APPRAISAL TO THE DEVELOPMENT OF WASTEWATER TREATMENT AND WASTEWATER TREATMENT METHODS

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ABSTRACT

Wastewater treatment has a much older history even before the advent of the Great Roman civilization. Today, wastewater has become a major problem with the rapid development, industrialization and population explosion. Since the beginning of the settlements, there were various methods of wastewater treatment used in many ancient cities, civilizations and countries. Along with the changes, the methods used were not adequate in response to current environmental problems. Thus, advance technology has to replace the old methods. However, history itself is an evidence of the use of advanced wastewater infrastructure. Though many papers have addressed wastewater treatment methods, there are fewer papers which address the development of wastewater treatment and methods of treatments. This appraisal expects to fill this gap.

KEYWORDS: History, Methods, Wastewater Treatment & Wastewater

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1 INTRODUCTION

1.1 Historical Background of Wastewater and Wastewater Treatment

Wastewater management is becoming increasingly a comprehensive problem along with urbanization, as urban as well as rural population are projected to nearly double in the future, where the sustainable development goal number six – clean water and sanitation’ – will become a challenge. At the current situation, a shortage of adequate wastewater management in most cities could be identified around the world, particularly due to ageing, absent, or inadequate sewage infrastructure. It is well documented that most of the technological developments relevant to wastewater treatment are developed by the use of ancient technical and scientific knowledge, where science and technology were not developed. The standard waste and sewerage treatment dates back to the third millennium BC. Angelakis and Rose (2014) argue this as more than 5000 years ago that the wastewater treatment had been implemented in ancient civilizations, now identified within the European continent. Many ancient cities had drainage systems. Among them, Minoans in the island of Crete (ca 3200–1100 BC) and Aegean islands and an unknown civilization (ca 2600–1900 BC) in the Indus valley at Mohenjo-Daro, Harappa and Lothal developed advanced, comfortable and hygiene (germ-free) lifestyles, as managed and manifested by efficient sewerage systems. However, the systems were predominantly planned to carry rainwater away from roofs and pavements. Wastewater management thus had not obtained much attention for centuries; therefore, ancient people used to dispose of wastewater at the settlements creating serious health and environmental impacts (Lofrano and Brown, 2010). Yet, there were few significant events in the history of mankind, which made a pathway to wastewater treatment and management. Habuba Kebira; a small city in Sumeria was among them. This was built to collect and carry wastewater outside the city walls. The pathways were similar to the U-shape made of terracotta pipes. Vallet
(1997) and Viollet (2000), both mentioned there were sewers covered with stone slabs. These sewers were oriented towards a location far from the street, where the pipe system was laid below the streets. In 2009, Corrigon authored an article on Minoan civilization, where the author stressed the impressive architectural and hydraulic system built for stormwater and wastewater sewerage. In that aspect, Minoans became one of the earliest universally distinguished architects. The Minoan’s centers (Figures 1.a and 1.b) were the ones that were created by the great Minoans. The most advanced Minoan sewage system was found in the villa of Hagia Triada. During the late Bronze Age (Knauss, 2003), Mycenaeans civilization constructed sewerage infrastructure, e.g., in Pylos. Orchomenos, Iolkos and Dimini Iolkos were other places found with applied advanced knowledge of wastewater management.

Mohenjo-Daro near the river Indus also developed wastewater management systems at about 1500 BC (Wiesmann, et al., 2007). The archaeological excavations in the Indus Valley found remains of latrines and cesspools along with conduit system connected to the main drainage system in the streets from each household in the area. The slope of the ditches was maintained to have a good flow towards the nearest river (Cooper, 2001). In that system, initially, wastewater was passed through elongated terracotta pipes into a small hole made to collect water, where settleable solids separated from the fluid and collected as sediments, while the clear fluids flowed over into drainage channels in the street (Lofrano and Brown, 2010). This could be considered as the world’s first attempt on wastewater treatment.

(a) (b)

Figure 1.1(a): Sewer Structure in the Palace of Knossos in Crete (b): Sewer Outfall on a Wall outside the Palace area in the Palace of Knossos in Crete (1700–1300 BCE).
Source: Corrigan, 2019 (Photographs credit: Keith Chapman)

The Romans in about 800 BC constructed world popular central sewer system called the “Cloaca Maxima” (Figures 1.2 and 1.3) for drain marshes and the system took surface water to the River Tiber (Cooper, 2001). Water was supplied by a watercourse system to carry sewage from the public baths and latrines to the sewers underneath the city and finally into the main river body, Tiber (Henze et al., 2008). According to Lofrano and Brown (2010), this system created by the Romans was one of the wunderkinder of the ancient world. However, the long-term discharge of waste and sewer water to a water body leads to contamination and pollution of water, eventually destroying the aquatic ecosystem. Tiber River also became highly polluted (WWAP, 2017). The greatest threat was that the Romans used the river water for their drinking purposes. The water became toxic with high pollution levels and the drinking, cooking, bathing and washing and other purposes were consequently limited creating a labyrinth of health issues. Apart from them, wastewater and sewerage infrastructure were found in the classical Hellenistic period too. Though it seems the evolution of wastewater treatment and management dates back to pre-history (earliest existence), where man knew instinctively the importance of allowing animal or human wastes to go downstream (Eddy, 2000).
Angelakis and Rose (2014) emphasize that throughout the Middle Ages, the progression of urban drainage and sewerage were not much noteworthy. Though bench holes and cesspits were used, most wastes were merely neglected and dumped into sewers to be flushed through gutters by floods. The houses built in the early 19th century used to install chamber pots connected to cesspits. In the meantime, the population expanded and the population growth rate doubled after the scientific revolution. The densely populated areas, such as Western Europe, South Asia and East America became polluted with rapid urbanization and industrialization. The local conditions of such areas became excruciating, making living difficult, as the cesspits frequently overflowed. Generally, the overflow of wastewater creates severe problems in public health, in particular. A well-known outbreak of cholera in the early and middle 19th century England was a consequence of contaminated well water in the line of human waste from bench holes and cesspits. This led to some vital decisions. All latrines in the larger towns connected directly to the storm gutters was another emerging problem; surface water pollution. During the 1900s, the solution for pollution was dilution. Natural purification of waters was possible if the discharge was minimum. However, water itself was difficult to purify naturally when the discharge exceeded the upper limit. Therefore, dilution failed to respond to pollution along with rapid urbanization. This made it necessary to treat wastewater physically chemically, or biologically to some degree before disposal led to the beginning of proper wastewater treatment methods.

Figure 1.3: Cloaca Maxima in Rome.
Source: Diamond & Kassel, 2018.
Wastewater treatment development was the most visible in the 20th century (Henze et al., 2008). Throughout history, rivers which were connected with the cities were used as the final discharge point of wastewater treatment. With the rapid development and expansion of cities, more pollutants were added into rivers that exceeded the assimilative capacities of rivers with increasing level of pollutants. Sewage treatment plants primarily used settling tanks to contain the suspended solids (primary treatment) before discharge to streams and rivers (Riffat, 2012) at the beginning of the 20th century. Use of hygiene standards (and testing methods) to be applied to effluents and sewage discharge to water courses was first framed with the emergence of the Royal Commission’s eighth report in 1912 (Royal Commission on Sewage Disposal 1912) (Cooper, 2001; Lofrano and Brown, 2010). With the emergence of hygiene standards, more attention had been given to the need of wastewater treatment for the productive elimination of pollutants in wastewater. As a result, the trickling filter system was developed to provide biological (secondary) treatment to wastewater (Riffat, 2012). After that the United Kingdom discovered the activated sludge system, which produced a well-treated discharge process (Henze et al., 2008). Since the mid-1900s, various types of biological and biochemical processes were developed and introduced for the removal of pollutants from wastewater (Riffat, 2012). With increased population growth, industrial development and scientific advance, more pollutants were introduced into wastewater, and it had made more environmental impacts such as eutrophication stressed the need for further processing than the secondary treatment, which led to tertiary treatment, which could be physical, chemical, biological, or a combination of these processes (Riffat, 2012).

2. WASTEWATER TREATMENT

According to Topare et al. (2011), “waste water treatment” comprises simply transforms complex organic substances in the wastewater into much simpler and stable substances by using either chemical, physical, or biological (involving microorganisms) processes. However, the purpose of wastewater treatment is to remove most, if not all, contaminants, including suspended settleable solids and colloidal particles, organic solid compounds, nutrients, toxicity and finally pathogenic microorganisms from water to get purified water or to meet the acceptable water quality standards. Templeton and Butler (2011) mention recover energy, nutrient, water and other valuable resources from wastewater as an indirect objective of wastewater treatment. The water quality standard depends on whether treated water will be reused or discharged into a water body or environment. However, Meneses, et al. (2010) commented that the key function is to minimize the environmental damage due to discharge of untreated wastewater freely into water bodies.

The contaminants in wastewater are removed by different treatment technologies or unit operations based on the source of wastewater and its characteristics. Those treatment technologies include mainly three types of unit operations, such as biological, chemical and physical. According to Wijetunga et al. (2009), all the process used for the treatment of wastewater have their advantages, disadvantages and limitations in terms of costs, treatability and secondary environmental impacts in the application for different types of wastewater. However, various array of a combination of these unit operations and processes take place in the wastewater treatment system (Topare et al., 2011).

The methods in which physical forces are predominant are included in the Physical treatment (Von Sperling, 2007). Physical treatment principally comprises screening, sedimentation, floatation and filtration process. One of the most common processes is “sedimentation”, where wastewater holds up for a shorter period in a cell under steady conditions, allowing the settling down of denser solids, and then clears away these sediments (Muralikrishna and Manickam, 2017).

Chemical treatment includes treatment methods in which the removal or conversion of the contaminants in the wastewater is brought about by the addition of chemicals or by stimulating other chemical reactions (Topare et al., 2011).
Typical chemical processes are precipitation, coagulation, adsorption and disinfection. In chemical precipitation, the insoluble chemical precipitate is formed by adding a chemical known as a coagulant (such as ferric sulfate, aluminium sulfate, etc.) and that chemical foam contains the constituents needed to be removed from the water. Some chemical sludge generated through the treatment may be difficult to treat (UN-Water, 2015). In most of the wastewater treatment plants and systems, both chemical and physical methods are often combined, especially in industrial wastewater treatment (Zia et al., 2013).

In contrast to both physical and chemical treatment processes, biological treatment process is perhaps the best technique in wastewater treatment with several advantages, such as decreasing the damaging effects to the environment. According to Von Sperling (2007), removal of pollutants in water occurs due to employing biological activity considered as biological treatment. Primarily, in this method, organic compounds (colloidal and dissolved) in wastewater is broken down into carbon dioxide (CO$_2$) and water (H$_2$O), methane (CH$_4$), or other end yields by microorganisms, such as bacteria, fungi and other microflora, which is also known as “biodegradation”. Apart from that, biological treatment is also used for the elimination of nutrients in wastewater. Depending on the dissolved oxygen (DO) level in the water, biological treatment methods distinguish as aerobic and anaerobic. The aerobic treatment method in ponds, lagoons, trickling filters and activated sludge, uses algae and bacteria that can survive under the aerobic condition for removal of contaminants. For many years, the anaerobic treatment system has been employed in industrial effluent treatment (Chang et al., 2009). In the study of Kudaligama et al. (2007) stated that anaerobic method of wastewater treatment is a simple and cost-effective method, which is noteworthy in enhancing the status of the environment in Less Developed Countries (LDCs). In anaerobic treatment, removal of biodegradable organic compounds occurs with the microorganisms that can survive in an environment, where there is no or low oxygen level. Anaerobic process degrades organic matter in wastewater into biogas, which is known as anaerobic digestion, as the gas is composed mainly of (CH$_4$) and (CO$_2$). The anaerobic treatment itself is very efficient in eliminating biodegradable organic substances, separating mineralized constituents like NH$_4^+$, PO$_4^{3-}$, S$^{2-}$ in the solution (van Lier et al., 2008). Distinguishing aerobic and anaerobic systems Chang et al. in 2009 explained suitability of each system for the treatment of low-strength wastewaters and high strength wastewaters, respectively. The combination of both anaerobic and aerobic treatment processes are commonly used in wastewater treatment systems and plants.

A typical wastewater treatment system or plant consists of different levels of treatment with a combination of the main types of treatment methods. Generally, such treatment is classified in the following levels (Figure 2.1):

- Preliminary Treatment or Pre-Treatment
- Primary Treatment
- Secondary Treatment
- Tertiary Treatment
- Disinfection
2.1 Preliminary Treatment or Pre-Treatment (PreT)

PreT is the initial process to occur when wastewater enters into the treatment plant. The aim of the PreT is to protect pumping equipment and facilitate subsequent treatment process by removing wastewater constituents, including larger suspended and floating solids (such as twigs, rags, dead animals, heavier grit, etc.), heavy inorganic solids and excessive oil and grease (Muralikrishna and Manickam, 2017; Spellman, 2000). Usually, physical methods are used in this treatment level and includes processes of screening, grit removal and floatation/skimming (Topare et al., 2011).

2.2 Primary Treatment (PT)

PT is the second level in the process after the PreT, which involves the elimination of settleable suspended solids and floating solids by mainly using physical methods. According to Muralikrishna and Manickam in 2017, “the primary treatment aims at sufficient reduction of the velocity of the wastewater to allow settling down of solids and floatable material to the surface” and “negligible importance for biological activity in primary treatment”. This process consists of a settling tank/sedimentation tank (Figure 2.2), clarifiers, or flotation tanks, which separates solids in wastewater (Zia et al., 2013). On some occasions, both PrT and PT are classified together, under PT (Barbosa and Sant'Anna Jr., 1989).
2.3 Secondary Treatment (ST)

ST, which is furthermore known as Biological Treatment (BT), involves the further treatment of supernatant, coming from PT. This treatment level involves the elimination of organic matter (dissolved or in suspension) in wastewater through biochemical reactions by using microbial communities under varying growth conditions (Von Sperling, 2007; Zia et al., 2013). According to Abdel-Raouf et al. (2012), this process is primarily mediated by a mixed population of heterotrophic bacteria that utilizes the organic substance for energy and growth. These microorganisms degrade the organic matter into CO₂, (H₂O) and cellular materials (growth and reproduction of the microorganisms) in the presence of oxygen (Von Sperling, 2007). This treatment is followed by sedimentation tank or secondary clarifier in which excess biomass is produced through the conversion of waste carbon to new cells, and is separated from the secondary treatment effluent (Riffat, 2012; Zia et al., 2013). Secondary BT can be categorized into either suspended growth process or fixed growth (film) process. In the suspended growth process, wastewater is brought in to contact with a variety of microorganisms in the suspension form in a biological reactor, and oxygen is introduced by air diffusers for biological activity to take place. The suspended growth process is used in oxidation ponds, aerated lagoons and activated sludge systems. From those, the activated sludge system is very effective with the versatile wastewater treatment process. Figure 2.3 illustrates such a conventional system, which includes a tank with aeration purposes and secondary subsystem to clarify to separate particulates (Zia et al., 2013). In aeration tank, wastewater is diversified with a microbial suspension, which metabolizes the organic pollutants in the presence of oxygen, and then this mixed effluent is separated into solids and treated effluents in a clarifier (Woodard and Curran, 2006). These clarified solids flow back to aeration tank and are called as “Activated Sludge”. In a fixed growth or film process, wastewater is sprayed or brought into contact with a biological mass in the form of a film (biofilm) fixed to a firm exterior medium (Dong et al., 2017). The biofilm process is included in Trickling Filters and Rotating Biological Contactors (RBC) (Figure 2.4) (Muralikrishna and Manickam, 2017). In the RBC, an array of closely packed circular disks are connected to a horizontal shaft, which is rotated in a chamber through which the wastewater is flowing and microbes that have attached themselves to the discs are adsorbed and absorb organic material and other nutrients from the wastewater (Riffat, 2012; Woodard and Curran, 2006). The trickling filter (Figure 2.5) is one of the oldest forms of BT for wastewaters (Spellman, 2000). A trickling filter consists of a shallow chamber filled with crumpled pebbles, rocks, or slag as media, which constitute a surface upon which the aerobic bacteria grow, digest and eliminate organic constituents in wastewater, and this wastewater is applied on the media from the top of the tank (Muralikrishna and Manickam, 2017; Riffat, 2012).

![Figure 2.3: Basic Components of an Activated Sludge System.](image)

Source: Von Sperling, 2007
Some anaerobic wastewater treatment practices can also be categorized under ST. In the anaerobic method, biodegradation occurs in the absence of oxygen and produce biogas as a useful byproduct (Zia et al., 2013). Secondary anaerobic treatment can be carried out either in anaerobic lagoons/ponds or closed anaerobic reactors. Anaerobic ponds are deep ponds used to treat wastewater that excludes oxygen and favor the growth of algae with bacteria to degrade constituents in the effluent (Quiroga, 2013). Anaerobic reactors can be categorized as attached growth (fixed film) and suspended growth process, as is the case with aerobic wastewater treatment systems. In the attached growth process, raw wastewater is digested by anaerobic microorganisms, which are fixed in the reactor. Attached growth system includes reactors, such as Expanded Bed Reactor (EBR) and Fluidized Bed Reactor (FBR) (Woodard and Curran, 2006). In the suspended growth process, microorganisms feed upon organic content of wastewater, which is freely suspended in the reactors (Woodard and Curran, 2006). There are various types of reactors developed on suspended growth process, which includes Upflow Anaerobic Sludge Blanket Reactor (UASB) and Anaerobic Contact Reactor. The typical and long-established anaerobic reactor is the UASB reactor (Zia et al., 2013). The UASB reactor (Figure 2.6) is an efficient process for the removal of organic substances and suspended particulates from wastewater. Particularly, in some tropical countries, UASB reactors have much tendency to be used in wastewater treatment (Von Sperling, 2007). Around 90% of organic constituents in the wastewater is removed during ST through microbial degradation (Muralikrishna and Manickam, 2017).

**Figure 2.4: Rotating Biological Contractor (RBC).**

Source: Lofrano and Brown, 2010

**Figure 2.5: Trickling Filter.**

Source: Lofrano and Brown, 2010
2.4 Tertiary Treatment (TT)

The TT is a synonym for the advanced method of wastewater treatment, but Spellman expressed (2000) TT and advanced method do not have exactly a similar sense of meaning. Treated wastewater after secondary treatment is clear and clean but is loaded with many impurities. If that effluent is discharged into the natural environment without any further treatment, it may cause many environmental hazards, such as eutrophication due to inorganic nitrogen and phosphorous (Abdel-Raouf et al., 2012). Therefore, TT is important to achieve environmentally acceptable water quality beyond secondary treatment. According to Von Sperling (2007), tertiary treatment is very rare in developing countries. This treatment involves mainly chemical and biological processes or their combination for the removal of wastewater constituents, including residual suspended solids, organic ions, inorganic nutrients and salts, heavy metals and toxic matter. TT includes processes such as activated carbon adsorption, chemical oxidation, ion exchange, electrodialysis, reverse osmosis, chemical precipitation, ozonation and nutrient removal (Zia et al., 2013; Topare et al., 2011). Study of de la Noüe et al. (1992) stated that the biological TT appears to perform well rather than the chemical methods because these chemical methods have high implementation cost and may cause secondary negative impact to the environment. Relating to that, the use of microalgae culture is very effective in the elimination of nutrients, such as nitrogen (N) and phosphorus (P) through absorption in TT (Dadrasnia et al., 2017).

Disinfection is the last level or step in the wastewater treatment process before releasing treated wastewater into the environment. None of the stages of the wastewater treatment process can guarantee the elimination of 100% of the incoming waste, thus, infectious species may remain in the treated effluent (Abdel-Raouf et al., 2012). The main aim of the disinfection process is to avoid contact with the infectious agent and pathogen viruses and bacteria, which result in waterborne diseases. So, Ahuja (2009) stated that disinfection greatly reduces the number of pathogenic viruses and bacteria in the water to protect public health. The quality of wastewater being treated, disinfectant dosage and type of disinfection being used influence the performance of the disinfection process. Disinfection of wastewater is achieved through various methods, including chemical, physical, biological, or their combinations. The disinfection processes include Chlorination, Ozonation, Ultraviolet (UV) Radiation, Membrane Filtration, Land Infiltration and Stabilization Ponds (Collivignarelli, 2017; Amin et al., 2013). Chlorination is a chemical method, which is used for disinfection, which is the commonest among other chemical methods due to its reasonable cost and long-established history of effectiveness. However, chlorination has become less and less attractive as disinfectant, mainly due to its potential toxicity to aquatic
organisms, especially fish (Abdel-Raouf et al., 2012). Therefore, the use of ecologically friendly wastewater disinfection techniques (Ergaieg and Seux, 2009) could be one of the most exciting advances in this field.

3. CONCLUSIONS

This paper traces the evolution of wastewater management associated with the treatment and disposal of wastewater and ecology since early history. Throughout history, there were various methods that had been used in the wastewater treatment based on the characteristics of wastewater. Use of naval technology for wastewater treatment has already begun among developed nations. Among such technologies, (1) the Lamella settler to remove oils and solids from residual water (Wang et al., 2005), (2) ‘membrane bioreactor’ of biological treatment methods is the newest method for biodegradation of soluble organic constituents in the wastewater. Another new treatment plant design introduced by the Australian scientists based on the theory of ‘passive aeration’ in which aerobic bacteria are exposed to the open air for a time interval by draining water from the reactors. With the development of naval technologies, it is vital to select a proper system for wastewater treatment based on operational costs, further extension capabilities, footprint, minimal sludge production, coop with variation in the type of pollutants and influent rate and environment-friendly are the few criteria of concern in order to have a clean and healthy environment in the world.

REFERENCES


AUTHOR'S PROFILE

**N.A.U.S. Seneviratne**, currently following an M. Sc.in Environmental Sciences in University of Colombo of Sri Lanka. I have received the B.Sc. (Special) Degree in Forestry and Environmental Sciences with a First Class from the University of Sri Jayewardenepura of Sri Lanka. As a fulfilment of the Special degree in Forestry and Environmental Sciences, I have conducted an individual research project with regard to “Estimation of aboveground carbon stocks in selected home gardens in four agro-ecological regions in the low country Intermediate Zone of Sri Lanka” and it has been presented at 18th International Forestry and Environment Symposium in 2013 (Link: http://journals.sjp.ac.lk/index.php/fesymo/article/view/1937). In 2014, I started to work as an Environmental Officer in Central Environmental Authority of Sri Lanka which is a main Government agency in the country to deal with environmental conservation, pollution control and waste management. My current research interest leans heavily towards wastewater management, environmental pollution control and climate change measures. I would like to explore new knowledge by carrying out research and thereby I will be able to work with research communities, universities, and industries. Since 2017, I have been a member of Institute of Environmental Professionals in Sri Lanka (IEPSL). I’m a highly dedicated and enthusiastic person with a proven ability and much sensitive to environmental conservation.

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