TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Department of Civil Engineering and Architecture

STUDY OF WASTEWATER TREATMENT SYSTEMS IMPLEMENTED IN TALLINN (ESTONIA), LISBON (PORTUGAL) AND KATHMANDU (NEPAL) AND INFERENCE OF THE ENHANCEMENT MEASURES FOR EXISTENT TREATMENT TECHNOLOGIES

TALLINNAS (EESTI), LISSABONIS (PORTUGAL) JA KATMANDUS (NEPAL) RAKENDATUD REOVEEPUHASTUSSÜSTEEMIDE UURING JA OLEMASOLEVATE PUHASTUSTEHNOLOOGIATE TÄIUSTAMISMEETMED

MASTER THESIS

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Tallinn 2020

(*On the reverse side of the title page*)

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THESIS TASK

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Thesis topic:

(in English) *Study of Wastewater Treatment Systems implemented in Tallinn (Estonia), Lisbon (Portugal) and Kathmandu (Nepal) and inference of the enhancement measures for existent treatment technologies*

(in Estonian) *Tallinnas (Eesti), Lissabonis (Portugal) ja Katmandus (Nepal) rakendatud reoveepuhastussüsteemide uuring ja olemasolevate puhastustehnoloogiate täiustamismeetmed*

Thesis main objectives:

1. To study the details of the existence of wastewater treatment technologies in all three cities.
2. To compare the influents/effluents and efficiency of pollutants treatment from WWTP in all three cities.
3. To find out the strategies or future plans and projects implementation for all three cities.

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AF	ACTIFLO^{TM}
AdP	Águas de Portugal
ASP	Activated Sludge Process
BOD	Biochemical Oxygen Demand
BRB	Bagmati River Basin
°C	Degree Celsius
COD	Chemical Oxygen Demand
CW	Constructed Wetland
DEWATS	Decentralized Wastewater Treatment System
ha.	Hectare
HELCOM	Helsinki Commission
in/km^2	Inhabitants per square kilometre
MASL	Meters above sea level
MF	MULTIFLO^{TM}
mg/L	milligram Per Liter
MLD	Million Liters per Day
p.e.	person equivalents
SBR	Sequencing Batch Reactor
SDB	Sludge Drying Bed
TSS	Total Suspended Solids
UV	Ultraviolet
WWTP	Wastewater Treatment Plant

1 INTRODUCTION

1.1 Background

Wastewater Management has become one of the cardinal scrutiny in modern days for both developing as well as a developed country. Wastewater is generally termed as the used water by the humans usually generated from a domestic and industrial source. The wastewater is regarded as the nugatory water which requires the proper management for the sustainability of the environment [1]. Thus, wastewater management is one of the delicate subjects to be studied for the current scenario and for time to come.

The eventual aim of wastewater management is to protect the environment and improvement in sanitation and socio-economic concerns. The main intention of the Wastewater treatment process is to remove the various constituents of the polluting load: solid particles, organic carbon, inorganic salts, metals, pathogens, etc. and get the quality of water which complies with the guidelines and the legislative regulations [2]. Nowadays, with the increase in urbanization and industrial development accompanying the population growth, the problem of wastewater management has become apparent and scientists and researchers are working continuously for the development of more efficient, more effective and more advanced wastewater treatment technology. Consequently, wastewater treatment technology is growing everyday being more efficient than conventional WWTP.

The three different countries Estonia located in northern Europe, Portugal located in southwestern Europe and Nepal located in South-East Asia have different climate and geographical features and different economic statuses. The country capital Tallinn, Lisbon and Kathmandu are picked respectively for the study, which is the most populated city in the country. Scrutinize the wastewater treatment in these three different cities gives us an idea about how the cities with different geography and infrastructure would have impacts in wastewater treatment. Besides, wastewater treatment systems in developing countries and developed countries with different economic statuses can be concluded as well. Overall, the study helps to acquaint the knowledge of wastewater treatment technologies along with the features of WWTP in three different cities.

1.1.1 General introduction of Tallinn, Estonia

Tallinn is the capital and largest city in Estonia with an area of 159.37 km^2 and lies at the altitude ranges from 9 to 64MASL. The population of the city in 2019 was 438,874 with a settlement density of 2754 in/km^2 [3]. According to weather-atlas, the average lowest temperature in Tallinn ranges from -7°C in winter and the average highest of 21.2°C in summer. Throughout the year, in Tallinn, 617 mm of precipitation is accumulated. Tallinn is located in the north-west of Estonia covering 48 km of Tallinn by Baltic Sea [3]. The city has two major lakes Lake Ülemiste and Lake Harku. No major rivers are flowing through the city but there is one significant river, Pirita River which lies in the Pirita, outlying district of Tallinn.

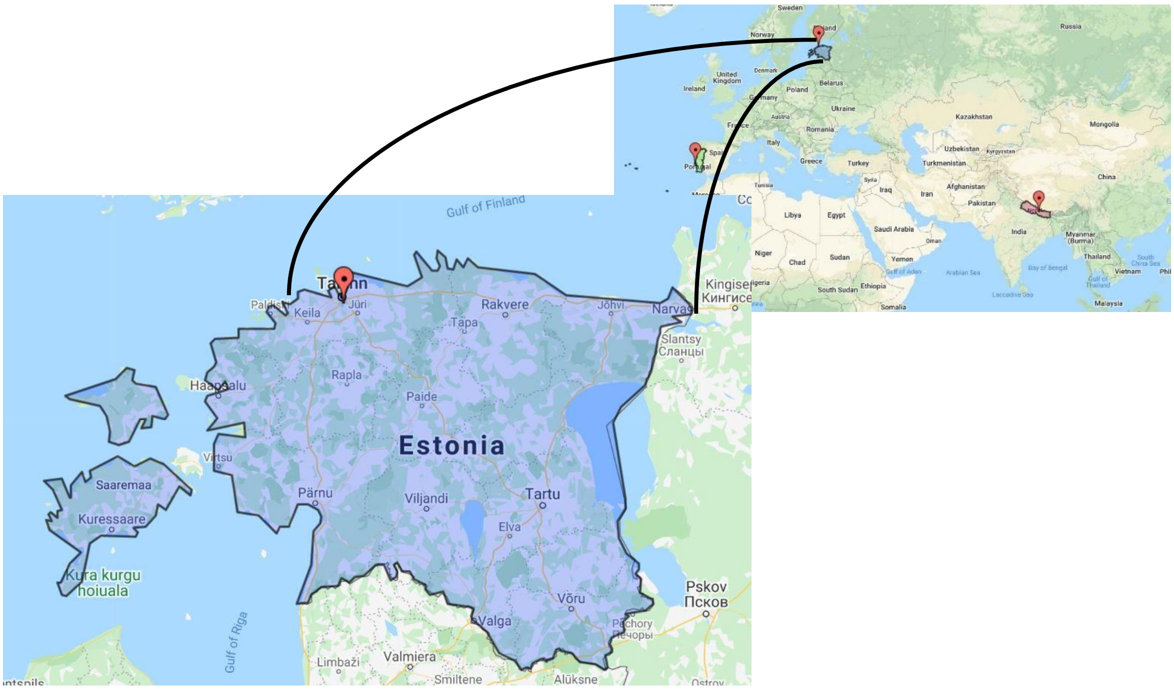

Figure 1.1: Location Map of Tallinn, Estonia

Tallinn city has the one centralized WWTP, Paljassaare Wastewater Treatment Plant, which treats the wastewater collected in Tallinn city and its nearby adjoining areas. WWTP has the combined sewerage network where the wastewater and stormwater are connected in the same sewage. It is estimated that the Paljassaare wastewater treatment plant provides the service for more than 400.000 people residing in Tallinn city and its nearby areas and including stormwater coming from the same sewer [4].

1.1.2 General introduction of Lisbon, Portugal.

Lisbon is the capital city of Portugal with an area of 100.05km^2 and home to 545,245 inhabitants [5]. Lisbon has a subtropical-Mediterranean climate and as per world-atlas, the average temperature ranges from lowest 8.3°C in winter to average highest 28.3°C in summer. Precipitation in Lisbon is accumulated to 774 mm during the year. The longest river in the Iberian Peninsula, Tagus River surrounds the south and east of part of the city [5]. Tagus River meets with the Atlantic Ocean after passing through the city.

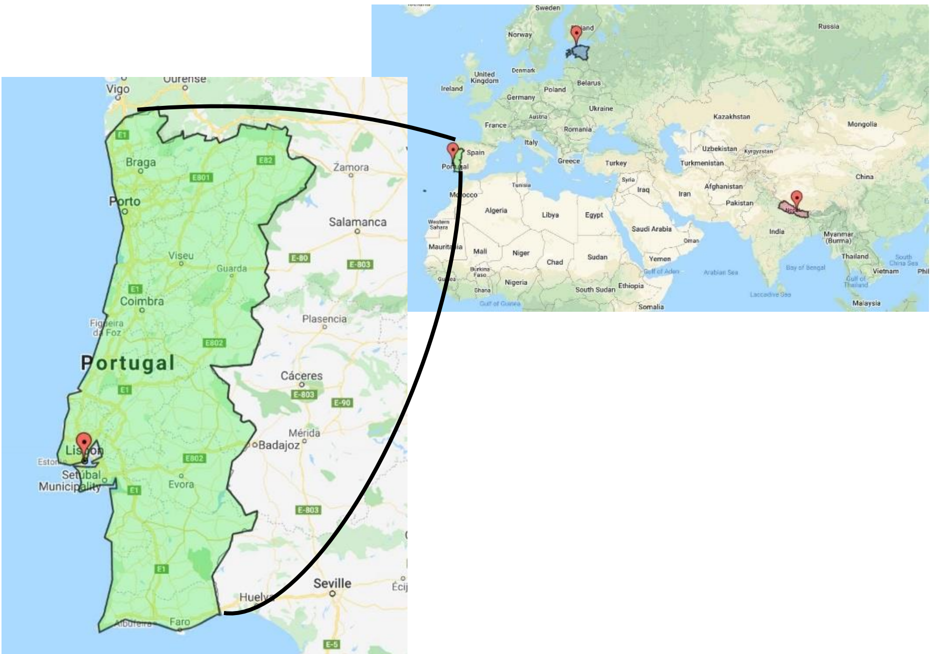

Figure 1.2: Location Map of Lisbon, Portugal

Lisbon city started to treat the domestic wastewater since the 1980s with the establishment of Alcântara WWTP which serves for 760,000 inhabitants-equivalent from Lisbon, Amadora and Oeiras Municipalities. The effluent is discharged to Tagus estuary. Alcântara WWTP is covered by a roof garden and improved to advanced technologies [6].

1.1.3 General introduction of Kathmandu, Nepal

Kathmandu is the capital city of Nepal located in the central part of Nepal at an average altitude of 1350MASL [7]. The area of Kathmandu city is 51 km^2 [8] and around 1.7 million population lives there [9]. Kathmandu city lies in the temperate zone and the temperature ranges from the highest 35°C in summer and the lowest 1°C in winter. The annual precipitation is 1407mm [8]. Many rivers flow through the Kathmandu of which Bagmati River is the main river which is also regarded as the holy river in Nepal. Other prevailing rivers lies in Kathmandu are Bishnumati River, Manohara River, Hanumante River, Tukucha River and Dhobi River.

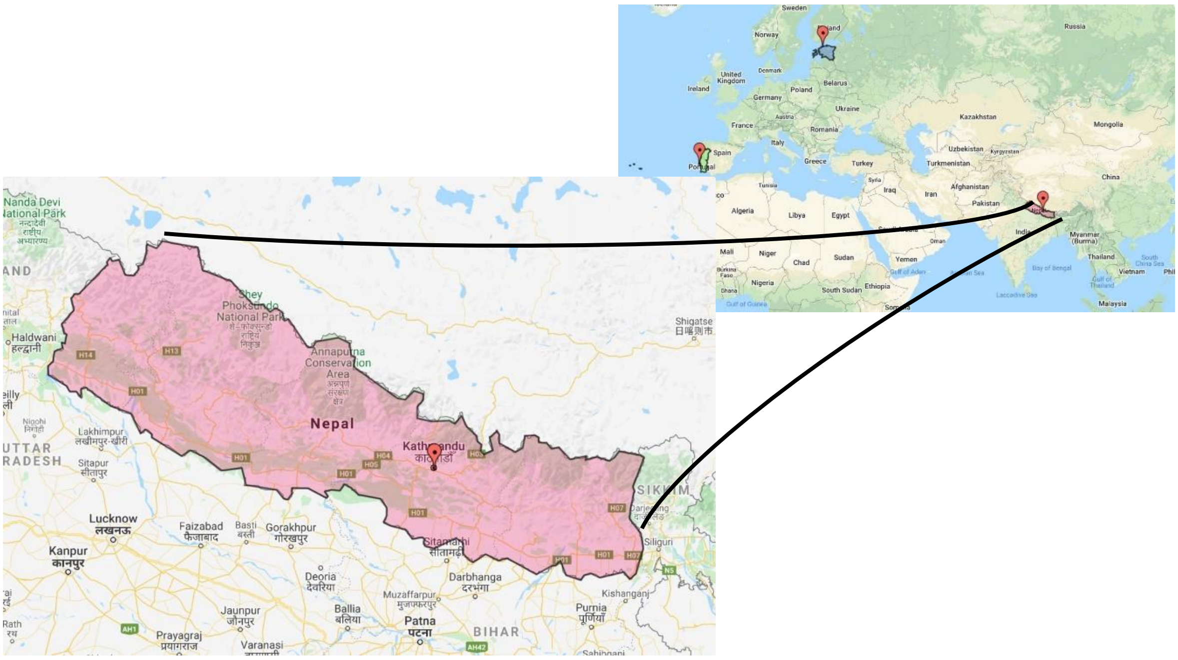

Figure 1.3: Location map of Kathmandu, Nepal

The service for the wastewater treatment in Kathmandu is essentially deficient to address the issues. During the 1980s, Kathmandu has constructed four centralized municipal wastewater treatment plants, two aerated lagoons at Sallaghari and Hanumanghat and two non-aerated lagoons at Kodku and Dhobighat, which are not in operational condition. In 2001, one an activated sludge treatment plant at Guheshwori was established, which is the only operating centralized treatment plant [9,10]. Besides centralized WWTP, 60 decentralized wastewater treatment systems (DEWATS) were constructed out of which 22 are in operational conditions [10]. The failure of the other WWTP is considered to be an insufficiency of expertise and management system [9]. Though considering the volume of wastewater production, the volume of treatment is not satisfactory for the Kathmandu region.

1.2 Objectives

- To figure out the policy, legislation, and regulations related to wastewater management for three different countries.
- To study the details of the existence of wastewater treatment technologies in all three cities.

- To compare the influents/effluents and efficiency of pollutants treatment from WWTP in all three cities.
- To find out the strategies or future plans and projects implementation for all three cities.

1.3 The rationale of the Study

With the escalation of population growth, urbanization and industrialisation, many countries are facing a catastrophe for water quality. Inadequate wastewater management or the discharge of untreated wastewater to the environment has emanated problems for human health and the environment. Around 90% of all wastewater in developing countries is discharged to water bodies without any treatment, which is inadmissible [1]. Estonia and Portugal are the two developed countries in Europe with better practice in wastewater management and Nepal, being a developing country, do not have an adequate wastewater management system. The capital city with the most densely populated city in a country represents the prominence in the wastewater management system in the country.

Tallinn is successful to treat all the wastewater generated in the city and the continual improvement and rehabilitation of WWTP ensure the excellence of sewerage treatment system. Lisbon, on the other hand, rewarded as a green capital 2020, has a paradigm of green and environmentally friendly wastewater treatment plant with advance technology to treat the sewerage in Lisbon. Kathmandu, a chaos capital city, doesn’t have proper waste and wastewater management system. The foul rivers flowing through Kathmandu epitomize the inadequacy of the wastewater treatment system in Kathmandu. The study of wastewater treatment system from these three cities gives us the general idea of the wastewater treatment system and their working mechanism in urban areas along with the limitations and enhancement measures for convenient wastewater treatment.

2 LITERATURE REVIEW

The literature review for this thesis study is outlined in the various aspects, starting from the characteristics of municipal wastewater, following by different wastewater treatment technologies (preliminary, primary, secondary and tertiary treatment). The study also presents the scenario of Municipal Wastewater Treatment in Tallinn, Lisbon and Kathmandu and also discuss the legislation and policy implemented in three different countries.

2.1 Wastewater Characteristics

2.1.1 Municipal Sewerage system

The collection, treatment and disposal of Wastewater sewerage are accomplished by the subsequent main alternatives:

- Off-site sewerage
    - Separate sewerage system (transporting only wastewater)
    - Combined sewerage system (transporting wastewater and stormwater)
- On-site sewerage

The separate sewerage system is adopted by several countries where the wastewater separates from stormwater, each being transported by separate pipeline systems. In most of the cases, in separate sewers, stormwater is directly transported to water bodies and doesn't impart to the WWTP. In some countries, a combined sewerage system is adopted, that directs wastewater and stormwater along into identical systems and treated in the same WWTP. Some countries, mostly developing countries, exist a significant number of on-site sewerage systems such as latrines and septic tanks [10]. The on-site system mostly benefits the place with a low density of population or some rural areas.

2.1.2 Municipal Wastewater Quality Parameters

- ***Biochemical Oxygen Demand (BOD):*** BOD is the measure of dissolved oxygen required to break down the organic material by using aerobic microorganisms in a given water sample at 20°C for a specific period [11]. The standard BOD is measured in 5 days (BOD_5), but some places BOD are measured in 1 day (BOD_1) and 7 days (BOD_7) [12]. BOD is usually expressed in mg/l.

- ***Chemical Oxygen Demand (COD):*** COD is the measure of oxygen required to chemically stabilise the organic or inorganic matter in water sample using a strong chemical oxidizing agent like Potassium Dichromate ($K_2Cr_2O_7$) or Potassium Permanganate ($KMnO_4$) [10,13]. COD also measures the amount of organic matter in a sample by using the chemical oxidant [14]. COD of wastewater can be measured in less time (less than 3 hours) in a laboratory.

- ***Total suspended solids (TSS):*** TSS is the total organic and inorganic solids which are not filterable [10]. Suspended solids are suspended in water and normally contain 70% of organic and 30% of inorganic solids which can be eliminated by a physical or mechanical process [15].

- ***Nitrogen:*** Nitrogen is a crucial nutrient for microorganisms growth in biological wastewater treatment. Total Nitrogen includes a different form of Nitrogen compounds like Ammonium (NH_4^+), Nitrites (NO_2^-) and Nitrates (NO_3^-) [10]. Nitrification and denitrification process occurs in the WWTPs which transform the various form of Nitrogen compounds to Nitrogen gas [16].

- ***Phosphorus:*** Phosphorus in wastewater is mainly due to the anthropogenic activity [17]. The main source of Phosphorus is agricultural run-off and domestic detergents [18]. Phosphates are found in several forms in wastewater such as orthophosphates, condensed phosphates (pyro-, poly-, meta-) and organic phosphorus and mostly orthophosphate (PO_4) are found in wastewater [18]. Nutrients like nitrogen and phosphorus cause Eutrophication in water bodies, so, these nutrients should be removed before release to the water bodies.

2.2 Wastewater Treatment Technologies

Wastewater Treatment is typically employed into various levels of treatment such as Preliminary, Primary, Secondary and Advanced Treatment [19].

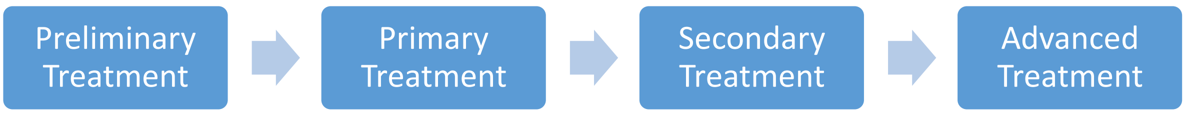

Figure 2.1 Wastewater Treatment Process

2.2.1 Preliminary Treatment

Preliminary Treatment is the process of removal of larger particles or insoluble particles before the biological or chemical treatment. Preliminary treatment includes the removal of coarse suspended solids particles, grit, oils and grease and also maintain the incoming flow which impedes the biological process and restrain the damage in equipment [19]. Preliminary Treatment mainly includes following processes;

- Screening (Removal of large particles)
- Grit Removal (Removal of grit)
- Floatation/Scum Removal (Removal of fats, oils, grease and other floating materials)
- Equalization (Stabilization of flow and balance organic content and nutrient)

2.2.2 Primary treatment

Primary treatment is the process of further removal of suspended solid particles and organic matters [19]. Primary treatment is of mainly physical treatment and also called as primary clarification, sedimentation or settling [20]. Primary treatment facilitates in the removal of Suspended solids, BOD and floating materials before secondary treatment which enhances the biological and chemical reaction in secondary treatment. Primary treatment includes:

- Primary sedimentation (Separation of clarified liquid and insoluble solids particles)
- Imhoff tank (Clarification of wastewater by sedimentation and digestion of the settled sludge)
- Dissolved Air floatation (Air bubbles are passed from the bottom and cohere the sediments and suspended matters are removed by floatation)

2.2.3 Secondary Treatment

Secondary Treatment is the process of removal of organic matter which is present in the form of both dissolved and suspended organic matter by using biological treatment process [10]. In secondary treatment, organic matters are biologically degraded into unpolluted products like water, Carbon dioxide and biomass. Biological wastewater treatment is generally categorized into the following groups [20];

- Suspended Growth processes (Activated-sludge and aerated lagoons)
- Attached-growth processes or fixed-film processes (Trickling filters, Rotating biological contactors, Bio-film reactors)

- Pond processes (Anaerobic, Facultative, Aerobic and maturation ponds which treats naturally)

2.2.4 Tertiary or Advanced treatment

Tertiary treatment or advanced treatment is the additional treatment process for the effluents coming from secondary treatment. This includes removing of residual constituents, removing of nutrients and heavy metals which are not eliminated in secondary treatment [19]. Advanced treatment undergoes filtration and disinfection process to remove the targeted contaminants, pathogens, heavy metals and additional nutrients which helps to fulfil the legislation to discharge in soil and water bodies. Tertiary treatment includes:

- Filtration and micro screening (Remove Total Suspended solids)
- Water softening (Removing of minerals)
- UV disinfection (Remove the harmful microorganisms for reuse of wastewater)
- Reverse Osmosis (Remove contaminates using semi-permeable membrane)
- Membrane technologies (Microfiltration and bioreactor used for disinfection)

2.3 Wastewater Treatment practice in Tallinn, Estonia

Wastewater Treatment System in Tallinn started in 1980 with the mechanical treatment and augmented to chemical and biological treatment unit in 1983 and 1991 respectively [21]. Paljassaare WWTP is the only centralized wastewater treatment plant for Tallinn. It is the combined sewerage treatment plant which treats physically, chemically and biologically and biofilter was added in 2011 [21]. AS Tallinna Vesi (Tallinn Water) is the largest water service company in Estonia which oversee the drinking water and wastewater treatment service in Tallinn and its surrounding areas [22].

2.3.1 Paljassaare WWTP

Paljassaare WWTP is located in the north-western part of the city near to the Baltic Sea. The treatment plant is an activated sludge system type and the process diagram is given in Figure 2.2 and the main components and process are described below [4,21,23]:

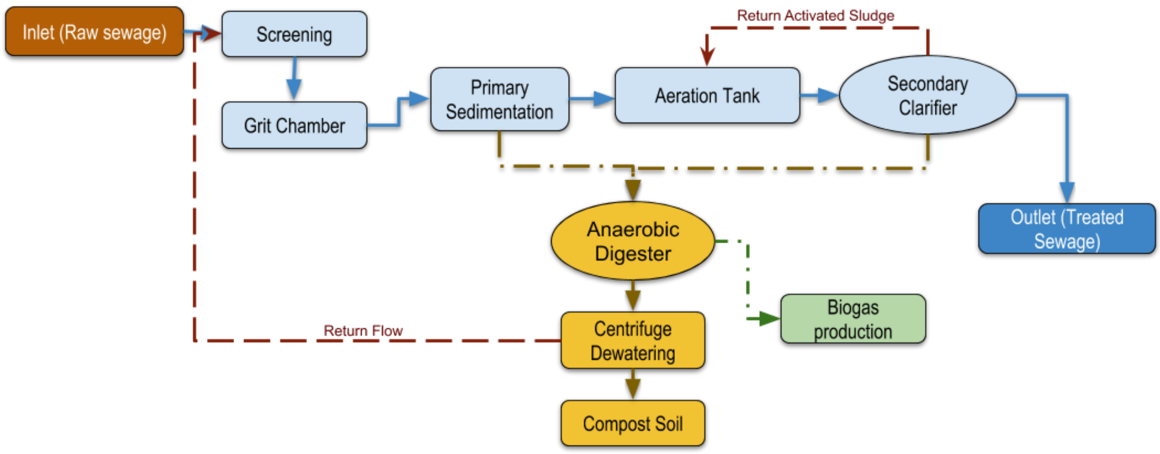

Figure 2.2: Schematic representation of the different process of Paljassaare WWTP

- ***Preliminary Treatment:*** Pre-treatment in the WWTP consist of screening for large particles are separated out and Grit removal to remove out grit particles like sand and gravel.

- ***Primary Sedimentation:*** Sedimentation for the settling of dense particles and the sludge from sedimentation is departed sludge treatment facilities. Additionally, $Fe_2(SO_4)_3$ is added to precipitate phosphorous.

- ***Aeration phase:*** There are six aeration tanks (10,500m^3 each). Air if passed to the tank and under aerobic condition, microorganism decomposes organic particles and also $Fe_2(SO_4)_3$ is added to reduce the remain Phosphorous.

- ***Secondary Sedimentation:*** The size of the basin is 5130m^3. The sludge which contains microorganisms, organic matters and phosphorus settles down the basin. Some part of sludge is returned to the aeration tank and excess sludge are transported to the sludge treatment facilities. The effluent from the secondary sedimentation is legit enough to discharge in the water bodies which is discharged to the Baltic Sea.

- ***Sludge treatment:*** The total quantity of waste sludge after treatment is around 72,000 tons. Some portion of waste sludge is treated by mud thickening and some sludge used to produce biogas by digestion. The excess water from sludge storage is pumped out to the screening phase.

2.3.2 Wastewater Legislation in Estonia

Water Act: Water Act was adopted on 30 January 2019 and put an entry into force from 01 October 2019. This act provides the planning and management of water for the sustainability of water use. This act covers all the requirements and responsibility for groundwater, surface water, wastewater treatment plant. Chapter 6 (Division 3) of this act defines the selection of wastewater location and the types of the wastewater treatment plant to be installed based on the physical and chemical properties of wastewater and Division 4 of this act defines the accountability of collection, treatment and transportation of Urban wastewater [25]. The territorial sea, coastal waters and internal water bodies of Estonia and the parts of transboundary water bodies belonging to Estonia are treated effluent sensitive recipients. [25].

Based on the Water Act, ***Regulation of the Minister of the Environment no 61 "Requirements for wastewater treatment and discharge, stormwaters, mining, quarrying and cooling water discharges into receiving water, compliance verification measures and conformity assessment activities and limit values for pollutants"*** was adopted and given in table 2.1.

Table 2.1: Limit values for pollutants to discharge for Estonia

Parameter	Agglomeration pollution load									
	<300 p.e.		300-1999 p.e.		2000-9999 p.e.		10000-99999 p.e.		100000 PE and >	
	LV, mg/l	R, %	LV, mg/l	R, %	LV, mg/l	R, %	LV, mg/l	R, %	LV, mg/l	R, %
BOD7	40	-	25	80	15	80	15	80	15	80
COD	150	-	125	75	125	75	125	75	125	75
TP	-	-	2	70	1	80	0.5	90	0.5	90
TN	-	-	60	30	45	30	15	80	10	80
SS	35	70	35	70	25	80	15	90	15	90

- ***Public Water Supply and Sewerage Act:*** This act was passed on 10 February 1999 and put an entry into force from 22 March 1999. This act directs and regulates the supply of drinking water and wastewater treatment and provides authorization and accountability of the local governments, state, water undertakings and clients. This acts also set the regulation and price for water and wastewater services. [24].

- ***Environmental Charge Act:*** This act was adopted on 07 December 2005 and put an entry into force on 01 January 2006. Environmental charges are established for the protection of the environment and the state's revenue collection for natural environment use. This act defines and determines the natural resource charge and pollution charge and their rates. Chapter 3 (Divison 1) of this act defines the pollution charge for the emission of pollutants into ambient air, water bodies, groundwater and disposal to soil and Chapter 3 (Division 2) defines pollution charge rates for the emission of pollutants into ambient air, water bodies groundwater and disposal to the soil [26].

- ***HELCOM Recommendation:*** HELCOM (Baltic Marine Environment Protection Commission – Helsinki Commission) is an intergovernmental organization (IGO) for the protection of the marine environment of the Baltic Sea area. HELCOM is also an environmental policymaker for the Baltic Sea area which preserve the Baltic Sea area environment by preventing and eliminating the discharge of pollutants to land and water bodies. HELCOM recognizes the limit value for the pollutants and harmful substance discharging directly or indirectly to the Baltic Sea [27]. HELCOM Recommendation gives the guidelines for the development of sewerage systems and treatment of municipal wastewaters discharging to the catchment of the Baltic Sea area. HELCOM Recommendation for discharging municipal wastewater to the catchment of the Baltic Sea is given in Table 2.2 [27].

Table 2.2: HELCOM Recommendation for discharging municipal wastewater to the catchment of the Baltic Sea

Parameter	300-2,000 p.e.		2,000-10,000 p.e.		10,000-100,000 p.e.		>100,000 p.e.	
	LV, mg/l	R, %	LV, mg/l	R, %	LV, mg/l	R, %	LV, mg/l	R, %
BOD5	25	80	15	80	15	80	15	80
TP	2	70	1	80	0.5	90	0.5	90
TN	35	30	-	30	15	70-80	15	80

- ***Urban Wastewater Treatment Directive (91 /271 /EEC):*** This council directive was adopted on 21 May 1991 concerned with the collection, treatment and discharge of urban wastewater along with the certain industrial sector. The main aim of this Directive is to protect the environment by proper management of wastewater discharges in urban areas. The directive gives the guidelines for collecting system, Discharging wastewater, Industrial wastewater and Reference methods for monitoring and evaluation of results. The requirement for the discharge from urban wastewater treatment plants content with Articles 4 and 5 of Directive is given in Table 2.3 [28].

Table 2.3: requirement for the discharge from urban wastewater treatment plants content with Articles 4 and 5 of the Directive

Parameters	Concentration	Minimum Reduction, % *
Biochemical oxygen demand (BOD_5 at 20°C) without nitrification **	25mg/l O_2	70-90 40 under Article 4 (2)
Chemical oxygen demand (COD)	125 mg/l O_2	75
Total suspended solids ***	35 mg/l *** 35 under Article 4 (2) (more than 10000PE) 60 under Article 4 (2) (2000-10000PE)	90*** 90 under Article 4 (2) (more than 10000PE) 70 under Article 4 (2) (2000-10000PE)
Total Phosphorus	2 mg/l P (10000-100000 PE) 1 mg/l P (more than 100000 PE)	80
Total Nitrogen	15 mg/l P (10000-100000 PE) 10 mg/l P (more than 100000 PE)	70-80

* Reduction concerning the influent load.

** The parameter can be replaced by another: Total organic carbon (TOC) or Total oxygen demand (TOD), if it is possible to establish a relationship between BOD_5 and the substitute parameter.

*** This requirement is optional

2.4 Wastewater Treatment practice in Lisbon, Portugal

In the mid-1980s, Lisbon Municipal Council set out upon the plan and development of wastewater treatment to preserve the River Tagus and its estuary. According to the AdP website, the Lisbon wastewater system is overseen by Águas do Tejo Atlântico which is a public limited company created by Decree-Law 34/2017. It is a company of the (AdP)Águas de Portugal Group. The company intends for consistent and effective collection, treatment and disposal of residential and urban effluents from around 2.4 million inhabitants covering Lisbon city and other different municipalities. Alcântara WWTP serves a populace of around 760,000 occupants living in Lisbon, Amadora and Oeiras municipalities. [6]. Alcântara WWTP is one of the oldest and largest wastewater treatment plants in Portugal which was established in the 1980s.

2.4.1 Alcântara WWTP

Alcântara WWTP is situated at the downstream zone of the Alcântara, which is located in the western part of Lisbon city. Primary Treatment, Advanced Primary Treatment and Secondary Treatment were established since 1989, 2003 and 2009 respectively [29]. Alcântara WWTP consists of preliminary, primary, secondary and tertiary treatment illustrated in Figure 2.3 and process used in the Alcântara WWTP are described below [30]:

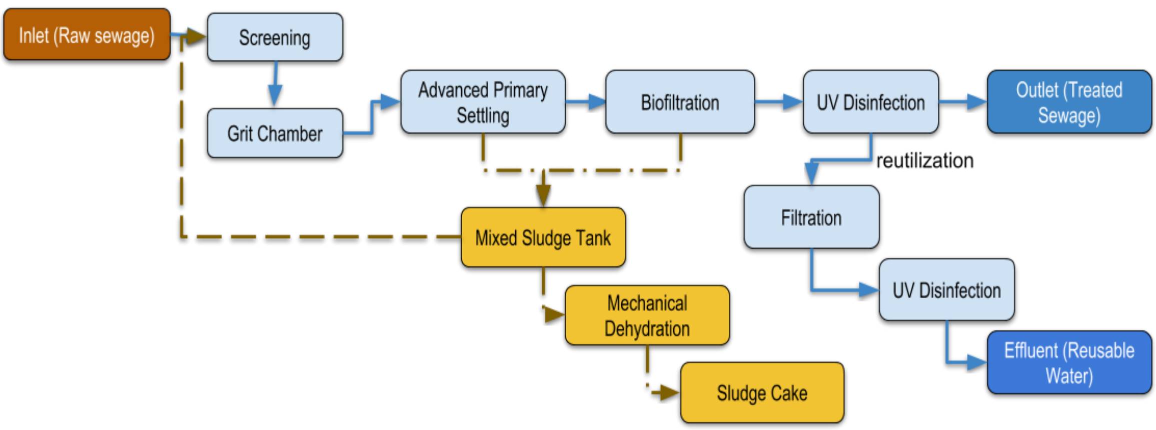

Figure 2.3: Schematic representation of the different process of Alcântara WWTP

- ***Preliminary Treatment***: Pretreatment in Alcântara WWTP includes the screening for removal of suspended solids and Grit removal to remove the sand and grits. Screening is done in two stages; Coarse grading (3 channels with 60mm spacing bars) and fine grading (3 channels with 6mm spacing).

- ***Primary Treatment:*** During the dry weather primary treatment uses 4 MULTIFLO™ working in parallel with a maximum flow of $3.3m^3/s$ and during wet weather it uses 2 ACTIFLO™ also in parallel at a maximum flow of $3.3m^3/s$. The MF is a Veolia technology where the coagulation, flocculation and lamella settling stages occurs in the same unit. Each MF has a total volume of $2577m^3$. ACTIFLO™ is also another technology patented by Veolia. AF is advanced sedimentation by lamella installed in countercurrent configuration, differing in the addition of micro-sand. The effluent from the lamella settling is sent to the secondary treatment.

- ***Secondary Treatment:*** Secondary treatment is done by the 15 BIOSTYR™ (Veolia technology). It is a biofiltration process where the biological treatment, clarification and filtration occurs in one unit. The area of each cell is $215m^2$, totalling $2335m^2$ of filtration area.

- ***Sludge Treatment:*** The primary and secondary sludge are gathered in a mixed sludge tank before mechanical dehydration. Dewatering of sludge is done by addition of cationic polyelectrolyte at the entrance centrifuges mechanically. Then, the quick lime is added to prevent fermentation of dehydrated sludge.

- ***Tertiary Treatment:*** Alcântara WWTP also has the tertiary treatment which is done by UV disinfection.

2.4.2 Wastewater Legislation in Portugal

- ***Decree-Law No. 152/97:*** The provisions of this law apply the collection, treatment and discharge of urban wastewater in the aquatic environment, transposing them to the national law of Council Directive 91/271 /EEC of 21 May. This law overviews the responsibility of the management entities of the public water distribution systems and public wastewater drainage systems that discharge into the aquatic environment.

Requirements for discharge from water treatment plants urban waste products subject to Articles 5 and 6 concentration values or percentage reduction will apply given in Table 2.4 [31].

Table 2.4: Limit values for wastewater pollutants to discharge for Portugal

Parameters	Concentration	Minimum Reduction, % *
Biochemical oxygen demand (BOD_5 at 20°C) **	25mg/l O_2	70-90
Chemical oxygen demand (COD)	125 mg/l O_2	75
Total suspended solids ***	35 mg/l ***	90***
Total Phosphorus	2 mg/l P (10000-100000 PE) 1 mg/l P (> 100000 PE)	80
Total Nitrogen	15 mg/l P (10000-100000 PE) 10 mg/l P (> 100000 PE)	70-80

* Reduction concerning the effluent load.

** The parameter can be replaced by another: Total organic carbon (TOC) or Total oxygen demand (TOD), if it is possible to establish a relationship between BOD_5 and the substitute parameter.

*** This requirement is optional

- ***Decree-Law No. 348/98:*** This law is the first amendment of the Decree-Law No. 152/97 covering the obligations for discharging to sensitive zones [32].

- ***Decree-Law No. 194/2004:*** This law is the second amendment of the Decree-Law No. 152/97 with the identification of the list of sensitive zones and less sensitive zones [33].

- ***Decree-Law No. 188/2008:*** This law is the third amendment of the Decree-Law No. 152/97 and identifies the new list of sensitive zones and less sensitive zones [34].

- ***Decree-Law No. 276/2009:*** It is the main legislation for sludge treatment and covers the utilization of wastewater sludge for cultivation purposes [35].

2.5 Wastewater Treatment practice in Kathmandu, Nepal

The first centralized wastewater treatment system was introduced in 1975 at Hanumanghat which is aerated lagoons system. After that, the other three lagoons (one aerobic and two non-aerobic) system was established in different places around Kathmandu valley during the 1980s [10]. In 2001, the activated sludge system was established in Guheshwori WWTP which is the only operation WWTP in present days.

2.5.1 Guheshwori WWTP

Guheshwori Wastewater Treatment Plant is the first and only operating WWTP in Kathmandu, Nepal which is located in the north-east part of Kathmandu. The schematic representation of Guheshwori WWTP is shown in Figure 2.4. The main components and process are described below:

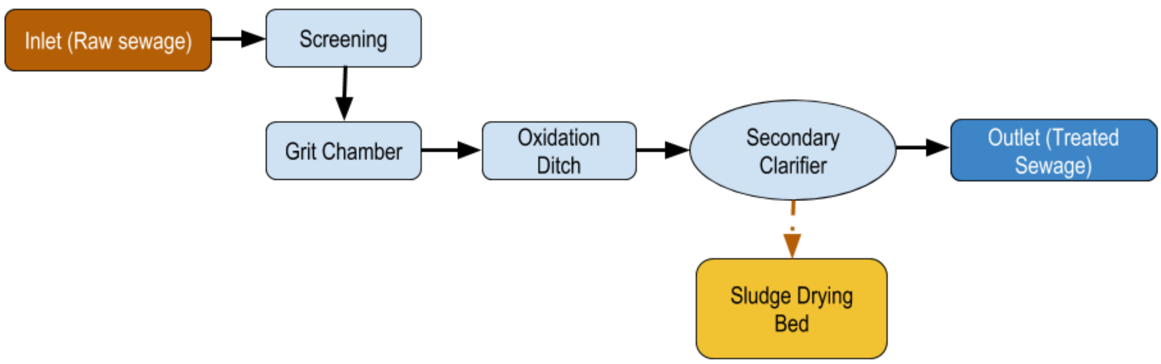

Figure 2.4: Schematic representation of the different process of Guheshwori WWTP

- ***Primary Treatment:*** Primary treatment includes the Mechanical Bar Screen to remove the large suspended solids and Mechanical Grit Removal System to remove out the inorganic particles like sand. Then, the water is passed to Oxidation Ditch. There is no primary clarification tank [36].

- ***Secondary Treatment:*** Secondary Treatment includes the oxidation ditch and secondary clarifier. There are two carousel type oxidation ditches and each oxidation ditches have three aerators. 10,400m^3 wastewater is treated in oxidation ditch. Then the wastewater after oxidation ditch is passed to the secondary settling tank, where the sludge settles down and clean water flows out after settling. There are 2 secondary sedimentation basin of diameter 27m and the base area of 570 m^2 [37]. Sludge from the secondary clarifier is pumped back to oxidation ditch and the excess sludge is pumped to the Sludge drying bed (SDB) [38].

- ***Sludge Treatment:*** The sludge production from Guheshwori WWTP is designed to estimated 40m^3/day. Sludge produced from the treatment plant is treated in a drying bed. There are 2 drying bed of size 27m*74m. The drying period is estimated to be 2 to 3 weeks [38].

2.5.2 Non-functional and other small WWTP

Besides Guheshwori WWTP, the other four centralized WWTP was established in Kathmandu valley which is not in functional these days. Kodku WWTP and Dhobighat WWTP are the two non-aerated lagoon facility with a design capacity of 1.1MLD and 15.4MLD respectively and their status is non-operational. Gatthagher and Hanumanghat are the two aerated lagoon facilities with a design capacity of 0.5MLD and 2MLD respectively and their status is also non-operational as well [39]. The reason for the failure of these treatment facilities is mainly due to the inefficiency in operational and maintenance of the plant.

With the demand and necessity of simple and cost-effective treatment technology, Constructed Wetland (CW) has considered the appropriate options in developing countries like Nepal. The first CW came into operation in 1997 at Dhulikhel Hospital with a type of Reed Bed Treatment System Horizontal Flow Bed followed by Vertical Flow Bed. In 1998, Kathmandu Metropolitan city builds a CW system of 59m3/day in Kathmandu Metropolitan city for a septage treatment [40]. The system consists of a three-chambered settlement tank (200m3), three units of sand and gravel filter beds (each 75m^2) and a 362m^2 of vertical flow bed [9]. Different problems are often encountered in this treatment plant due to the irregular maintenance and monitoring of the wetland [41]. Constructed wetlands are considered as the ideal treatment facilities for the cost-efficiency treatment and several CWs are established in various places of Nepal as a decentralized wastewater treatment system.

2.5.3 Wastewater Legislation in Nepal

There is no separate policy for wastewater management, however, the issues related to wastewater management are comprehension to water supply and sanitation-related legislation and regulations [42].

- ***Water Resource Act, 1992:*** This Act was published and authorized on 17 December 1992. This act governs water resource management for sustainable water use. This act covers the priority on the utilization of water resources, provision of license, service charge, fixing the quality standard of water resources and water resources pollution. Government of Nepal authorize the liability value for the pollution in water resource. [43].

- ***Environmental Protection Act, 1996:*** This act is expedient to protect the environment by the sustainable development and proper use of natural resources by minimizing the negative impacts likely to cause by any plan and activities by human beings. This act prescribed to carry out IEE or EIA and prevention and control of pollution on the environment. This act also deals with the pollution in water and provide a control certificate [44].

  Following the right given by Government of Nepal under Rule 15 of the Environmental Protection Rule 1997 the corresponding criteria have been specified to be applied as directive criteria. The tolerance limit for Wastewater to be sent to Inland Surface water from combined wastewater treatment plant is given in Generic Standard Part III [45].

Table 2.5: Tolerance limit for Wastewater to be sent to Inland Surface water from combined wastewater treatment plant is given in Generic Standard Part III

Characteristics	Tolerance Limit
Total Suspended solids, Max	50 mg/l
Biochemical oxygen demand (BOD) for 5 days at 20°C, Max	50 mg/l
Ammonical nitrogen, Max	50 mg/l
Oils and grease, Max	10 mg/l
Chemical Oxygen Demand, Max	250mg/l

*Note: There are no general standards for domestic wastewater to be discharged into inland surface water from municipal WWTPs. Therefore, this standard will only be applied as a guide in the absence of a generic standard for discharge from municipal wastewater treatment plants [46].

- ***National Water Supply and Sanitation Sector Policy 2014:*** This policy is the merge and revision of two separate policy; Rural Water Supply and Sanitation National Policy 2004 and Urban Water Supply and Sanitation Policy 2009. This integrated policy ensure the safe and adequate water supply and sanitation services to the coverage targets with the participation of all the users including poor and marginalized groups. This policy also aims to protect the surface and groundwater sources from wastewater pollution [47].

3 MATERIALS AND METHODS

The study is done based on secondary data and research materials available. Literature review is done through related books, scientific articles, published papers and internet. Three cities, Tallinn, a developed city in northern Europe, Lisbon, green capital of Europe 2020 and Kathmandu, a city from developing country in South Asia are selected for the study of the wastewater treatment system.

The crucial characteristics of wastewater like BOD_5, COD, TSS, Nitrogen and Phosphorus from all three WWTP of Tallinn, Lisbon and Kathmandu are taken respectively for study. Then, the comparative graph representing the pollutants of influents and effluents are drawn with the help of MS-Excel. The separate bar graph is drawn to compare BOD_5, COD and TSS from each WWTP. From the influents and effluents characteristics, Removal or Reduction efficiency (E_r) is calculated using the formula;

$$E_r = \frac{\text{Influent} - \text{Effluent}}{\text{Influent}} \times 100$$

Then, the Efficiency from all three wastewater treatment plants for BOD_5, COD and TSS are also represented in a separate chart. Similarly, using MS-Excel, another comparative graph is drawn for the effluent discharge and respective national standard limit.

4 ANALYSIS AND DISCUSSIONS

4.1 Characteristics of all three WWTP

The WWTP of Tallinn (Paljassaare WWTP), Lisbon (AlcântaraWWTP) and Kathmandu (Guheshwori WWTP) are epitomised in Table 4.1. This gives the general idea of the wastewater treatment system in each city.

Table 4.1 Wastewater Treatment Plant Characteristics from three different cities

Characteristics	Tallinn, Estonia	Lisbon, Portugal	Kathmandu, Nepal
	Paljassaare WWTP	AlcântaraWWTP	Guheshwori WWTP
Established date	1980	1989	2001
Treatment technology	Activated Sludge (Mechanical, Chemical and Biological)	Multiflo™, Actiflo™ and Biostyr™ (Veolia Technology)	Activated Sludge-Oxidation ditch
Tertiary treatment	None	Ultraviolet Disinfection	None
Influent characteristics	Municipal Wastewater & Stormwater	Municipal Wastewater & Stormwater	Residential, Industrial and Institutional Wastewater
Sources of sewage	Tallinn city area and its vicinity (Saue and Saku)	Lisbon, Amadora and Oeiras Municipalities	Gokarna, Chabahil, Bouddha and Jorpati area of Kathmandu city
Population served	400,000	756,000	120,000
Design capacity	120,000m^3/day	181,000m^3/day	16,400m^3/day
Sludge Treatment	Biogas and composting	Mechanical dehydration	Drying bed
Effluent Discharge location	Baltic Sea	Tagus estuary	Bagmati river

4.2 Wastewater characteristics from all three cities

From all the three WWTP, wastewater pollutant parameters like BOD_5, COD, TSS, Nitrogen and Phosphorus are taken from both influent and effluent. Table 4.2 presents the data of both influent and effluent from all three WWTP. The data for all the parameters are taken an average of dry weather and wet weather or average data over the year.

Table 4.2 Wastewater influent and effluent Characteristics from three WWTP

Parameters	Tallinn, Estonia		Lisbon, Portugal		Kathmandu, Nepal	
	Paljassaare WWTP, 2018 [48]		AlcântaraWWTP, 2014 [49]		Guheshwori WWTP, 2018[50]	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
BOD_5 (mg/l)	197.65*	5	261.5	16.5	355.88	86.36
COD (mg/l)	529	45	573.5	70.5	1146.68	263.48
TSS (mg/l)	331	6	318	22	320.11	106.08
Total Nitrogen (mg/l)	51.9	7.2	-	10	48.06	40.67
Total Phosphorus (mg/l)	6.41	0.39	-	1	19.00	9.62

*Paljassaare WWTP had the original BOD_7 which is converted to BOD_5 using PLC_water guidelines 2019: $BOD_5 = BOD_7/1.15$

The influent and effluent of different parameters from all three WWTPs are represented graphically and shown in Figure 4.1 for BOD_5, Figure 4.2 for COD and Figure 4.3 for TSS respectively.

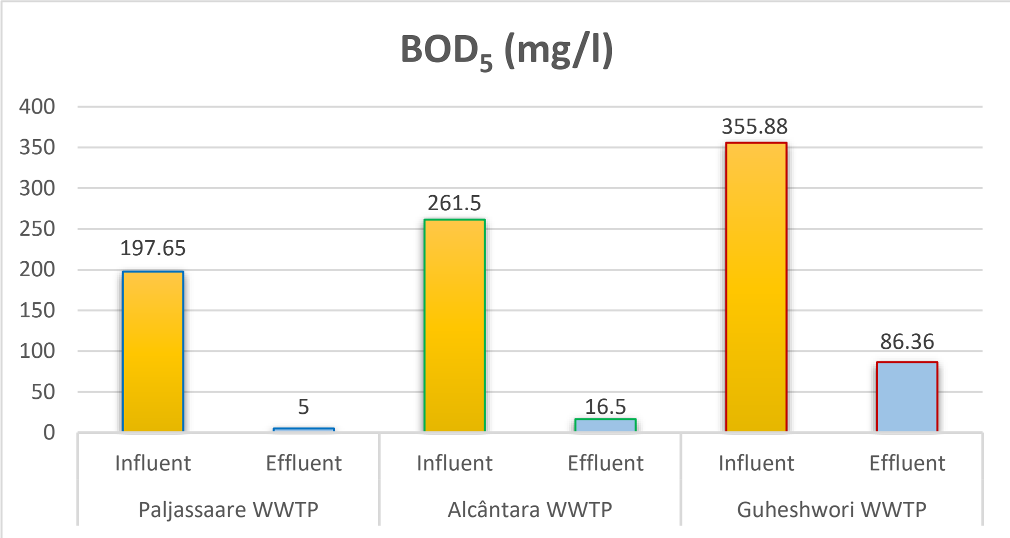

Figure 4.1: Graphical representation of BOD_5 from 3 different cities

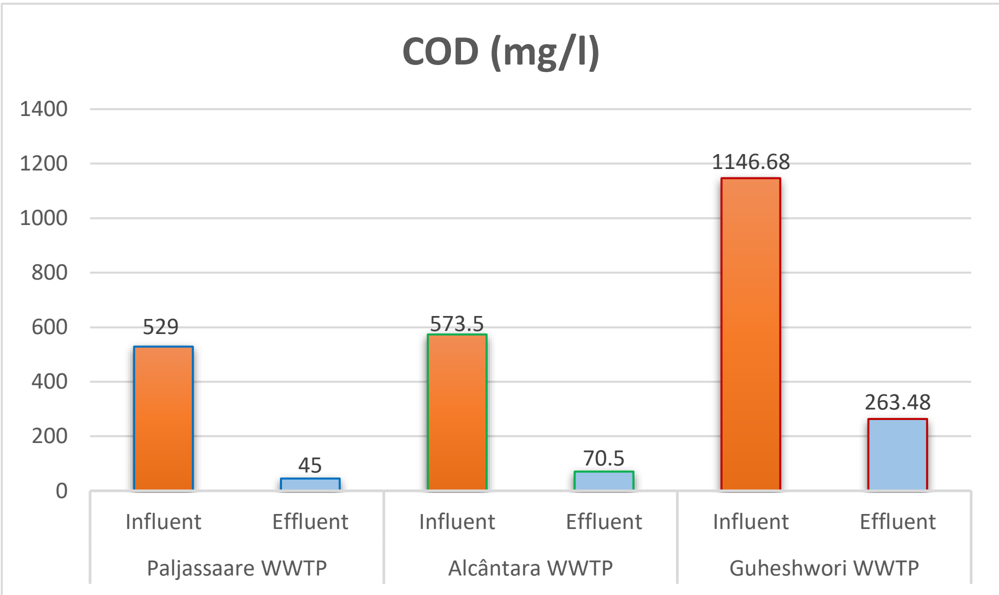

Figure 4.2: Graphical representation of COD from 3 different cities

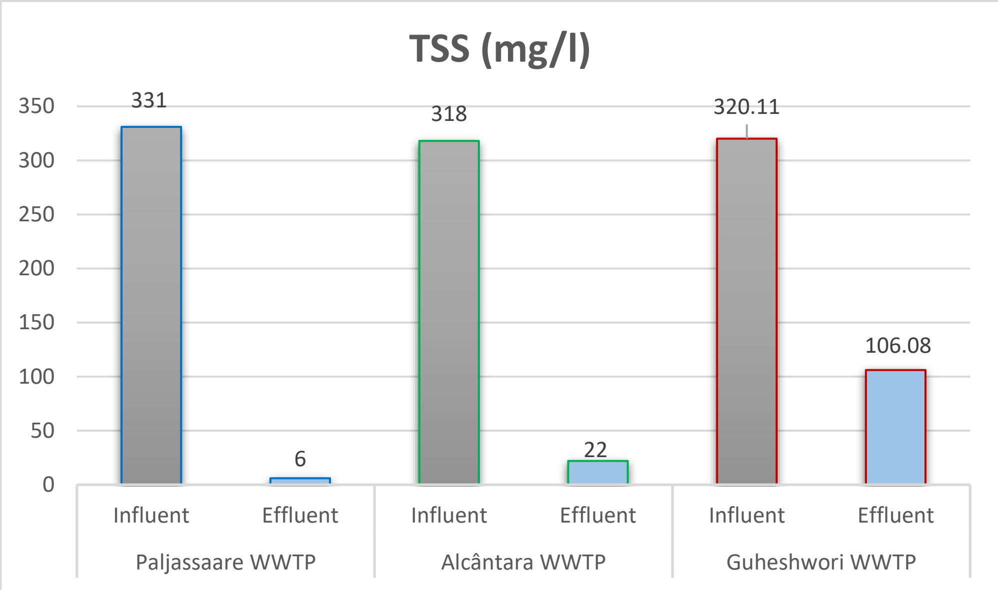

Figure 4.3: Graphical representation of TSS from 3 different cities

4.3 The efficiency of WWTP from all three cities

Efficiency (E_r) for the removal or reduction of pollutants (BOD, COD, SS, TN and TP) are calculated by using the formula given in Chapter 3:

Table 4.3: Efficiency for the removal or reduction of pollutants from all three WWTP

Removal/Reduction Efficiency	Tallinn, Estonia	Lisbon, Portugal	Kathmandu, Nepal
	Paljassaare WWTP	Alcântara WWTP	Guheshwori WWTP
BOD_5 (mg/l)	97.47	93.69	75.73
COD (mg/l)	91.49	87.71	77.02
TSS (mg/l)	98.19	93.08	66.86
Total N (mg/l)	86.13	-	15.38
Total P (mg/l)	93.92	-	49.38

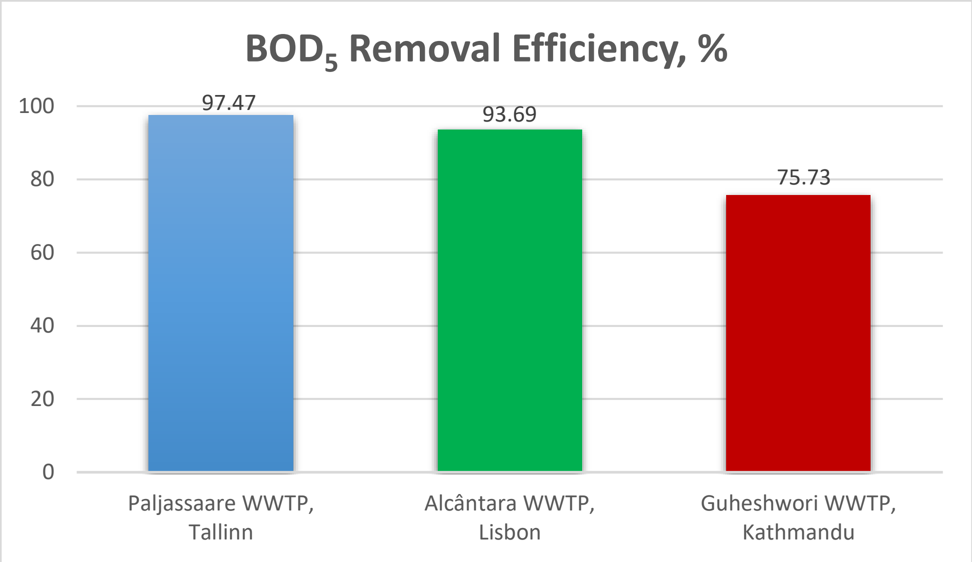

Figure 4.4: Graphical Representation of BOD_5 Removal Efficiency from all 3 WWTPs

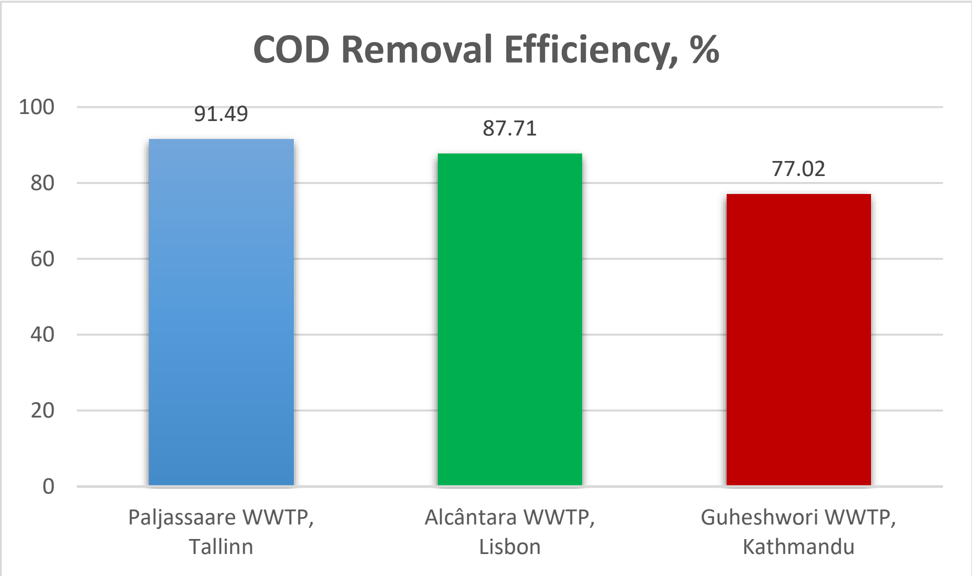

Figure 4.5: Graphical Representation of COD Removal Efficiency from all 3 WWTPs

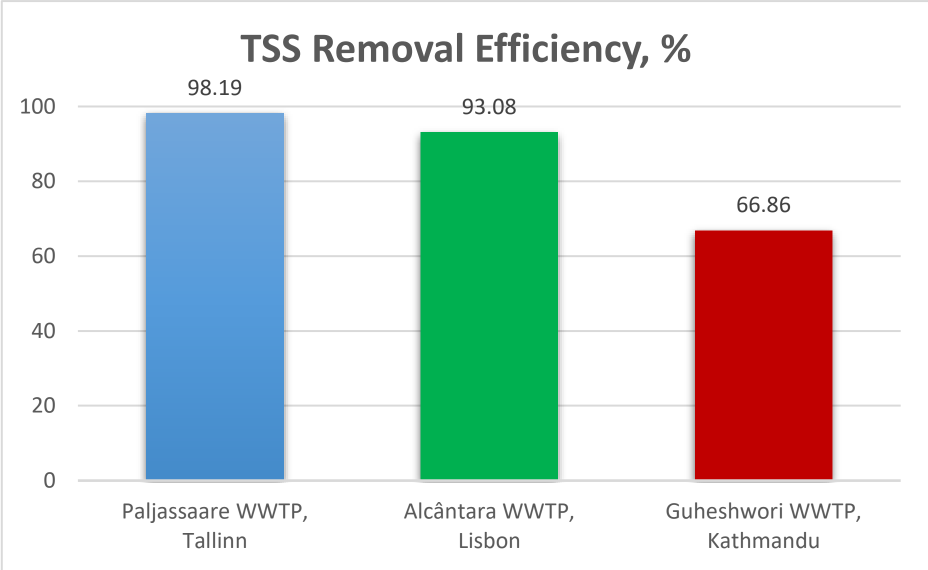

Figure 4.6: Graphical Representation of TSS Removal Efficiency from all 3 WWTPs

4.4 Effluents discharged from all three WWTP and respective national legislation

Table 4.4: Comparison of the effluents with the permissible concerning their National standard

Parameters	Tallinn, Estonia		Lisbon, Portugal		Kathmandu, Nepal	
	Paljassaare WWTP		Alcântara WWTP		Guheshwori WWTP	
	Effluent	Standard	Effluent	Standard	Effluent	Standard
BOD5 (mg/l)	5	15	16.5	25	86.36	50
COD (mg/l)	45	125	70.5	125	263.48	250
TSS (mg/l)	6	15	22	35	106.08	50
Total Nitrogen (mg/l)	7.2	10	-	10	40.67	50
Total Phosphorus (mg/l)	0.39	0.5	-	1	9.62	-

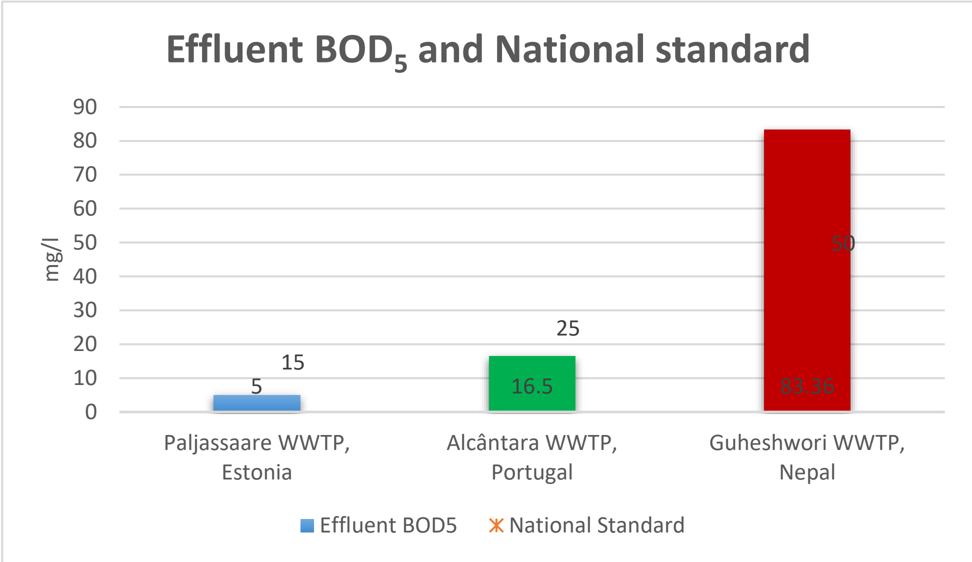

Figure 4.7: Graphical Representation of BOD_5 effluent with comparison to standard in all three countries

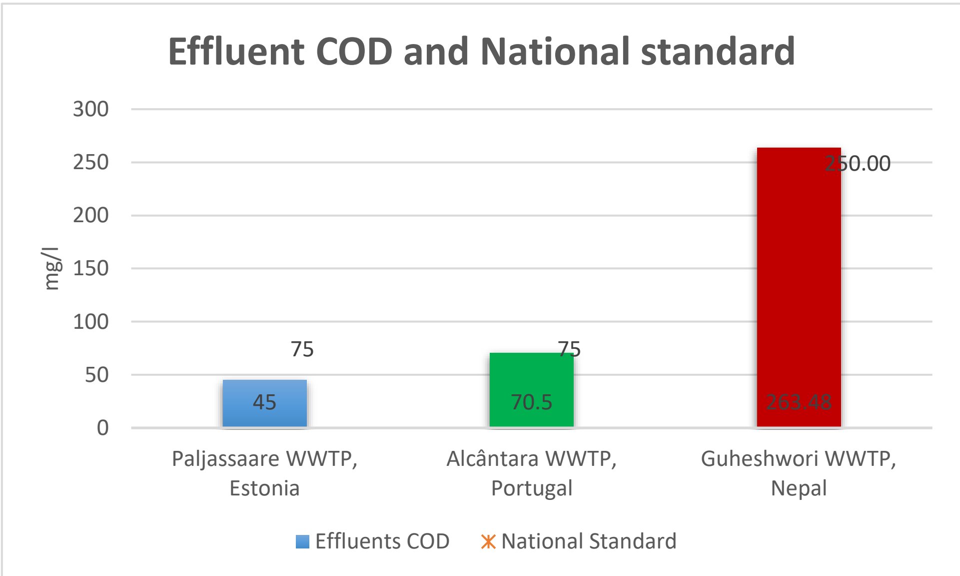

Figure 4.8: Graphical Representation of COD effluent with comparison to standard in all three countries

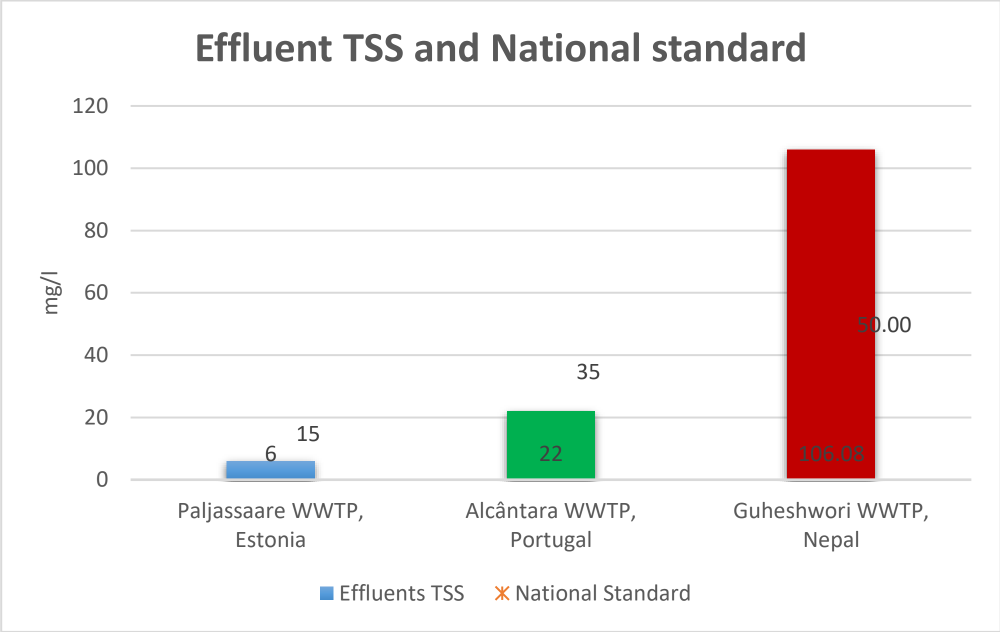

Figure 4.9: Graphical Representation of TSS effluent with comparison to standard in all three countries

4.5 Improvement of wastewater treatment in Tallinn, Estonia

4.5.1 Sewerage service

All the wastewater generated in Tallinn city is treated in Paljassaare WWTP. The public sewerage system is available for 99.8% of the population of Tallinn whereas 0.2% of the population are not facilitated to sewerage system which is not economically practical. Those who don't have access to sewerage network are collected in liquid-proof tanks and are transferred to the sewerage system [23]. Overall, sewerage service in Tallinn appears to adequate.

4.5.2 WWTP efficiency

The reconstruction and modification of WWTP from 2003 to 2010 and instalment of a biofilter in 2011 has significantly increased the purification efficiency of WWTP [23]. Paljassaare WWTP is continuing for the replacement of old equipment and updating the technology for better efficiency of plants. In 2018, Paljassaare WWTP achieved a magnificent efficiency, 97.5% for BOD5, 91.5% for COD, 98.2% for Suspended solids, 86.1% for Nitrogen and 93.9% for Phosphorus, which complies with the national requirements and the Urban Wastewater Treatment Directive (91 /271 /EEC) as well with HELCOM recommendations.

4.5.3 Sludge Management

Sludge generated from the WWTP is no more taken to the landfill site. Sludge is mixed with peat and dried to make composting which are used for landscaping and ground filling. Biogas is also generated in the methane tank which is used for heating the buildings. During the winter, all biogas produced is consumed in the buildings, whereas, in the summer only 20-30% are consumed and the excess gas is burnt in a residual gas burner [23].

4.5.4 Sewerage network

Most of the sewerage pipelines of Tallinn are time-worn and Tallinn is focusing on the reconstruction or replacement of the sewerage network which is older than 60 years. The ancient sewerage pipes are mostly of concrete and asbestos cement and the new material used for which reconstructing is plastic whose lifetime is estimated for 100 years which is superior to concrete and asbestos cement sewerage pipes [23]. Most of the sewerage network of Tallinn are of a combined sewerage system. Now, Tallinn is establishing new stormwater drainage pipes and new catchment area for stormwater which don't flow to the WWTP and improve the working mechanism of plant and increase the efficiency of WWTP.

4.5.5 Snow handling

Snowfall is very common in Tallinn during winter. Tallinn has combined sewerage collection system for both stormwater and wastewater which induce the problem in handling and collection of snow, with the heavy snowfall. Thus, the snow handling concept will be developed where the special snow depositing sites will be constructed which have liquid-proof bottoms and facilitate with oil and sand traps. The collection sites are separated for clean snow (freshly fallen snow) and the old snow [23]. The proper collection system of snow and its proper utilization can help in economic and environmental sustainability.

4.6 Improvement of WWTP in Lisbon, Portugal

In 1989, primary treatment was built and disinfection with Chlorine. Since 2009, it has undergone a thorough modernization and expansion and a tertiary level treatment with disinfection is done by ultraviolet radiation [29]. The wastewater treatment plant space is entirely closed, ventilated and properly deodorized.

4.6.1 The sewer system of Lisbon

The collection system for wastewater in Lisbon is a combined system where stormwater and sewerage is transported in the same sewer. 100% of wastewater in Lisbon is collected and treated in WWTP [51]. The continual improvements of the collection system and rehabilitation and replacement of the worn equipment make the more efficient of the collection system in Lisbon.

4.6.2 WWTP Efficiency

Alcântara WWTP is in fully operational after its rehabilitation in 2009 [51]. The wastewater has separate flow for dry weather and humid weather and treated through Multiflo^{TM} and Actiflo^{TM}, Veolia technology respectively. Secondary treatment is done through Biostry^{TM} biofiltration technology and finally disinfected through UV radiation. The efficiency achieved by Alcântara WWTP is 93,7% for BOD_5, 87,8% for COD and 93,1% for total suspended solids, which complies with the national requirements.

4.6.3 Reuse of wastewater

Wastewater after the secondary treatment is passed for tertiary treatment which is done by filtration following by UV disinfection [29]. There is no Portuguese legislation for reuse of wastewater, however, Lisbon is pledged to increasing reuses of wastewater. According to the Lisbon Energy-Environmental Strategy 2020, the target for wastewater reuse is 3.1m^3/inhabitant/year, which has already been achieved [51]. The treated wastewater after disinfection is generally used for non-potable uses, road cleaning and irrigation purposes.

4.6.4 Sludge Treatment

Sludge from the primary treatment and secondary treatment are stored in a sludge storage tank and transported to the mechanical dewatering by centrifuges. The cationic polymer is used for sludge aggregation and quicklime-Cao is added for the better sludge drying [52]. The sludge after dehydration can be used as fertilizer in agricultural or as compost. For the energy-efficient solution, there is a plan for generating biogas for energy production from the sludge extracted from Alcântara WWTP [51].

4.6.5 WWTP natural landscape

Alcântara WWTP could an example of modern infrastructure, covered with vegetation for environmental preservation. It is covered by around 2ha. of the landscaped green roof which is naturally protective and visually aesthetic [53]. This landscaped roof visually extends the green slopes of the Alcântara valley and appears aesthetically pleasant.

4.7 Improvement of WWTP in Kathmandu, Nepal

Kathmandu city needs an urgent improvement in wastewater treatment systems as there are no proper sewerage systems and untreated wastewater has been discharged directly to the river. Bagmati River, the holy river is plagued by the pollution due to the rapid increase in population density and encroachment on the Bagmati river for the last two and a half decades.

4.7.1 Rehabilitation and Expansion

The rehabilitation and expansion of Guheshwori WWTP were started since 2016 for the design capacity up to the 32.4MLD by Project Implementation Directorate (PID)/KUKL and funded by ADB and Nepal government. [37]. The process diagram of Guheshwori WWTP after the rehabilitation and expansion is shown in Figure 4.10 which is expected to be completed by 2021.

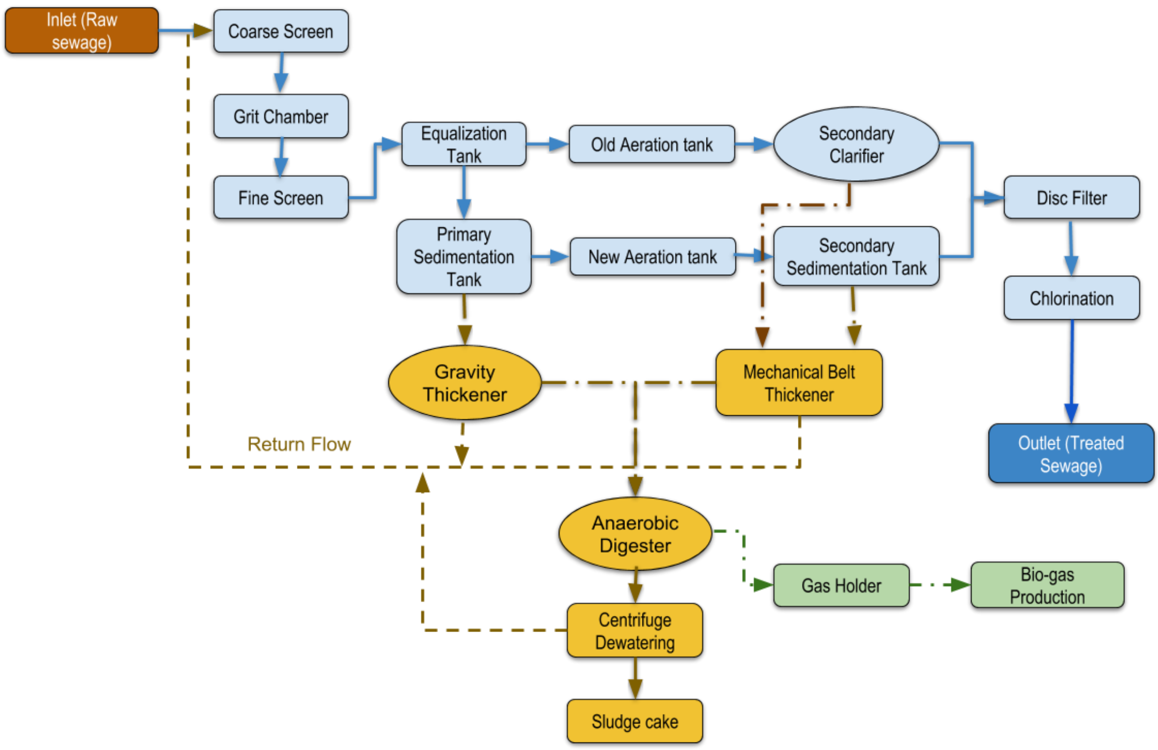

Figure 4.10: Process diagram of Guheshwori WWTP after the rehabilitation

The rehabilitation and expansion are supposed to improve the pollutant removal efficiency of Guheshwori WWTP which was not up to the mark with Nepali standard. A new Activated Sludge Process (ASP) plant will be established of size 16MLD average flows. The old system was based on Oxidation ditch principles and the new system is based on ASP and surface aerators replaced by diffuser blocks which are attached to the floor. Diffusor blocks oxygenate the water by pumping the air through it and also helps in stirring the liquid. After the rehabilitation and expansion, it is estimated to serve for around 300,000 populace of Kathmandu by 2021 [37].

4.7.2 Sludge Management

Sludge production from the Guheshwori WWTP is proposed for the management of Energy production from Anaerobic Sludge Digester. The sludge from Anaerobic digester is passed to centrifuge dewatering and sludge cake are made mixing some lime. This sludge cake is used for agricultural purpose.

4.7.3 Additional WWTP

Guheshwori WWTP is the only operating WWTP in Kathmandu which treats sewage from only small parts of Kathmandu. Therefore, there is an utmost need for additional wastewater treatment facilities in Kathmandu for the residential, institutional and industrial sewerage treatment in Kathmandu valley. Tukucha WWTP is proposed to construct near the mouth of Tukucha River under the sub-project of Bagmati River Basin (BRB) improvement project. The plant will be a Sequencing Batch Reactor (SBR) type and of the design capacity of 17.3MLD for the PE of 145,000. The plant will treat water treated directly from the river at upstream and treated wastewater will be deposited to a little downstream of the river. The project is planned to construct under a design-build-operate (DBO) contract where all the responsibility for the detail design preparation, construction, operation and maintenance is given to DBO contractor. The Estimated Base cost for this project cost is $29.62millions [54]. Beside Tukucha WWTP, there is an exigency of other additional big and small wastewater treatment facilities to clean and protect the river by preventing the direct disposal of untreated sewerage to the river.

4.7.4 WWTP for the small community

Bagmati Action Plan (2009-2014) has recommended the Decentralized wastewater treatment system (DEWATS) as a new approach to manage sewerage in semi-urban and rural areas around Kathmandu valley [10]. Nepal, being a developing country, DEWATS are recognized as the more appropriate sewerage treatment system due to cost-effectiveness and low maintenance compared to the centralized system [10]. In Nepal, DEWATS is installed and operated in private sectors (schools and hotels), community level and municipal level. Community levels DEWATS are supposed to be an alternative for conventional centralized wastewater treatment systems at the community level. The study has shown that the private sector has better performance than that of community and municipal sectors [10]. If more DEWATS are established at a community level and the efficient operation and maintenance activities are done with the proper financial and technical plan, DEWATS could be one of the alternatives for conventional centralized WWTP.

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The goal of the study was to figure out the wastewater management system from three different cities which are located in different countries having different economic status and also analyse the data and information from all three different wastewater treatment plants. Tallinn, the capital city of Estonia, has one centralized activated sludge wastewater system, Paljassaare WWTP, which treats all the wastewater of Tallinn city and its vicinity (Saue, Saku). The wastewater of Lisbon, the capital city of Portugal, is treated in Alcântara WWTP using Veolia Technology. Kathmandu, the capital city of Nepal, have only of operating centralized wastewater treatment system in Guheshwori. Guheshwori WWTP is based on the Oxidation ditch and treats the wastewater from Gokarna, Chabahil, Bouddha and Jorpati area of Kathmandu.

Comparison of major wastewater characteristics like BOD_5, COD and TSS of both influents and effluents from all three WWTP gives the general idea of characteristics of wastewater and treatment efficiency of WWTP. BOD_5 removal or reduction efficiency from Paljassaare, Alcântara and Guheshwori WWTP is 977%, 93,69% and 75,73% respectively. Efficiency for the removal or reduction of COD from Paljassaare, Alcântara and Guheshwori WWTP is 91,49%, 87,71% and 77,02% respectively. Similarly, reduction or removal efficiency of TSS from Paljassaare, Alcântara and Guheshwori WWTP is 98,19%, 93,08% and 66,86% respectively.

The acts and regulation regarding wastewater for Estonia, Portugal and Nepal are different and the effluent discharge limit standard is also different for each country. Comparison of parameters of effluent discharge concerning the national wastewater emission gives us a clearer outlook about the efficiency of WWTP. The effluents from the Paljassaare WWTP are discharge to the Baltic Sea and all wastewater pollutant parameters of effluent complies with the national limit values, European directive on Urban Wastewater treatment and HELCOM recommendations. The effluent from AlcântaraWWTP are discharged to Tagus estuary and some are reused for non-potable purpose after disinfection. BOD_5, COD and TSS of effluents from AlcântaraWWTP also comply with the national standard given in Decree-Law no. 152/97. The effluent quality parameters of Guheshwori WWTP doesn't comply with the tolerance limit for discharge according to the national standard. However, the effluent is discharged to the Bagmati River that is already a polluted river due to inadequate waste and wastewater management system.

Wastewater treatment plant needs regular maintenance, improvement and rehabilitation for the inflated performance. Paljassaare WWTP has done a remarkable improvement since the establishment of the wastewater treatment plant. Improvement in operational efficiency of the treatment plant is noticeable, by the regular maintenance of the equipment and updating with new technology. Production of biogas from waste sludge and the introduction of biofilter in secondary treatment are some noticeable improvement in a wastewater treatment plant that assures the efficient and sustainable treatment of wastewater. Alcântara WWTP has also done a tremendous improvement since its establishment. The treatment plant, established with primary treatment and disinfection Chlorine, has now turned to the advanced primary, secondary, tertiary level treatment with the disinfection by UV radiation. Green roof landscape is another main feature of Alcântara WWTP which makes it outstanding from other wastewater treatment plants. On the contrary, Wastewater treatment system in Kathamandu is inadequate and the only operating centralized wastewater treatment plant, Guheshwori WWTP, has the deficient performance. After finishing the ongoing rehabilitation work of Guheshwori WWTP, it is expected to treat almost double the amount of wastewater and function more efficient than now. Even though after the rehabilitation, wastewater management in Kathmandu would not be adequate. However, Guheshwori Wastewater treatment plant helps to clean the Bagmati River to some extent.

5.2 Recommendation

Following are the recommendations made after the study of wastewater treatment system from different cities from a different country.

- Maintenance and rehabilitation of wastewater treatment plant should be performed regularly for operating wastewater treatment plant in optimum conditions.

- Updating the wastewater treatment technologies must be done with time for the sustainable and efficient treatment of wastewater.

- Green roof landscape concept from Alcântara WWTP should be an assimilated by other wastewater treatment plants for the social, economic and environmental sustainability.

- Energy generation from waste sludge is an efficient way to handle the sludge and must be practised by each wastewater treatment plants. Biogas production is also an environmentally friendly sustainable way for the management of wastewater sludge.

- Additional centralized WWTP in Kathmandu is crucial and the cost-efficient and sustainable WWTP must be established to clean the river. Establishment of communal DEWATS at various places could also help to some extent.

- Besides financial problems and inadequate wastewater management system, unawareness in people are causing the pollution in the river of Kathmandu. Thus, awareness in people is must for the proper management of waste and sewage, which are causing river pollution.

- The strong policy and regulation could help in the illegal discharge to untreated sewage to water bodies.

6 SUMMARY

Pursuing the population growth, urbanization and industrialization, wastewater management is crucial in the protection of the environment and sustainable development. Accompanying the development of new technology, the treatment of wastewater is becoming more advanced, efficient and sustainable. Three cities, Tallinn, Lisbon and Kathmandu, most populated and capital city of country Estonia, Portugal and Nepal are selected for the study of the wastewater treatment system. The study of the wastewater treatment system in these three different cities gives a comparative idea of the wastewater treatment system of different cities with the different economy, infrastructure and policy. The main aim of the study is to figure out the existence wastewater treatment system and compare the efficiency of treatment plants from all three cities. Additionally, the study of rehabilitation and future plans of each wastewater treatment plants are carried out.

Tallinn city has a centralized WWTP at Paljassaare, which treats all the sewerage collected in Tallinn city and serves for more than 400.000 inhabitants. Alcântara WWTP of Lisbon treats the wastewater from Lisbon, Amadora and Oeiras Municipality for around 750,000 inhabitants. Kathmandu has only one functional centralized wastewater system which treats only a small area of Kathmandu which is inadequate for the wastewater generated in Kathmandu. Wastewater characteristics of both influents and effluents from all three wastewater treatment plants conclude the treatment efficiency of each WWTP. The removal or reduction efficiency of BOD5 for Paljassaare, Alcântara and Guheshwori WWTP is 97.47%, 93.69% and 75.73% respectively. COD removal or reduction efficiency from Paljassaare, Alcântara and Guheshwori WWTP is 91.49%, 87.71% and 77.02% respectively. Similarly, TSS removal or reduction efficiency from Paljassaare, Alcântara and Guheshwori WWTP is 98.19%, 93.08% and 66.86% respectively. BOD5, COD and SS of effluent from Paljassaare WWTP comply with the Estonian national limit value and HELCOM standard. The effluent from Alcântara WWTP also complies with the Portuguese national standard of Decree-Law no. 152/97. In contrast, BOD5, COD and TSS of effluents from Guheshwori WWTP doesn’t comply with the tolerance limit given by Nepal government though the tolerance limit of Nepal is high compare to Portugal and Estonia. The major reason for the failure of Guheshwori WWTP is due to the irregular maintenance of plant and the sewerage is mixed with industrial waste. The rehabilitation work of Guheshwori Wastewater treatment plant is ongoing and expected to finish by 2021 and assumed to solve this problem to some extent.

The wastewater treatment plant with regular maintenance and rehabilitation gives the utmost performance for sewerage treatment. Update to advanced treatment technology with green roof landscape and energy generation from waste sludge is the most effective and sustainable way of handling wastewater and sludge.

LIST OF REFERENCES

1. Corcoran, E., & GRID--Arendal (Eds.). (2010). Sick water? The central role of wastewater management in sustainable development: a rapid response assessment. UNEP/GRID-Arendal.

2. Hopcroft, F. J. (2015). Wastewater treatment concepts and practices. http://public.ebookcentral.proquest.com/choice/publicfullrecord.aspx?p=1816350

3. Tallinn City Enterprise Department (2019). Facts about Tallinn, Tallinn-Estonia's Economic Centre

4. AS Tallinn Vesi (2018). Environmental report 2018

5. Lisbon Metropolitan City (2016). City profile Lisbon

6. David, L. M., & David, C. (2010). Rehabilitation of the Alcântara Sewage Treatment Plant – Effect of the design capacity on CSO discharges. 9.

7. Bhandari, M. (2012). International Centre for Integrated Mountain Development. In G. Ritzer (Ed.), The Wiley-Blackwell Encyclopedia of Globalization (p. wbeog308). John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470670590.wbeog308

8. German Federal Foreign Affairs Office and EMI (2010). Sectoral Profile Kathmandu Metropolitan City, Nepal Activity I.I: Development of a Risk-Sensitive Land Use Plan for Kathmandu City

9. Jha, A. K., & Bajracharya, T. R. (2014). Wastewater Treatment Technologies in Nepal. 7.

10. ENPHO (2017). Journal of Environment and Public Health, Volume 1, Issue 1

11. Clair N. Sawyer; Perry L. McCarty; Gene F. Parkin (2003). Chemistry for Environmental Engineering and Science (5th ed.). New York: McGraw-Hill.

12. Mogens Henze, Mark C. M. van Loosdrecht, George A. Kama, Damir Brdjanovic (2008) Biological Wastewater Treatment. IWA Publishing.

13. Gerba, C. P., & Pepper, I. L. (2019). Municipal Wastewater Treatment. In Environmental and Pollution Science (pp. 393–418). Elsevier. https://doi.org/10.1016/B978-0-12-814719-1.00022-7

14. Mohammed, D. N. H. (n.d.). Study of chemical oxygen demand (COD) in relation to Biochemical oxygen demand (BOD) In Tigris river at Missan Governorate. 20.

15. Ireland, & Environmental Protection Agency. (1997). Wastewater treatment manuals: Primary, secondary and tertiary treatment. E.P.A.

16. Ferree, M. A., & Shannon, R. D. (2001). Evaluation of a second derivative UV/visible spectroscopy technique for nitrate and total nitrogen analysis of wastewater samples. Water Research, 35(1), 327–332. https://doi.org/10.1016/S0043-1354(00)00222-0

17. Bunce, J. T., Ndam, E., Ofiteru, I. D., Moore, A., & Graham, D. W. (2018). A Review of Phosphorus Removal Technologies and Their Applicability to Small-Scale Domestic Wastewater Treatment Systems. Frontiers in Environmental Science, 6, 8. https://doi.org/10.3389/fenvs.2018.00008

18. Korostynska, O., Mason, A., & Al-Shamma'a, A. (2012). MONITORING OF NITRATES AND PHOSPHATES IN WASTEWATER: CURRENT TECHNOLOGIES AND FURTHER CHALLENGES. International Journal on Smart Sensing and Intelligent Systems, 5(1), 149–176. https://doi.org/10.21307/ijssis-2017-475

19. Tchobanoglous, G., Burton, F. L., Stensel, H. D., & Metcalf & Eddy. (2003). Wastewater engineering: Treatment and reuse.

20. Kekpugile, D. K. (2014). Modelling and Simulation of an Activated Sludge System for Industrial Wastewater Treatment. 5(7), 6.

21. Myllymaa, T. (n.d.). TALLINN WATER TREATMENT AND SEWERAGE. 6.

22. AS Tallinn Vesi. (2008). Environmental report 2008

23. European Green Capital. (2019). Indicator 9 Wastewater management

24. Riigikogu. (2019), Public water supply and sewerage Act. https://www.riigiteataja.ee/en/eli/529082019006/consolide

25. Riigi Teataja. (2019). Water Act. https://www.riigiteataja.ee/en/eli/527122019007/consolide

26. 25. Riigi Teataja. (2020). Environmental Charge Act. https://www.riigiteataja.ee/en/eli/509012020004/consolide

27. HELCOM Recommendation. (2007). Municipal Wastewater Treatment https://helcom.fi/wp-content/uploads/2019/06/Rec-28E-5.pdf

28. Council Directive (1991). Urban Wastewater treatment Directive (91/271/EEC). Official Journal of the European Communities.

29. Águas do Tejo Atlântico (2018). Alcântara WWTP 'The Water Factory'

30. Inocêncio, P. J., Eusébio, M., & Paixão, F. (2018). Otimização da linha de espessamento da ETAR de Alcântara. 151.

31. MINISTÉRIO DO AMBIENTE, (1997), Decreto-Lei n.o 152/97 de 19 de Junho, DIÁRIO DA REPÚBLICA — I SÉRIE-A

32. MINISTÉRIO DO AMBIENTE, (1998), Decreto-Lei n.o 348/98 de 9 de Novembro, DIÁRIO DA REPÚBLICA — I SÉRIE-A

33. MINISTÉRIO DAS CIDADES, ORDENAMENTO DO TERRITÓRIO E AMBIENTE, (2004) Decreto-Lei n.o 149/2004 de 22 de Junho, DIÁRIO DA REPÚBLICA — I SÉRIE-A

34. MINISTÉRIO DO AMBIENTE, DO ORDENAMENTO DO TERRITÓRIO E DO DESENVOLVIMENTO REGIONAL, (2008) Decreto-Lei n.º 198/2008, Diário da República, 1.ª série — N.º 195 — 8 de Outubro de 2008

35. MINISTÉRIO DO AMBIENTE, DO ORDENAMENTO DO TERRITÓRIO E DO DESENVOLVIMENTO REGIONAL, (2009) Decreto-Lei n.º 276/2009, Diário da República, 1.ª série — N.º 192 — 2 de Outubro de 2009

36. Richards, A. (2003). Effects of Detergent Use on Water Quality in Kathmandu, Nepal. Massachusetts Institute of Technology. 85.

37. KUKL, (2013). NEP: Kathamandu Valley Wastewater Management Project.

38. Rai, M., & Bhattarai, N. (2016). St. Xavier's College Maitighar, Kathmandu. 16.

39. Green, H., & Poh, S. C., Richards A. (2003). Wastewater Treatment in Kathmandu, Nepal. Massachusetts Institute of Technology. 25.

40. Anup Gurung. (2012). An overview of water pollution and constructed wetlands for sustainable wastewater treatment in Kathmandu Valley: A review. Scientific Research and Essays, 7(11). https://doi.org/10.5897/SRE12.053

41. Shrestha, R. R., Haberl, R., Laber, J., Manandhar, R., & Mader, J. (2001). Application of constructed wetlands for wastewater treatment in Nepal. Water Science and Technology, 44(11–12), 381–386. https://doi.org/10.2166/wst.2001.0855

42. Shukla, A., U. R. Timilsina and B. C. Jha, 2012. Wastewater production, treatment and use in Nepal.https://www.ais.unwater.org/ais/pluginfile.php/232/mod_page/content/134/Nepal_CountryPaper.pdf

43. Government of Nepal (1992). WATER RESOURCES ACT, 2049(1992). 11.

44. Government of Nepal (1997). Environment Protection Act, 2053 (1997). 12.

45. Ministry of Environment, Government of Nepal (2010) A collection of environmental standards and related information, original in Nepali

46. KUKL, (2018). NEP: Kathamandu Valley Wastewater Management Project-Guheshwori (PART B)

47. Ministry of Urban Development (2014). National Water Supply and Sanitation Sector Policy 2014. 31.

48. Estonian Environmental Agency (2019).

49. Fonte, B. M. D. (2017). Avaliação de Desempenho de ETAR - Balanços de Massa, Área Departamental de Engenharia Química, Instituto Superior de Engnharia de Lisboa

50. Thapa, B., Khatiwada, N. R., Ghimire, A., Adhikari, B., & Badaila, R. (2019). Study on Kinetics of Pollutants Removal in Guheshwori Wastewater Treatment Plant, Kathmandu. 7.

51. European Green capital (2020). Application form for the European Green Capital Award 2020 Indicator 9. 26.

52. Fernandes, C. C. R. (2016). Contribuição para a otimização da operação de lavagem em biofiltros: Tecnologia BIOSTYR®. Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa

53. de Seabra, R. V. (n.d.). Águas de Portugal. Edições Especiais, lda. 114.

54. KUKL (2019). Project Administration Manual, Nepal: Additional Financing for the Bagmati River Basin Improvement Project