constructed wetland system should produce an effluent with less than 30 mgBOD_5/l , less than 25 mg/l total suspended solids and less than 10,000 cfu/100ml, fecal coliform bacteria (David et al., 2002 , cited in Farooqi et al., 2007)).

(i) Design calculations of CW

The design Reed et al. (1995) equation is the following:

$Acw = A = \frac{Q\ln(\frac{Ci}{Co})}{(KT)ny}$ and $K_T = K_{20}\theta^{(Tw-20)}$

For BOD removal (For Free water surface CW): K_{20}= 0.678 d^{-1}; θ = 1.06 (Reed et al., 1995, cited in Kayombo et al., 2004)

According to Reed et al (1995), typically, y= 0.1 – 0.46 m; n= 0.65 – 0.75

Assuming, y = 0.3 m and n = 0.70; Tw = 10.8°C

K_T= $0.678(1.06)^{10.8 - 20}$ = 0.3966

Acw = A = $\frac{17{,}300 * \ln(60/20)}{0.3966 * 0.3 * 0.7}$ = 228,202 m^2 = 228,500 m^2 = 22.85 ha.

Checking BOD_5 loading rate of CW (Lvcw) = $\frac{Lcw}{Acw} = \frac{1{,}038\ kgBoD5/d}{228{,}202\ m2}$ = 45.49 $kgBOD_5$/ha/d., which is less than 100 $kgBOD_5$/ha/d (Reed et al., 1995).

Assuming length to breadth ratio is 3:1, which is in the design range 2:1 to 10:1.

If breadth = b, then length (l) = 3b.

A = l*b = 3b*b = 228,202 m^2

b= 275.81 m = 276 m; l = 3b = 3*275.81 m = 827.43 m = 828 m

The detention time is calculated as follows:

$t = \frac{n * y * A}{Q} = \frac{0.7*0.3\ m*228{,}202\ m2}{17{,}300\ m3/d}$ = 2.77 d

The hydraulic loading rate (HLR, cm/d) that provides a measure of the volumetric application of wastewater into the wetland, is calculated using the following expression:

HLR = $\frac{Q}{A} = \frac{17{,}300m3/d}{228{,}202\ m2}$ = 7.58 cm/d

6. Policies and Legislative Frameworks for Wastewater Management

6.1 The Constitution of Nepal

The Constitution of Nepal recognizes access to safe water and sanitation as a fundamental right (Ministry of Water Supply and Sanitation, 2016). In the context of water and sanitation, Province has necessary power on State level "water supply services", use of water and environmental management within the State is shown in Table 6.1.

T able 6.1 Provision of WASH services in the Constitution of Nepal

SN	Articles & Schedules	Provisions
1	Article 30 (1)	Every citizen shall have the right to live in a clean and healthy environment.
2	Article (30 (2)	Victim of environmental pollution or degradation shall be entitled the right to compensation from the polluter as provided in the law.
3	Article 35 (4)	Every citizen shall have the right to access to basic clean drinking water and sanitation services.
4	Article 56 (2)	The exercise of Nepal"s State power shall be used by Federations, States and Local units as mentioned in the Constitution.
5	***Schedule 5: List of Federal Power***	
5.1	No. 11	Policies relating to conservation and multiple uses of water resources
5,2	No. 14	Central level large electricity, irrigation and other projects
5,3	No. 35	Any matter not enumerated in the Lists of Federal Powers, State Powers and Local Level Powers or in the Concurrent List and any matter not specified in this Constitution and in the Federal laws
6	***Schedule 6: List of State Power***	
6.1	No. 7	State level electricity, irrigation and water supply service, Navigation
6.2	No. 19	Use of forests and waters and management of environment within the State
7	***Schedule 7: List of Concurrent Powers of Federation and State***	
7.1	No. 18	Tourism, water supply and sanitation
8	***Schedule 8: List of Local Level Power***	
8.1	No. 7	Local level development plans and projects
8.2	No. 9	Basic health and sanitation
8.3	No. 19	Water supply, small hydropower projects, alternative energy
9	***Schedule 9: List of Concurrent Powers of Federation, State and Local Level***	
9.1	No. 5	Services such as electricity, water supply, irrigation
9.2	No. 14	Royalty from natural resources

Source: Constitution of Nepal, 2015, cited in Uprety, 2017

6.2 Draft Policy of Waste Water Management, 2006 A.D.

The Government of Nepal is currently drafting a policy on Waste Water Management that will provide guidelines for project preparation, planning, [survey, investigation, design, construction, operation and maintenance, financing, partnership, community mobilization], repair and maintenance, and delineation of role and responsibilities of various stakeholders. The proposed primary objectives of the Policy are:

a) Improving Sanitary conditions of the environment [water courses] by compliance to standards established by a competent agency,

b) Reducing morbidity and mortality rate related to wastewater system,

c) Facilitating construction and management of [separate] storm and sanitary sewerage systems,

d) Improving sanitary condition of local streams, rivers, lakes and ponds, [and other water sources as springs, spouts, water supply lines, reservoirs] to safe reusable conditions as established by a competent authority,

e) Establishing coordination and integrated approach among the stakeholders for planning, construction, operation, maintenance, and management of sewerage system,

f) Establishing relation [partnership] with the Government and Private Institutions [Sector] for research and development of appropriate technologies for wastewater disposal and management, and [financing],

g) Developing mechanism for building awareness among the stakeholders and beneficiaries (Nyachhyon, 2006; Shukla et al., 2012)

6.3 National Urban Development Strategy, 2017 A.D.

This Strategy addresses matters related to systems, infrastructure, environment and economic issues and calls for an integrated approach to manage sewers and sanitation facilities. It outlines 5 to 15 years milestones for improved infrastructure, healthy environments, efficient management, and vibrant economies. This Strategy identifies key issues and proposed several strategies related to water security, safety, sanitation, solid waste collection, reduce, reuse and recycle along with resource generation and mobilization to address water supply and sanitation challenges in urban areas (Ministry of Urban Development, 2017) .

6.4 National Urban Water Supply and Sanitation Policy, 2014 A.D.

This policy adopted a goal of ensuring socio-economic development, improving health status and quality of life of urban population. The Policy targets the poor and marginalized for sustainable water supply and sanitation services and protection of the environment (Uprety, 2017)

Shukla, Timilsina, and Jha (2012) observed that in the country, the related issues of wastewater management are dealt under the purview of sectoral policies and strategies relating to water supply and sanitation due to the absence of separate policy for wastewater management. They stated the two documents that reflect upon the national commitment to the improvement of water supply and sanitation are:

i. Rural Water Supply and Sanitation National Policy 2004 and Rural Water Supply and Sanitation National Strategy 2004 : The principal objectives of this policy were to set a new set of targets : (a) To provide safe, accessible and adequate water supply with sanitation facility to all Nepalese people on priority basis especially targeted to the backward people and ethnic groups, (b) To reduce water borne diseases and its victims in the nation, and (c) To save the time and labour of women, men and children saved from fetching the water (Ministry of Urban Development, 2014)

ii. Urban Water Supply and Sanitation Policy (2009): It envisions improvement in the water service delivery in the urban areas, including improvement in the wastewater systems and services, promotion of public private partnership in the development of infrastructure and services and enforcement of national guidelines for safe disposal and use of wastewater (Shukla et al., 2012)

The legislations and regulatory provisions encompassing the issues relating to wastewater management and safeguarding of water bodies, related directly or indirectly to water environment are mentioned below with key element (Bhandari, 2014; Shukla et al., 2014; Shrestha et al., 2015)

6.5 Environment Protection Act (1997 A.D.): This Act aims to protect the environment with proper use and management of natural resources, taking into consideration that sustainable development could be achieved from the inseparable inter-relationship between the economic development and environment protection. It also makes legal provisions in order to maintain clean and healthy environment by minimizing, as far as possible, adverse impacts likely to be caused from environmental degradation on human beings, wildlife, plants, nature and physical objects (https://theredddesk.org/countries/laws/environment-protection-act-nepal)

6.6 Local Self-Governance Act (1999 A.D.): This Act legislated for the decentralisation and democratisation of governance within the country including the enhancement of the participation of all people and the institutional development of local bodies to bear the responsibility for carrying out plans at the local level. The local bodies in the context of this act have been considered to mean Village Development Committees (VDCs) which play a significant role in project implementation and monitoring at the local level (https://theredddesk.org/countries/laws/local-self-governance-act-nepal)

6.7 Industrial Enterprises Act (1993 A.D.): This Act has a scheme to provide license to industries producing energy by water resources as well as to other industries. This act provides that prior approval has to be acquired to establish, extend or diversify any industries that create considerable adverse impact on safety, public health and environment (http://www.wepa-db.net/policies/law/nepal/list.htm)

6.8 National Wetland Policy Act (2003 A.D.): This Act sets legal provisions for the conservation and management of wetlands resources wisely and in a sustainable way with local people s participation. This acts also put the conservation and management aspects of wetlands conservation within the framework of broader environmental management (http://www.wepa-db.net/policies/law/nepal/list.htm)

6.9 Solid Waste Management and Resources Mobilization Act (1988 A.D.): The act sets out provisions for the collection, transportation and disposal of solid wastes in the manner that it does not cause environmental damage in the area designated for the disposal of the solid wastes (http://www.wepa-db.net/policies/law/nepal/list.htm)

6.10 Water Resource Act (1992 A.D.): The Act prohibits the activities that may cause pollution of the water bodies and governs water resources management. The act sets the priority of water use based on the utilization that ranks drinking water and domestic uses in the highest priority followed by irrigation, agriculture use such as animal husbandry & fisheries, hydroelectricity, cottage industry, industrial enterprises and mining, navigation and recreational uses. The act also provides for the formation of water user associations and establishes a system of licensing (Water Aid-Nepal, 2005; http://mowss.gov.np/assets/uploads/files/water_laws_in_nepal_english__february_2005-Water_Aid.pdf)

6.11 Pesticide Act (1992 A.D.): Pesticides act lays out legal provisions with regards to use of chemicals for the control of agricultural and domestic insects and pests. The act has also restricted use of certain types of chemicals considering their damaging effects to the environment. This act sets provisions with regards to import, export, production and consumption of pesticides for which clearance of the government has been made compulsory (Shukla et al., 2012)

6.12 The Aquatic Animal Protection Act, 2017(B.S.): This Act prohibits use of explosives and poisonous substances in any water bodies (Shrestha et al., 2015).

6.13 Kathmandu Valley Development Authority Act, 2045 (B.S): This Act empowers the authorities to regulate the environmental situation of the Valley in a more holistic manner (Shrestha et al., 2015)

6.14 National Sanitation Act (1994 A.D.): This Act is focused to safeguarding water sources and ensuring environmental sanitation for the protection of environment. This also deals with creating awareness and knowledge and awareness building on sanitation and hygiene practices among all section of population, focusing specifically on women and children and bringing attitudinal and behavioral changes within the community (Shukla et al., 2012)

7. Discussion of Chapter 3 and Chapter 6

The Chapter 3 shows that the current status of wastewater management in Nepal is poor, although, the Chapter 6 reveals that the commitment at the policy level and the existing legislations and regulatory provisions are adequate, in general, for protection of water sources and public health in the country. Now, it can be discussed that, from Table 3.3, it is observed that the centralized WWTPs were introduced in early 1980s with total capacity of 19 MLD in the support of Germany and the USA. After 1992, most of the Acts and policies were formulated, which are related directly or indirectly to wastewater management. This shows that the GoN took into consideration wastewater management, a crucial for protection water sources and public health. Then on the gaps of 4-5 years (after formulating Acts and policies), in 2001, the GoN established 17.3 MLD capacity plant which reflect the pace in development of WWTPs. After 2001 to till today (on 16-17 years gaps) no any WWTP is seen. The reasons behind it, could be ongoing political instability, constitutional debates, corruption allegations, natural disaster (Devastating 2015 Gorkha Earthquake and flood 2017 Nepal) and lack of money.

i. Ongoing political instability, constitutional debates and corruption allegations

Nepal's people had witnessed the transition, in 1990, from authoritarian Hindu kingdom to a constitutional monarchy; the massacre of members of the royal family in 2001 by the heir to the throne. In 1996, the Nepalese Civil War was launched by the Communist Party of Nepal (Maoist), with the aim of overthrowing the kingdom and establishing a 'People's Republic.' After a decade long, Civil War ended by signing peace agreement between the government and Maoist and on May 2008, Nepal becomes a republic. In the last 9 years, 16 times, government has been changed of which 9 governments period were less than 9 months. Small parties of the Tharu and Madhesi ethnic communities organized protested against the constitution, leading to widespread violence (more than 40 people died). Many politicians were maneuvering to get their hands on money from foreign aid, tourism and hydropower; even the Maoists have become crony capitalists, reaping large profits for themselves and their ostensibly proletarian party. (https://www.nytimes.com/2012/06/06/opinion/nepal-on-the-brink-of-collapse.html?_r=2&ref=opinion ; https://thediplomat.com/).

ii. Devastating 2015 Gorkha Earthquake and Flood 2017Nepal

A 2015 Gorkha Earthquake for almost 45 days, described in Section 3.4, which was experienced by me too, can say as a black day as it took the lives of thousands people, causing thousands injuries and huge loss in infrastructures. While the country was struggling from the hard time, after two year of the Earthquake, in

2017, the worst rains in 15 years struck Nepal, triggering widespread large-scale flooding and landslides (http://www.nrcs.org), which caused about USD 77 million in damage, primarily to rice paddy and vegetable crops (agriculture only represents about a third of the country's GDP), and damaged worth about USD 24 million in irrigation systems around the country (https://thediplomat.com/2017/08/floods-devastate-nepals-southern-plains/).

iii. Lack of money

As mentioned in Section 3.3.5, Nepal, one of the least developed countries in the world with low GDP per capita, mid HDI, a quarter of the population living below the national poverty and economy the 133rd freest in the 2018 Index (https://www.heritage.org/index/country/nepal). Moreover, as described in Section 3.4 about the Melamchi Water Supply Project (MWSP) which was estimated to the cost USD 464 million in 2000 prices. ADB shouldered the largest financing share (USD120 million). The GoN shares USD118 million which is in loan from ADB. (https://www.adb.org/sites/default/files/project-document/225741/31624-023-esmr-02.pdf).

It can be summarized that the, from the last two decades, the country is suffering from political instability which led to ineffective government institutions. This may cause lack in wastewater management. In addition, the damaged caused by natural disaster (Earthquake and Flood) drop the country's economic and also huge money have been spent on rehabilitation or may require more which reveals no any WWTP in these last 2.5 – 3 years.

It can also be discussed that the Nepal, the poor country, without financial support of others cannot afford the WWTP in the recent few years as the country has to return loan with other condition (may be interest) to ADB within some time frame which was asked for MWSP. Further, most of donor countries and Loan agencies may be scared of providing fund/loan to Nepal because of political instability and corruption allegations.

8. Institutional Arrangements for Wastewater Management

The WASH sector was placed under newly formed Ministry of Urban Development (responsible to formulate, implement, monitor, regulate and evaluate policy, plan and programme related to urban development, urban infrastructure, including physical planning, coordination, monitoring and evaluation of municipalities (GoN, 2015, cited in Uprety, 2017) Even then WASH sector was seen as matter of secondary primacy. There was demand for dedicated Ministry for Water and Sanitation and then, on 24th of December, 2015, the GoN has instituted the Ministry of Water Supply and Sanitation (MoWSS). (http://mowss.gov.np)

Ministry of Water Supply and Sanitation (MoWSS): MoWSS has the responsibility of formulating, implementing, monitoring, regulating and evaluating policy, plan and programme related to drinking water, sanitation and sewerage and to provide effective, sustainable and quality water supply and sanitation to the people throughout the country (GoN, 2015, citied in Uprety, 2017; http://mowss.gov.np)

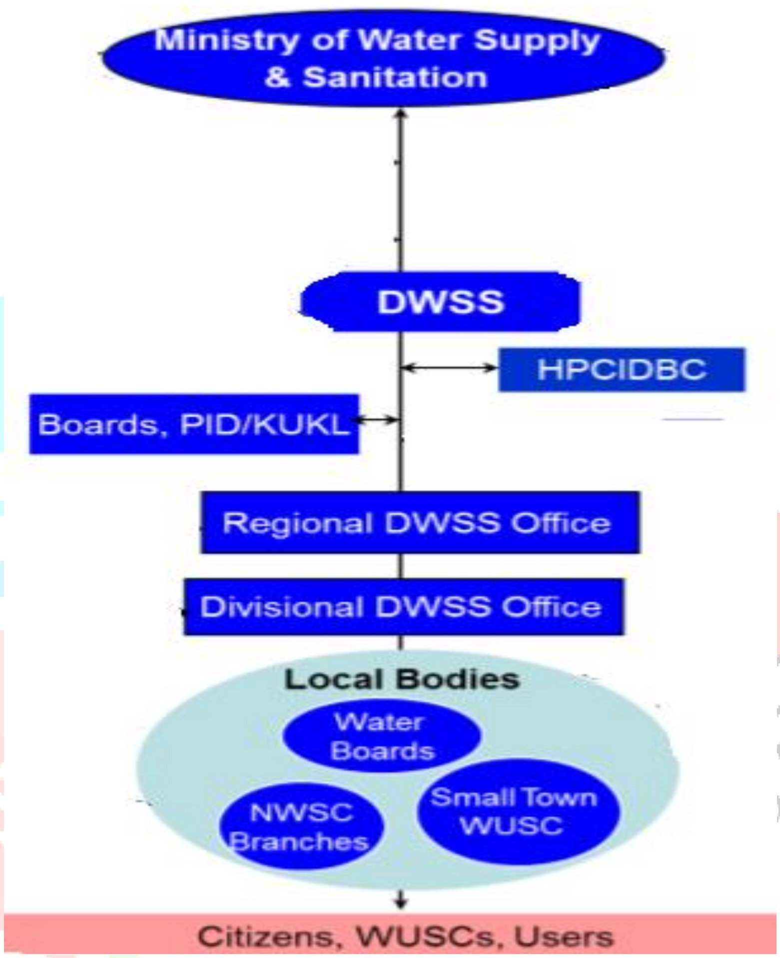

Figure 8.1 Present WASH Institutional Framework (Ministry of Water Supply and Sanitation, 2016)

Department of Water Supply and Sewerage (DWSS): Under MoWSS has a long-dedicated body, DWSS, established in 1972 which is responsible for planning and implementation, O&M of water supply and sanitation systems in the both rural and urban areas of Nepal. With offices at the center, 5 regions, and divisional/sub-divisional offices throughout 75 districts of the country (Ministry of Water Supply and Sanitation, 2016; Uprety, 2017; http://mowss.gov.np/content/department-of-water-supply-and-sewerage.html)

Apart from the above Department, under MoWSS, there are Boards, Nepal Water Supply Corporation (NWSC), Kathmandu Upatyaka khanepani Limited (KUKL), Project Implementation Directorate (PID) and

Water Tariff Fixation Commission as regulatory body for the urban water and sanitation services delivery (http://mowss.gov.np/content/institutions-under-mowss.html)

Nepal Water Supply Corporation (NWSC): NWSC is an autonomous corporation responsible for water supply and sewerage in the major urban centers outside the Kathmandu Valley (http://www.nwsc.gov.np/aboutus.php).

Kathmandu Upatyaka Khanepani Limited (KUKL): KUKL is a public company, operates under the Public Private Partnership (PPP) modality, is responsible for operation and management of water and wastewater services in the Valley (http://kathmanduwater.org/; Uprety, 2017)

Water Users and Sanitation Committee (WUSC): A kind of committee formed by the consumer themselves, is responsible to operate and manage most of the rural and semi-urban water schemes (Ministry of Water Supply and Sanitation, 2016).

9. Research on Wastewater Management

Shukla, Timilsina, and Jha (2014) observed that in the country, research and knowledge development and dissemination of pertinent knowledge on wastewater management are highly scattered and non-systematic. The research efforts are limited to small number of educational and research institutions and R&D organizations and the professionals engaged.

Conclusion

Approximately 93% of the total wastewater generated is domestic and remaining 7% is industrial wastewater in the five most urbanized areas of Nepal. In urban areas of the country, the theoretical estimate of the total domestic wastewater generation is 867 MLD where 70% is collected in on-site sanitation system and 30% is collected by sewers. About 7% of wastewater (i.e., 20.1 MLD) is treated out of which 86% (i.e., 17.3 MLD) is contributed by centralized wastewater treatment system and 14% (i.e., 2.8 MLD) by DEWATS. The total five centralized WWTPs are existing of which the first and only plant is activated sludge (design capacity of 17.3 MLD) which is located in Kathmandu, is partially functioning. The remaining plants of design capacity of 19 MLD are aerated lagoons and oxidation ponds (not in operation). Overall, the current status of wastewater treatment is poor in Nepal. The existing problems of wastewater treatment in Nepal can be solved using appropriate and viable technologies. A CEPT technology alone is the most relevant for the wastewater treatment in Kathmandu Valley. Since uncontrolled urbanization, industrial and commercial activities in Kathmandu lead to higher wastewater flow rate, such higher rate can normally handle by CEPT. Such urban areas may not have enough area available, so CEPT is more relevant. It is observed that Bagmati River in Kathmandu is highly polluted though, activated sludge WWTP is existing. So, CEPT is still more relevant for an effective step to control pollution. This is a bonus in Kathmandu as it has energy scarce. A combined WSPs – CWs and a combined CEPT -WSPs or CWs technologies are the most promising for future wastewater treatment in Nepal where the land often available, skilled labor in short supply and funds become available. Moreover, WSPs and CWs depend strongly on temperature so hot climatic condition need to be taken in consideration while designing in the needed region of the country.

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