Tan Phong HO

CLOSED-LOOP AND LINEAR URBAN WATER MANAGEMENT: CASE STUDY OF SINGAPORE AND HO CHI MINH CITY

Indirect potable reuse as a recommendation of water management in Ho Chi Minh city, Vietnam

Thesis
CENTRIA UNIVERSITY OF APPLIED SCIENCES
Degree Programme
September 2023

ABSTRACT

Centria University of Applied Sciences	Date September 2023	Author Tan Phong HO
Degree programme Environmental Chemistry and Technology		
Name of thesis CLOSED-LOOP AND LINEAR URBAN WATER MANAGEMENT: CASE STUDY OF SINGAPORE AND HO CHI MINH CITY, VIETNAM. Indirect potable reuse as a recommendation of water management in Ho Chi Minh city, Vietnam.		
Centria supervisor Jana Holm		**Pages** 66

The thesis aims to transition Ho Chi Minh City (HCMC) from traditional water management strategies to a sustainable water management approach, drawing lessons from Singapore. To achieve this, HCMC should develop new water sources through rainwater catchment, wastewater reclamation, and desalination for an indirect potable reuse system. The establishment of a new organization by the HCMC government to manage the entire urban water cycle is crucial for seamless planning, construction, and operation, providing a foundation for the implementation of an indirect potable reuse system.

The thesis emphasizes the importance of water use and management as a collective effort involving all citizens. It presents a coherent and simplified logical framework to facilitate understanding even for individuals with limited background knowledge in engineering.

Key words

Water and wastewater treatment, water management, water reuse

CONCEPT DEFINITIONS

List of abbreviations

aq	aqueous solution
AWTP	Advanced water treatment plant
DPR	Direct potable reuse
HCMC	Ho Chi Minh city
IPR	Indirect potable reuse
RO	Reverse osmosis
s	Solid
SAWACO	Saigon Water Corporation
WTP	Water treatment plant
WWTP	Wastewater treatment plant

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1 INTRODUCTION

Climate change is becoming increasingly complex worldwide, and its impact on water quality is unpredictable. Many countries are predicted to face water scarcity in the future. The raw water sources in Ho Chi Minh City are also becoming more polluted and complicated. The city is planning to switch its raw water source by extracting water from a cleaner location 15-20 km away. However, the pollution situation in the river streams is severe, and nobody can guarantee the absolute safety of the upper water source without additional harmful factors. The root issue lies in managing water source security. (Nguyen & Ha 2021.). Water reuse presents an approach to address the impending shortage of clean water worldwide. Since drinking water is an essential daily survival need for humans, and searching for distant clean water sources is not a sustainable solution, water reclamation has the potential to utilize wastewater as a new water source to expand water supply for people. Especially, direct water reuse minimizes dependency on the environment during the water treatment process. This thesis provides a summary of basic information about water reuse to establish a fundamental foundation in this field.

Furthermore, according to a study on rainwater usage in Ho Chi Minh City, a significant number of people are hesitant to use rainwater due to concerns about its safety, primarily driven by a lack of scientific awareness (Le & Le 2019). Comparing natural rainwater that has sustained human life for centuries with treated wastewater from "toilet to tap," it can be predicted that gaining public consensus on using treated wastewater in the future may encounter similar or even worse challenges. Recognizing the importance of public awareness in effectively implementing water reuse, this thesis strives to present easily understandable explanations, catering to individuals with limited engineering knowledge while still meeting academic requirements. The hope is that this paperwork can serve as a foundation for the author's future comprehensive studies to enhance public awareness of drinking water and water reuse in the future.

To determine the feasibility of applying water reuse to address persistent issues discussed in Chapter 4, fundamental knowledge about water reuse is introduced in Section 2.4 of the literature review. The choice of focusing on water reuse, rather than other concepts, is elaborated upon. In Chapter 3, the urban water cycle of Ho Chi Minh City and Singapore is introduced and described to highlight the differences between the two case studies. Singapore, with several natural similarities to Ho Chi Minh City, has successfully implemented water reuse in urban areas, establishing an efficient closed-loop water management system.

Additionally, Chapter 2.3 provides a basic introduction to the operation of water treatment plants and wastewater treatment plants, revealing how the clean water consumed daily by individuals is the result of a comprehensive water treatment and wastewater treatment system, utilizing a suitable raw water source as a crucial input. Chapter 2.1 and 2.2 presents fundamental factors such as water treatment methods, water quality, and more. The thesis does not cover every related piece of information but aims to identify characteristic information and establish a perspective on water reuse and water treatment, enabling readers to conduct further in-depth research with the provided references if interested. Knowledgeable researchers can still access a portion of the urban water cycle of Ho Chi Minh City within the article. While the pipeline system plays a significant role in water transportation, affecting water treatment processes and water quality to some extent, it is not extensively discussed in this paper. The source materials include books on water treatment, wastewater treatment, and water reuse from the United States, United Kingdom, Finland, United Nations, WHO, along with various online resources, which will be listed in the References section.

2 LITERATURE REVIEW

In the literature review section, the primary objective is to identify key and interconnected information, aiming to establish a coherent and seamless logical framework. This approach allows readers to develop a fundamental understanding of water and wastewater treatment, as well as water reuse, while ensuring academic rigor. The reference materials include books on water treatment, wastewater treatment, and water reuse from the United States, Finland, some other countries, the United Nations , and WHO, as well as numerous online resources. Materials from a variety of countries and organizations may support readers to find a suitable materials to study deeply any related topic in this thesis.

First of all, section 2.1 explains how and why water is polluted smoothly in nature, and the scientific perspective allowing for the quantification of water quality. Water treatment methods are introduced in section 2.2 to briefly explain operating principles of these methods rooted from fundamental science. Section 2.3 presented water treatment plants, households, and wastewater treatment plants to describle a fundamental approach how different types of water is consume in different facilities. If water treatment methods were likened to individual mathematical operations in section 2.2, water treatment plants and wastewater treatment plants could be seen as the application of a combination of these operations to solve specific problems. Circular economy and classification of water reuse are explored in section 2.4 and 2.3, so readers have inside preparing for case studies in section 3.

2.1 Basis of water, water quality and water contaminants

Evaluating the cleanliness of a glass of water solely based on human senses can be challenging, as certain contaminants that lead to contamination may not always be discernible through ordinary sensory perceptions. The assessment of water quality is imperative, as it involves a comprehensive examination of the water's state, considering its physical, chemical, and biological characteristics, while employing suitable techniques for monitoring purposes. Furthermore, it is imperative to acknowledge that there is not universally defined "optimal" water quality. Rather, the assessment of water quality must be conducted with respect to its appropriateness for particular intended applications. (Water Quality Association; Schutte 2006, 3-12.)

In order to ensure the provision of safe and reliable drinking water, regulatory authorities have been instituted by governments worldwide. These authorities play a crucial role in establishing and enforcing standards for water quality across different countries. The esteemed authorities diligently implement public regulations to ensure the protection of human health against the perils posed by water contamination. They derive guidance from esteemed regional organizations like the European Union (EU), as well as esteemed global organizations such as the United Nations (UN) and the World Health Organization (WHO) . (Kemira 2020, 34.). In order to attain the desired water quality that is appropriate for a particular purpose, various water treatment techniques are employed. These methodologies utilize fundamental principles derived from the realms of physics, chemistry, and biology to proficiently eliminate impurities from water. By employing various physical, chemical, and biological techniques, water treatment procedures effectively eradicate or diminish impurities to meet acceptable thresholds and enhance the overall water quality. (Kemira 2020, 34; Schutte 2006, 7-12.)

2.1.1 Water

Water is commonly recognized as a colorless, odorless, and tasteless liquid that boils at around 100°C and freezes at approximately 0°C. Consequently, deviations from these characteristics, such as water having an unusual color, odor, or taste or evaporating at 80°C and freezing at 10°C, can indicate potential issues. All matter is comprised of countless molecules or atoms, according to chemistry. In the case of water, it is made up of extremely small water molecules. These water molecules contain the chemical formula H_2O, which means that hydrogen and oxygen form polar covalent bonds, resulting in polar, or asymmetrically charged molecules. Because of this polarity, hydrogen has a slightly positive charge and oxygen has a slightly negative charge, facilitating attraction forces between water molecules. As a result of the opposing charges, water molecules are brought together, producing hydrogen bonds. Water also has attractive interactions with other polar molecules and ions. This property permits polar compounds or ions to dissolve readily in water, as demonstrated by the dissolving of the salt sodium chloride in water. The hydrogen bonding in water provides an environment that is favorable to polar molecules. (OpenStax; Horky 2018.). Non-polar molecules, on the other hand, are unable to form hydrogen bonds. Non-polar molecules tend to cluster together in a polar environment like water, generating a tight barrier that prevents water from surrounding the non-polar molecule. This process explains the reason, as non-polar molecules, oils and fats form a barrier between themselves and water when in contact with it. (OpenStax 2.5; Horky 2018.)

While water cannot dissolve non-polar substances, it has earned the title "universal solvent" due to its exceptional ability to dissolve a broader range of substances than other liquids (Water Science School 2018). However, this feature makes water vulnerable to pollution from a variety of sources, including soil pollution, air toxins, and the activities of living creatures. It is important to highlight that pure water is never seen in nature, and the discovery of an untreated water source appropriate for direct ingestion is becoming increasingly unusual. (Binnie & Kimber 2013, 9.). Most water sources require some type of treatment before they can be used for potable water supply. Water encounters a wide range of substances along its voyage through the hydrological cycle, which includes activities such as rainfall, runoff, infiltration, impoundment, usage, and evaporation. These compounds have the capacity to dissolve or remain suspended in water to varied degrees. (Schutte et al. 2007, 5-7; Binnie & Kimber 2013, 9.). Interactions with numerous polar compounds in the environment, soil, and other water sources can lead to pollution. Comprehend the intricate dynamics by which water quality can be changed and contaminants can enter the water supply requires a thorough grasp of the chemical characteristics of water. This information contributes to the development of effective strategies for the preservation and safeguarding of water resources for both human and environmental well-being. (OpenStax 2.5; Binnie & Kimber 2013, 9; Schutte et al. 2007, 5-7.)

2.1.2 Water quality

The concept of clean water cannot be based exclusively on our shared sensory understanding in the context of human perception. While a glass of water may appear visually clean to the human eye, free of any visible objects, colors, odors, or tastes, this does not always imply that the water is sufficiently clean or safe for consumption. This is because there may be disease-causing bacteria, viruses, parasites, or inorganic chemicals in the water that our human senses cannot detect. (Water Quality Association.). On the contrary, water that appears black to the naked eye does not always imply contamination (Water Quality Association). Coffee powder, for example, is a soluble solid material. When coffee powder is dissolved in a cup of boiling water, the boiling water converts into hot coffee and its qualities alter. A colorless, odorless, and tasteless cup of boiling water transforms into a black cup of coffee with the aromatic aroma of coffee and a bitter coffee flavor. Despite its dark color, the coffee in the cup is regarded a healthy beverage that is helpful to human health since caffeine has several favorable effects on the brain. (Nehlig 2015.)

Furthermore, adverse impacts can be categorized into several sorts. Direct touch, for example, can have negative consequences, such as the harm caused by drain or toilet bowl cleaners when it comes into direct contact with the human body (healthdirect 2022). Consumption can also be hazardous to the health; for example, eating untreated polluted water can introduce harmful germs into the body, causing gastrointestinal discomfort. Excessive purity can sometimes be harmful, as shown with distilled water, which comprises mostly water molecules and lacks vital minerals. Drinking such water for an extended period of time may result in mineral deficiencies in the body in case of without mineral supplementation .(SVALBARDI.). Excessive supplementing can also be harmful, as demonstrated by consuming a glass of vitamin C water created by dissolving 100 vitamin C tablets (1000 mg of vitamin C/tablet) in a glass of clean water. Each tablet already meets the average person’s daily vitamin C need. Consuming this vitamin C water would be harmful because it would exceed the body's absorption capability. (Shmerling 2023.)

Water quality assessment is more complicated than just labelling it as good or bad. Water quality, from a scientific standpoint, refers to the total condition of water, taking into consideration its physical, chemical, and biological properties, frequently in relation to its intended purpose. When determining water quality, several parameters are taken into account, including pH, temperature, dissolved oxygen levels, turbidity, nutrient concentrations, the presence of pollutants or contaminants, etc. (Schutte 2006, 3-5; National Oceanic and Atmospheric Administration.)

Water quality standards are a comprehensive framework that defines a collection of parameters and specifications relating to the condition and characteristics of water for various applications. When the real state or qualities of water is investigated, these standards apply. They are definitive rules or prescribed limitations developed by regulatory authorities with the goal of ensuring that water resources correspond to explicit quality requirements, thereby maintaining both humanity’s and the natural environment’s well-being. Water quality standards include the intended use of a body of water, the criteria aimed to preserve these intended uses, and the anti-degradation rules designed to conserve existing applications. The criteria used to evaluate water quality can have either quantitative characteristics, such as establishing permissible maximum concentrations of pollutants within a given water body, or qualitative characteristics that vividly depict the desired state of a water body, emphasizing its liberation from specific adverse factors. (EPA 2023b; EPA 2017.)

For example, the QCVN 08-MT:2015/BTNMT National technical regulation on surface water quality in Vietnam includes 33 factors for measuring surface water quality. Water is classified into two classes in this regulation: Class A (A1 and A2) for water appropriate for drinking water production and Class B (B1 and B2) for other purposes, based on the stated limit values for each parameter (QCVN 08-MT: 2015/BTNMT). Governments in several nations have formed regulatory authorities to standardize water quality, with a special emphasis on drinking water quality requirements. These authorities enforce public regulations to protect human health from the dangers of contaminated water. They base their judgments and approaches on references from regional organizations such as the European Union (EU) as well as global organizations such as the United Nations (UN) and the World Health Organization (WHO). (Few-trell & Bartram 2001, vii-viii; Binnie & Kimber 2013, 16-21.)

For instance, in Singapore and Vietnam, the National Water Agency has created drinking water standards in compliance with the Environmental Public Health (EPH) Regulations. These requirements are based on World Health Organization (WHO) principles for assuring the quality of drinking water. The drinking water standards in Singapore include 129 factors that are examined and monitored. (PUB 2021.). In the case of Vietnam, the domestic water quality is regulated by the technical regulation QCVN 01-1:2018/BYT, which was issued by the Ministry of Health. This regulation was accompanied by Decree No. 41/2018/TT-BYT dated December 14, 2018. Vietnam's home water quality standards include 99 factors that are studied and evaluated to assure the quality of water intended for household consumption (QCVN 01-1:2018/BYT). Singapore and Vietnam have both established guidelines to protect the quality of drinking water and domestic water supply, with their respective standards encompassing a wide range of parameters to ensure the safety and suitability of water resources for human consumption and daily use. (PUB 2021; QCVN 01-1:2018/BYT.)

2.1.3 Water contaminants and pollutants

Contamination is defined as the presence of a substance in an area where it is not normally found or in proportions greater than background values. Pollution, on the other hand, is defined as contamination that causes or has the potential to have unfavorable biological consequences for resident communities. (Chapman 2007.). It is crucial to note that while all pollutants are considered contaminants, not all contaminants are designated as pollutants. Basing on previous definitions, water contaminants are substances or materials that are not naturally occurring or exist in proportions greater than background levels in water. These contaminants have the potential to have a negative impact on the physical, chemical, and biological aspects of water, compromising its suitability for specific uses. Water pollutants, on the other hand, are water impurities that endanger the health of residents when water is used for its intended function. There are some contaminants that appear in the water during water treatment process. For example, chloride is added to the water for disinfection. The remaining amount of chloride, if not removed, will become pollutants to humans. (Schutte 2006, 21.)

The contaminants or chemicals that may be found in water sources are numerous and classically included suspended matter, oxygen-consuming substances, nutrient salts, bacteria, viruses, parasite spores and eggs, toxic metals (heavy metals), environmentally harmful substances. These contaminants in water can be classified using a variety of classification systems. These systems can distinguish substances based on their state as dissolved or particulate, their nature as inorganic or organic, their magnitude as macro or micro substances, their origin as natural or synthetic compounds, or even their occurrence as microorganism suspensions, among other criteria. Similar substances with shared characteristics in a classification system and can be effectively treated using the same type of treatment process are typically grouped together for design purposes and general discussion. In most cases, considering each specific substance of concern separately in terms of treatment feasibility is impractical. However, there are exceptions to this approach, particularly when addressing the removal of toxic substances from water, which often requires specific treatment methods tailored to the particular substance. (Schutte 2006, 5-10; Kemira 2020, 47-57.)

Water already contains a variety of impurities when it arrives at a water treatment facility. Because water is largely a mixture; it is difficult to tell which parts are solutions and which are solids. Except in rare situations, substances with comparable qualities are frequently treated collectively rather than separately from the water. Contaminants in visible suspension in water are classified using the categories of dissolved and suspended contaminants (particulate). Soluble contaminants are substances in water that have the ability to dissolve entirely or partially. There are two types of soluble contaminants: gas solutes and non-gaseous solutes. Gases such as oxygen (O_2), carbon dioxide (CO_2), and ammonia (NH_3) are examples of gas solute contaminants. Non-gaseous soluble contaminants are divided into two types: inorganic compounds and organic substances. Organic components include humic acids and carbohydrates, whereas inorganic compounds include sodium chloride (NaCl) and calcium sulfate ($CaSO_4$). (Schutte 2006, 5-7.)

Soluble contaminants in water are more difficult to remove than suspended contaminants. These impurities must be converted into solid or gas forms before they can be eliminated. To transform soluble contaminants into solid particles, precipitation and precipitation reactions are used. When it comes to transforming soluble contaminants into gases, introducing oxygen into the water via appropriate techniques allows the contaminants to escape or be removed from the water in gas form. Advanced techniques such as reverse osmosis and activated carbon adsorption can be used in addition to these approaches to successfully remove soluble contaminants. (Schutte 2006, 5-7;.Spellman 2003, 293, 298.)

Non-soluble contaminants, on the other hand, are substances that do not dissolve in water but often remain suspended in the form of particles, either suspended or colloidal. Among these non-soluble contaminants, settleable solids stand out. Settleable solids or sedimentary contaminants are bigger and heavier than suspended and colloidal solids. Settled sediments naturally settle at the bottom of water and can be easily removed, reducing their impact and relevance. However, settleable solids, such as stones, are often removed by screening in preliminary process. Non-soluble contaminants are classified basing on size. (Schutte 2006, 5-7; Spellman 2003, 298, Kemira 47-57.)

Suspended solids are relatively big particles that settle easily when the water is quiet. The presence of suspended solids is determined by filtering a known amount of water sample and measuring the mass of the solids after they have dried. Colloidal particles, on the other hand, are significantly smaller in size and have an electrical charge that prevents them from settling. They can float in water for extended periods of time without settling. Colloidal suspensions are stable and must be destabilized in order to aggregate into bigger floc particles that can be successfully removed via sedimentation and filtration. Coagulation results in destabilization, while flocculation results in aggregation. Colloidal particle size and effect to water are frequently used as defining factors. (Schutte 2006, 5-7; Spellman 2003, 293, 298, 300.)

Turbidity particles in surface water range in size from 0.2 to 10 μm and are mostly composed of hydrophobic inorganic clay minerals. Coagulation-flocculation and separation procedures can easily reduce turbidity. Colouration in natural water is typically caused by colloidal organic compounds with molecular weights ranging from 800 to 50,000 Da, such as humic and fulvic acids. Water colouring can also be caused by colloidal metal hydroxides, such as iron. These color-causing particles are primarily hydrophilic, making coagulation removal more difficult than turbidity particles. Bacteria, viruses, and micro-algae can also display colloidal characteristics. These bacteria are made up of polar organic molecules that are hydrated and have hydrophilic properties. Certain complex organic molecules in treated industrial effluent can also be termed colloidal in nature. (Schutte 2006, 5-7; Spellman 2003, 293, 298, 300.)

These contaminants, as previously mentioned, have the ability to influence and modify the physical, chemical, and biological aspects of water. Their implications on water quality are now being considered. When evaluating physical qualities, it is vital to remember that natural water is not made up entirely of water molecules. Water's physical quality is determined by its intrinsic properties as well as the presence of dissolved and colloidal particles. Temperature, viscosity, and surface tension are examples of intrinsic physical qualities. However, the presence of dissolved and colloidal particles in water has a substantial impact on other physical attributes like as electrical conductivity, color, taste, and odor. As a result, the primary physical attributes influenced by pollutants are electrical conductivity, color, taste, and odor. (Schutte 2006, 10-11.)

Chemical characteristics characterize a substance's reactivity and chemical behavior. These features include the ability of the material to undergo chemical processes, interact with other chemicals, and convert into new molecules. Dissolved organic and inorganic components determine the chemical quality of water. These chemicals have a variety of effects on the chemical characteristics of water. For example, certain chemicals, such as chromium and arsenic, can be hazardous, making the water itself toxic. Others, such as calcium carbonate, can cause water hardness or scaling. As a result, dissolved organic and inorganic pollutants have an effect on the chemical characteristics of water. (Schutte 2006, 7-10.)

Physical and chemical properties are combined in physicochemical properties. Although they are referred to as physical qualities, physicochemical features are chemical in nature. The physicochemical property pH is one example. It is physical in the sense that it can be quantitatively measured using instruments and stated on a numerical scale. pH values vary from 0 to 14, with 7 being neutral, values less than 7 indicating acidity, and values more than 7 indicating alkalinity. Nonetheless, pH is inextricably tied to a substance's chemical properties. It represents the concentration of hydrogen ions, which directly determines the acidity or basicity of the substance. The concentration of hydrogen ions in an aqueous environment influences chemical reactions, compound solubility, and the behavior of numerous compounds. (Schutte 2006, 7-10.)

Microbiological quality is defined by the types and numbers of microorganisms present in water. A variety of microorganisms may be present even in high-quality home waters. While the vast majority of these bacteria are non-pathogenic, polluted water may include pathogens. Pathogens are microorganisms that cause diseases such as cholera, gastroenteritis, and hepatitis, among others. As a result, when undesired microbes invade or particular microorganisms flourish beyond control, the microbiological quality of water deteriorates. Furthermore, radioactive pollutants provide both a high level of threat and a limited frequency of occurrence. Radiological pollutants are chemical elements with an uneven number of protons and neutrons that produce unstable atoms capable of generating ionizing radiation. Cesium, plutonium, and uranium are examples of radioactive pollutants. (Schutte 2006, 11-12; EPA 2022.)

2.1.4 Parameters

Each country's government regulates and announces the quality of its drinking water. There are regulations in place to control the concentration of dangerous compounds such as heavy metals. However, due to expense and operational challenges, it is not practical to test every single water component on a regular basis. As a result, effective instruments for assessing water quality are required, and these tools are parameters such as pH, turbidity, color, smell, taste, dissolved oxygen, and others. These factors might be qualitative (such as odor and taste) or quantitative (such as pH and dissolved oxygen levels). They function similarly to the "°C" on a thermometer, with people deciding what clothes to wear based on the temperature measurement. Water at an optimal temperature of 50-60°F (10-15.6°C), for example, is considered pleasant. Turbidity, which indicates the presence of suspended particles in the water, aids in determining the amount of contaminants present. (Schutte 2006, 10-12; O’Donnell 2021; Kemira 2020, 47-57.)

These requirements not only protect the safety of the water, but also regulate the water treatment process. Water turbidity, for example, is an important element since it impacts water clarity. Water can become hazy due to the presence of sand or dust particles. Chloride, on the other hand, is not naturally plentiful in water sources and is often added during water treatment processes, particularly disinfection. Monitoring chloride levels shows not only the safety of drinking water, but also whether the addition of chloride throughout the water treatment process is calculated efficiently by the water treatment facility. Physical parameters (color, odor, taste, turbidity, conductivity, pH, temperature, total solids, total dissolved solids) and chemical parameters (acidity, alkalinity, chloride, hardness, dissolved oxygen, total organic carbon (TOC), dissolved organic carbon (DOC), chemical oxygen demand (COD), biological oxygen demand (BOD) are the most common. To test water safety, biological factors such as algae, viruses, total coliforms, faecal coliforms, and E. coli are also measured. It is critical to monitor these characteristics to ensure safe drinking water and efficient water treatment operations. Regular examination and control of these elements help to the provision of safe and healthy drinking water. (Schutte 2006, 10-12; O’Donnell 2021; Kemira 47-57.)

2.2 Water treatment methods

Water treatment, as previously noted, strives to achieve certain quality criteria for a variety of uses. The treatment procedure includes the use of physical, chemical, and biological principles to remove contaminants from water samples and achieve the desired water quality for a specific usage. In a more practical approach, author classifies a method as energy intensive method which uses much more energy than other methods. (Cheremisinoff 2002, 1.). Water treatment entails more than just collecting acceptable water; it also entails the proper separation of water and contaminants. While qualifying water can be used, contaminants can be recycled for acceptable applications or properly disposed of to avoid pollution. (UN-Water 2017, 1-7.)

Certain approaches, such as evaporation, are more suited for assessing the state of a water sample in a laboratory setting. However, in water treatment plants, the primary goal is to create cost-effective water that meets domestic criteria. As a result, water treatment procedures are used in conjunction rather than in isolation to improve efficiency and efficacy. In this section, for the purpose of simplification, some methods are classified under either physical or chemical approaches, although they incorporate principles from both physical and chemical aspects. Take activated carbon filters as an example; while adsorption is a complex process involving both chemical and physical factors, it can be more easily understood through a simplified explanation. However, further research is necessary to fully understand the nature of each method. These below methods represent general treatment approaches, and it should be noted that there exist numerous other treatment methods not covered in this section. (Schutte 2006, 12-13.)

2.2.1 Physical (or mechanical) treatment

To remove water from impurities, physical treatment methods use a variety of approaches based on heat, pressure, gravity. A variety of general physical treatment procedures can be used. Physical treatments indicated below cover popular water treatment approaches, however it is crucial to note that there are numerous additional physical treatment methods that are not covered in this section. The physical treatments are covered as boiling, evaporating, distillation, filtering, microfilter, sand filter, activated charcoal filter, reverse osmosis (RO), sedimentation, flotation, ultraviolet (UV) radiation. (Cheremisinoff 2002, 35-36; Schutte 2006, 20; Spellman 2003, 28.)

Boiling water is a common way for disinfecting water at home. Boiling water involves the use of heat to raise the temperature of the water, creating an environment that kills hazardous germs that cannot tolerate high temperatures. When pathogenic bacteria, protozoa, and viruses are exposed to temperatures about 100 °C, they are rendered inactive. Temperature and time are both important elements in achieving good disinfection. However, boiling water on a big scale in drinking water or wastewater treatment plants may appear impracticable due to the massive amount of water involved, which necessitates a significant amount of energy. Furthermore, a significant volume of water would evaporate during the process. (Schutte 2006, 20; Cheremisinoff 2002, 33-34; WHO 2015.)

The evaporating water method primarily use evaporation to identify solids in water. In principle, this method of separating water and contaminants is quite efficient. However, treating water to improve water quality is pointless if all of the water evaporates. As a result, rather than being used to purify water, the total evaporation method is used in laboratories to detect the state of water. By completely evaporating a sample of polluted water at 103°C, all dissolved or undissolved solids in the water sample is retained, allowing total solids in the water sample to be determined. (Cheremisinoff 2002, 34; Spellman 2003, 28.)

Distillation makes use of the evaporation and condensation processes. Impurities having boiling temperatures greater than water cannot evaporate with the water molecules once they evaporate. As a result, when the water molecules condense, contaminants with differing condensation properties than water will not condense. Chemical pollutants with lower boiling points than water, on the other hand, will readily evaporate and condense with the water during simple distillation. As a result, the distilled water recovered will still be polluted. The primary purpose of distillation is to extract dissolved minerals and salts from water. Distilled water is near to pure water because it is created by distillation. As a result, distilled water lacks several vital minerals and is unsuitable for long-term consumption without mineral supplement. (Cheremisinoff 2002, 34.)

Filtering is a type of water treatment that uses either gravity or pressure. Water is filtered through a filter with adequately sized holes. Water molecules can travel through these holes while larger contaminants are trapped. Filters are classified into several types, with the primary difference being the material utilized. Making an efficient filter is more than just making the proper size holes on a flat surface. Openings of appropriate size are inherent in natural materials. It is critical to choose the right material when making a filter with the right size apertures for water purification. Microfilters, sand filters, and activated charcoal filters are three regularly used filters. Microfilters use either pressure or gravity. The filter filters water through small holes. Microfilters are used to filter water of cysts, suspended particles, protozoa, and, in certain situations, bacteria. One disadvantage of microfilters is the possibility of bacterial development on the filter medium. The material used to make the filter has an impact on its functionality and reusability. (Cheremisinoff 2002, 35-36.)

Slow sand filters, which are a form of sand filter, work by either gravity or pressure. Water slowly flows through a sand bed, removing pathogens and turbidity by natural die-off, biological action, and physical filtering. The filter is typically composed of a sand layer and a gravel layer with an integrated drainpipe. To prevent water from rapidly bypassing the sand layer, the gravel does not come into contact with the filter walls. Slow sand filters are typically huge boxes with a loading rate of 0.2 m^3/m^2 surface area per hour. Slow sand filters are ideal for ongoing water treatment due to their architecture. To guarantee efficient performance, the water entering the filter should contain the fewest suspended solids feasible, or the pumping method might be adjusted to reduce turbidity. The filter can be cleaned multiple times before the sand needs to be replenished. Rapid sand filters are another form of sand filter that is often utilized. They are comparable to slow sand filters but have a higher flow rate. The primary distinctions are in construction, control, and operation. The water flow in quick sand filters normally travels downhill at around 5 m/h. Backwashing, which involves reversing the flow of water to release trapped particles, is used to clean these filters and keep them efficient. The intervals between backwashing might range from 12 to 72 hours. (Schutte 2006, 19-20; Cheremisinoff 2002, 35; Spellman 2003, 473.)

Activated charcoal filters rely on absorption and use gravity or pressure. The adhesion of substances to the surface of a solid or liquid is referred to as absorption. Activated charcoal's porous structure gives a huge surface area per unit mass, up to 1,000 m^2/g, with countless tiny pores and empty spaces. When water travels through the filter, chemicals and some heavy metals are drawn to the surface of the charcoal and become entangled in its pores and empty spaces. While charcoal filters can filter certain pathogens, they quickly exhaust their adsorptive capacity (available-empty area) and can potentially become a source of contamination due to the charcoal's ability to support bacteria and algae growth. The amount of activated charcoal in a charcoal filter determines its lifetime. The carbon bed should be deep enough to maintain appropriate contact with the water. (Cheremisinoff 2002, 36; Spellman 2003, 26.)

Osmosis is a natural process in which molecules migrate across a membrane from a low concentration area to a high concentration area. In contrast to osmosis, reverse osmosis requires an additional force to cause the flow of molecules over a membrane. In reverse osmosis, molecules travel from a high concentration location to a low concentration area. This procedure is particularly effective in water treatment since it allows water containing higher amounts of contaminants and dissolved particles to pass through a semipermeable membrane, resulting in a purer water stream with lower contaminants. Reverse osmosis may remove a considerable number of contaminants from water, producing water that is exceedingly pure and similar to distilled water. It is crucial to remember, however, that mineral supplementation is required to ensure that the treated water fulfils the required drinking water requirements. RO membrane is general for desalination and wastewater treatment for potable reuse. (Cheremisinoff 2002, 34; Kemira 2020, 35-37; Spellman 2003, 26,370; Gatewood 2020.)

Sedimentation, also known as clarifying, uses gravity to remove settleable materials from water. Because solid particles like silt, organic materials, and suspended particles are denser than water, they naturally sink or settle in a calm aquatic environment. This allows them to be removed more easily, either by collecting the settled solids at the bottom of the pool or by extracting the cleaner water from the top layer. Flotation, on the other hand, uses formation of small air bubbles to separate light flocs. In suitable condition, small air bubbles are created in water. These air bubbles are flocculated and rise attached flocs which contact them in the way to the surface of water. As a result, these contaminants float or rise to the surface of the water, making them easier to remove or gather cleaner water far from the surface layer. Hydrophobic liquids, such as oil, which are insoluble in water, tend to form a distinct layer when it in water. Therefore, they can be removed by flotation like flocs. (Spellman 2003, 31, 472; Schutte 2006, 19; Cheremisinoff 2002, 81, 317.)

When exposed to appropriate radiation levels, ultraviolet (UV) radiation effectively destroys or deactivates microorganisms by destroying their DNA (Reed 2010). A low-pressure mercury bulb releases a considerable part of its energy, ranging from 30 to 90%, at a specific wavelength of 253.7 nm, which falls inside the UV spectrum. The effectiveness of UV irradiation is dependent on ensuring that each unit of water receives an acceptable length and intensity of radiation, known as fluence. UV light has the advantage of not producing any byproducts during the disinfection process. To accomplish effective disinfection, UV light must be able to enter the moving water, requiring little turbidity. UV light is dangerous to the eyes and must be avoided at all costs. When entering areas where UV lamps are in use, it is critical to wear suitable eye protection and avoid direct exposure to the UV light source. (Schutte 2006, 119; Cheremisinoff 2002, 41.)

2.2.2 Chemical treatment

Chemical methods of water treatment entail using chemical interactions to address pollutants in water. Specific chemicals are used in these approaches to either remove contaminants from water or counteract their detrimental effects. Essentially, this study concentrates on the employment of chemicals for water treatment, which is referred to as the implementation of chemical treatment methods. It is crucial to note that this section does not include all of the chemical treatment procedures and compounds available. Alum and chlorine are two regularly utilized compounds in water treatment. They are mentioned here to emphasize the importance of basic chemical reactions in the water filtering process. Coagulation-flocculation procedure, precipitation reaction and acid-base reaction are highlighted from application of alum when acid-base reaction is highlighted from application of chlorine. (Schutte 2006, 9-10, 15-18; Cheremisinoff 2002, 37-38, 248-249; Kemira 2020, 25.)

Alum is aluminum sulfate ($Al_2(SO_4)_3 \cdot 16\ H_2O$ or $Al_2(SO_4)_3 \cdot 14H_2O$), a standard coagulant used in water treatment. For $Al_2(SO_4)_3 \cdot 14H_2O$, it is a solid with white to cream color. (Schutte 2006, 15; Cheremisinoff 2002, 91-92.). Coagulation is a water treatment technique that includes destabilizing and mixing small suspended particles to form larger ones known as flocs. Flocculation, on the other hand, is the gentle stirring or mixing of water to promote the generation of these larger flocs. The coagulation-flocculation procedure is utilized for eliminating small suspended and colloidal particles from water, which is required since these particles may shield pathogens from disinfection methods such as chemical or thermal treatments and UV rays. Therefore, coagulation-flocculation is used prior to disinfection. (Schutte 2006, 15-18; Cheremisinoff 2002, 91-92, 248-249.)

Colloidal particles present a challenge due to their negative charges, which generate electrostatic repulsion among them. This repulsion keeps the particles from colliding and settling, resulting in a stable colloid. As a coagulant, alum is used to remove colloidal particles from water. When alum dissolves in water, it releases aluminum ions (Al^{3+}), which balance the negative charges of suspended particles and colloids. This destabilizes the particles and encourages their aggregation. The aluminum ions are hydrolyzed and precipitate as solid aluminum hydroxide ($Al(OH)_3$). Following coagulation, flocculation occurs through gentle stirring, resulting in the collision and attachment of destabilized particles. During flocculation, the aluminum hydroxide flocs entrap the tiny colloidal particles. Flocculation promotes the growth of flocs and improves their settling properties. (Schutte 2006, 15-18; Cheremisinoff 2002, 248-249.)

It is critical to allow the entire precipitation of aluminum as its hydroxide compound to assure water safety. Because high aluminum concentrations can be dangerous, it is critical to closely manage and control the pH of the water. The amount of precipitation is greatly impacted by the pH level, which must be kept within a controlled range of 6.0 to 7.4. By carefully maintaining the pH in this range, the aluminum present in the water can be successfully and completely precipitated as hydroxide, reducing any potential dangers associated with elevated aluminum concentrations. (Schutte 2006, 17-18; Cheremisinoff 2002, 91.)

In the coagulation-flocculation process, the precipitation reaction leads to the formation of solid aluminum hydroxide ($Al(OH)_3$). In the realm of water treatment, the occurrence of precipitation reactions becomes apparent as cations and anions harmoniously unite within an aqueous solution, thereby giving rise to the emergence of an insoluble solid entity commonly referred to as a precipitate (LibreTexts. Precipitation Reactions). To illustrate:

$A^+(aq) + B^-(aq) + C^+(aq) + D^-(aq) \rightarrow A^+(aq) + D^-(aq) + CB(s)$

(or $AB(aq) + CD(aq) \rightarrow AD(aq) + CB(s)$)

The aqueous solution of A^+ ions reacts with the aqueous solution of B^- ions, resulting in the formation of A^+ ions and D^- ions (AB reacts with CD to form AD in the aqueous phase and CB as a solid precipitate.). Additionally, a solid precipitate of CB is formed. This can be elucidated as the hydrochemical phenomenon wherein a combination of two or more substances undergoes a chemical reaction within an aqueous solution, resulting in the generation of insoluble products that precipitate as solid particles. The aforementioned precipitates can be efficiently eliminated from the water using widely utilized methods like flocculation, sedimentation, and filtration. The precipitation process is of utmost importance in the elimination of dissolved contaminants from water, as it effectively aids in their removal. In the context of water treatment, it is worth noting that numerous heavy metals have the potential to undergo precipitation as hydroxides. This precipitation process can be facilitated by the addition of a caustic substance such as sodium hydroxide or lime. This process facilitates the elimination of these impurities and aids in the comprehensive purification of the water. (Schutte 2006, 186-188.)

Understanding acid-base reaction is important for pH adjustment in water. The optimal pH range for achieving full precipitation of solid aluminum hydroxide is carefully controlled between 6.0 and 7.4. This process is a crucial component of acid-base reactions employed in the field of water treatment. In the realm of water treatment, acid-base reactions encompass the captivating phenomenon of hydrogen ion (H^+) transference from an acidic entity to a basic entity. These chemical reactions play a vital role in the process of pH adjustment in water to achieve the desired levels. The manipulation of pH is of utmost importance in order to optimize various water treatment processes and ensure compliance with regulatory standards. Through the precise addition of acids or bases to the water, the pH can be skilfully regulated, thereby optimizing the efficiency of water treatment processes. (Schutte 2006, 47-48.)

The pH of water is determined through the measurement of hydrogen ion concentration ($[H^+]$), which is then expressed using a logarithmic scale. This scale helps to indicate whether the water is acidic or basic in nature. The pH value is determined by employing the equation $pH = -log[H^+]$, wherein $[H^+]$ denotes the concentration of hydrogen ions measured in moles per litter. When strong acids such as HCl and H_2SO_4 are introduced into water, they undergo complete dissociation, leading to the formation of H^+ and Cl^- ions. Consequently, the solution contains minimal quantities of the initial acid. Hydrochloric acid (HCl) undergoes dissociation in aqueous solution, resulting in the formation of hydrogen ions (H^+) and chloride ions (Cl^-). (Schutte 2006, 47-48.)

On the contrary, it is important to note that weak acids, such as carbonic acid (H_2CO_3) and acetic acid (CH_3COOH), exhibit only partial dissociation when introduced into an aqueous solution. In the context of water treatment, it is important to note that carbonic acid can be found in a state of equilibrium with H^+ and HCO_3^- ions. It is worth mentioning that a considerable amount of the initial acid remains in the solution, coexisting with the dissociated ions. The chemical equation $H_2CO_3 \leftrightarrow H^+ + HCO_3^-$ represents the dissociation of carbonic acid (H_2CO_3) into hydrogen ions (H^+) and bicarbonate ions (HCO_3^-). In the realm of water treatment, it is important to acknowledge that water possesses the characteristic of being a weak acid. As a result, it engages in a state of equilibrium, ultimately generating H^+ and OH^- ions. The chemical equation $H_2O \leftrightarrow H^+ + OH^-$ represents the process of water ionization, which occurs when water molecules dissociate into hydrogen ions (H^+) and hydroxide ions (OH^-). (Schutte 2006, 47-48.)

Therefore, the process of pH adjustment in water entails the manipulation of hydrogen ion (H^+) concentration through the regulation of the solubility of acidic and basic substances found within the water. This modification has an effect on the overall pH level of the water. In the realm of water treatment, it is of extreme significance to possess a thorough comprehension of chemical equilibrium. This knowledge plays a pivotal role in efficiently managing the pH levels in various water treatment procedures. Chemical equilibrium, in this context, pertains to the state wherein the rates of the forward and reverse reactions are harmoniously balanced. (Schutte 2006, 47-48; Khanacademy, The equilibrium constant K; CK-12.). This understanding aids in the assurance of accurate pH regulation throughout the process of water treatment (Khanacademy, The equilibrium constant K; CK-12).

Chlorine, an extensively utilized oxidizing agent, holds significant importance in the field of water treatment as it plays a crucial role in ensuring effective purification. In the realm of wastewater treatment, chlorine plays a pivotal role by performing a multitude of indispensable functions. These functions encompass crucial aspects such as disinfection, odor mitigation, and the resolution of bulking concerns. At ambient conditions, chlorine is observed to manifest as a yellow-green gaseous state, characterized by a discernible pungent scent, and it exhibits a higher density compared to the surrounding atmosphere. Under certain conditions of pressure or temperature, it has the ability to undergo a phase transition and assume a liquid state. Chlorination, a pivotal procedure in water treatment, involves the introduction of chlorine or chlorine compounds into water. This step holds immense significance as it effectively curbs the transmission of waterborne illnesses. Chlorine possesses attributes that render it highly efficient for the purpose of disinfection. (Schutte 2006, 9-10; Cheremisinoff 2002, 37-38; Kemira 2020, 25.)

When chlorine is dissolved in pristine water, it undergoes a chemical reaction with H^+ ions and OH^- radicals, resulting in the formation of hypochlorous acid (HOCl) and hypochlorite ions (OCl^-). These compounds possess potent disinfecting properties, making them effective agents for water treatment. In the realm of water treatment, when microorganisms are present, these substances have the ability to infiltrate the cellular structure and interfere with targeted enzymes, ultimately resulting in the demise of said microorganisms. The equilibrium reactions pertinent to this process can be symbolized as follows:

Cl_2 (chlorine) + H_2O (water) $\leftrightarrow$ HOCl (hypochlorous acid) + HCl (hydrochloric acid)

HOCl $\leftrightarrow$ H^+ + OCl^- (hypochlorite ion)

Significantly, it is worth mentioning that HOCl exhibits significantly higher efficacy as a disinfectant in comparison to the hypochlorite ion, showcasing a potency that is approximately 80 times (or even more) greater. The concentrations of these species are pH-dependent in water treatment. In the realm of water treatment, it is crucial to acknowledge the influence of pH on the behavior of chlorine compounds. When the pH of a solution dips below 7, the primary form that chlorine takes is known as hypochlorous acid (HOCl). However, as the pH rises beyond approximately 7.5, the hypochlorite ion (OCl^-) gains prominence and becomes more abundant in the solution. Hence, it is of utmost importance to consider the pH level of the water when determining the precise amount of chlorine required for optimal disinfection. The measurement of chlorine concentration in water is commonly expressed in milligrams per liter, which is a standard unit used in water treatment studies. (Schutte 2006, 9-10; Cheremisinoff 2002, 37-38; Kemira 2020, 25.)

Fundamental of effective disinfection of chlorine comes from nature of oxidation-reduction reaction. Oxidation-reduction, commonly referred to as redox reactions, are chemical reactions that involve the transfer of electrons, resulting in a modification of the oxidation number of specific atoms or ions participating in the reaction. During the process of oxidation, electrons are lost, leading to an elevation in the oxidation number of one or more atoms. In contrast, reduction processes entail the acquisition of electrons, resulting in a decline in the oxidation state. It is crucial to comprehend that these processes invariably transpire concurrently within a redox reaction. In the context of water treatment, an oxidizing agent, typically in the form of an atom, ion, or molecule, exhibits the ability to receive electrons from other substances that are partaking in the chemical reaction. Both HOCl (hypochlorous acid) and OCl^- (hypochlorite ion) exhibit an oxidation state of +1 and exhibit an inherent inclination to undergo electron gain (oxidation) in order to attain a heightened level of stability. The inherent tendency to gain electrons is the underlying reason why HOCl and OCl^- exhibit remarkable efficacy as potent disinfectants in water treatment. (Schutte 2006, 54-55; khanacademy, Oxidation–reduction (redox) reactions; Benjamin 2006.)

2.2.3 Biological treatment

Biological treatment techniques employed in water treatment encompass the utilization of microorganisms that naturally inhabit aquatic environments to metabolize organic substances, regardless of whether they are in a dissolved or suspended state within the water. Every category of microorganism exhibits distinctive abilities to metabolize particular organic compounds, leading to the generation of specific end products. The achievement of a highly effective biological treatment strategy hinges upon the meticulous management and stimulation of appropriate microorganisms' proliferation. A thorough comprehension of the composition and traits of these microorganisms offers valuable insights into the management of their growth, their performance and presence of pathogens. (Cheremisinoff 2002, 81; Spellman 2003, 307.)

Aerobic and anaerobic digestion, which effectively utilize the growth and performance of suitable bacteria in environment of oxygen presence and in environment of oxygen absence, are two basic biological methods in water treatment. During aerobic treatment processes, it is observed that microorganisms effectively utilize the oxygen present, along with organic matter, essential nutrients (such as nitrogen and phosphorus), and trace metals (like iron). This utilization results in the generation of additional micro-organisms, as well as the formation of stable dissolved and suspended solids, and the release of carbon dioxide. (Cheremisinoff 2002, 242-243; Spellman 2003, 617; Kemira 2020, 141-142.)

In contrast, anaerobic treatment processes take place in the absence of oxygen and involve two distinct stages that result in the production of a valuable by-product known as methane gas. During the initial stage, facultative microorganisms actively engage in the consumption of organic matter as a nourishment, leading to the generation of additional microorganisms, volatile (organic) acids, carbon dioxide, hydrogen sulfide, and various gases. Simultaneously, specific solid particles with enhanced stability are also formed. During the subsequent phase, anaerobic microorganisms efficiently metabolize the volatile acids, which serve as their predominant nourishment. This metabolic process results in the proliferation of further microorganisms, the formation of stable solids, and the production of methane gas. The utilization of methane gas as an energy source is beneficial for multiple components within the water treatment system. (Cheremisinoff 2002, 242-243; Kemira 2020, 142-143; Spellman 2003, 614-615.)

2.3 Water treatment plants, households, and wastewater treatment plants

The linear water consumption presents process with collecting raw water as begin and discarding treated water to environment as end. This linear is popular in many cities over the world. Some cities may not have a wastewater treatment plant (WWTP) to treat wastewater. This leads to environment pollution. Figure 1 illustrate the linear water consumption as following:

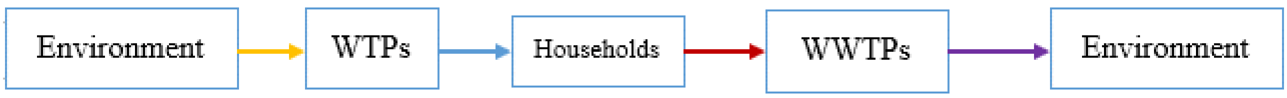

FIGURE 1. The linear water consumption (yellow: raw water, blue: drinking water, red: wastewater, violet: Treated water to be released into the environment) (addapted from UN-Water. 2017, 1-7)

The linear involves five factors: environment (raw water intake, WTPs, households, WWTPs, environment (treated water disposal). In this case, environment in the begin is often waterbodies such as rivers, lakes, wells, etc. which is water resource for human to collect raw water. Water treatment plants collect raw water from environment to produce drinking water for households. Drinking water consumption of households generate wastewater which is introduced to wastewater treatment plants for treatment.

Treated wastewater is introduced to environment. If wastewater is discarded directly to environmental, ecosystem will be polluted. (UN-Water. 2017, 1-7.)

2.3.1 Water treatment plants

As a production facility with drinking water as product, a water treatment plant needs to ensure adequate water source, suitable equipment and technology, customers, and legal work. From that, the water treatment enables to achieve primary object as providing quality drinking water from water resource to households with reasonable cost. (Schutte 2006, 12.). Generally, raw water (often surface water and ground water) as materials of drinking water treatment are cleaner than wastewater, so treatment operations of a water treatment plants are often smaller and simpler than a wastewater treatment plant (Public Education Committee of the PWEA). Basing on different qualities of raw water in different places, a variety of treatment methods or processes are applied with suitable combination to achieve the primary goal. Detailed process may not be similar in different factories, but the primary goal is achieved due to three main steps as removal of suspension, disinfection, chemical stabilization. To optimize treatment process, pretreatment step can apply physical, chemical, biological methods to removes large materials which can reduce efficiency of following treatment or damage machines. (Schutte 2006, 12; Public Education Committee of the PWEA; Spellman 2003, 532.)

However, in general situation, simple settling of water is enough. Removal of suspension removes suspended and colloidal matter in water to a required quality by solid-liquid separation processes following coagulation-flocculation, sedimentation, flotation, and filtration (commonly sand filtration). During the process, suspended and colloidal solids are condensed into large flocs by coagulation-flocculation, then, all collectable matters are removed from bottom of the water by sedimentation and from surface of the water by flotation. The water is introduced to sand filtration containers (rapid sand filtration or slow sand filtration) as final filtration. After water is clear, disinfection applies chlorination or UV irradiation to eliminate or inactivate harmful microorganism, so water gains potable safety. Drinking water need to provide to customers by distribution system, chemical stabilization implements suitable chemicals to adjust chemical quality of water due to prevention of corrosion or scale formation in pipeline system. (Schutte 2006, 12-23.)

In case there are pollutants in water which conventional treatment cannot removed effectively and completely; advanced treatment may be applied. Advanced wastewater treatment is “Any process which reduces the level of impurities in a wastewater below that attainable through conventional secondary or biological treatment. Includes the removal of nutrients such as phosphorus and nitrogen and a high percentage of suspended solids”. (Institute for sustainability.). From this definition, advanced water treatment maybe any process which reduces the level of impurities in a water below that attainable through conventional treatment. Or to simplify, advanced water treatment may be any process which can remove contaminants in water that conventional treatment cannot remove. Conventional treatments processes in water treatment plants include coagulation-flocculation, sedimentation, flotation, sand filtration, chlorination or UV light. Advanced treatment processes are “membrane processes (reverse osmosis RO, nanofiltration NF, ultrafiltration UF and electrodialysis ED), activated carbon absorption, ozonation, oxidation processes for iron and manganese removal and processes for removal of specific substances such as fluoride.”. (Schutte 2006, 16-24.)

2.3.2 Households and types of wastewater

Households often are main consumers of drinking water. In a city, besides households, drinking water are also used by office building, schools, hospitals, industrial factories, etc. For industrial factories, besides daily consumption of workers, drinking water can be used as materials for some applications. Because different consumers produce wastewater with different compositions, types of wastewater should be classified (FIGURE 2 and TABLE 1). In a city, urban wastewater consists municipal wastewater and urban runoff, which are most of wastewater generating by a city. Urban runoff is surface runoff of rainwater and other forms of precipitation (i.e., snowmelt). Municipal wastewater is wastewater from domestic, industrial, commercial, or institutional activities of facilities or communities. From that, there are smaller classification basing on related activities, such as industrial wastewater is wastewater from industrial process of industrial factories, hospital wastewater is wastewater from operation of hospitals and domestic wastewater is wastewater from activities of households. (UN-Water 2017, 172-174; Eriksson et al. 2002.)

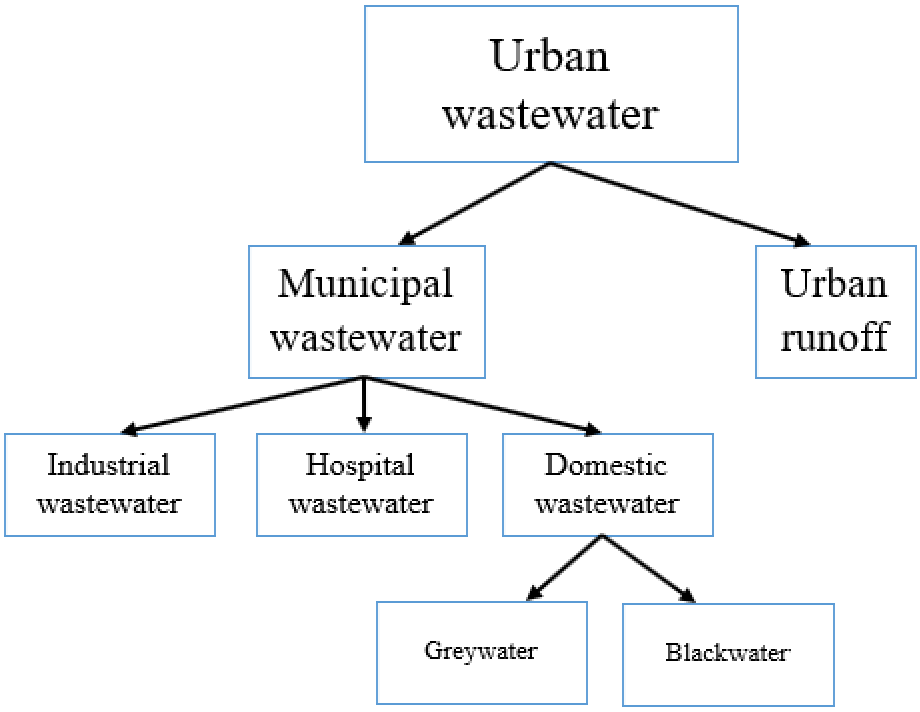

FIGURE 2. Types of urban wastewate (adapted from UN-Water 2017, 172-174)

Generally, households consume potable water and generate domestic wastewater which includes grey-water, blackwater and potentially other types of wastewater. Blackwater is wastewater generated from toilet in households. It consists of urine, faeces, flush water, and toilet paper. Grey water is wastewater generated from most of household activities in residential settlements except of toilet using, such as washing, cooking, showering, laundry, etc. Greywater contains variety of contaminants from related activities from household such soaps, chemicals for cleaning, oils, organic matter, etc. Depending on wastewater management of a city, different types of wastewater can be collected separately for specific treatments, or combined in a combined sewer system for transportation to wastewater treatment plants or disposal to environment. (UN-Water 2017, 172-174; Eriksson et al. 2002.). In some cities such as cities in Vietnam, septic tank can be settled as a pre-treatment for blackwater before discarding to a sewer system (Pham & Kuyama 2013, 1).

TABLE 1. Composition of domestic wastewater and urban wastewater in Ha Noi, Vietnam. (adapted from Quan 2022)

Type of wastewater	COD (mg/L) (chemical oxygen demand)	BOD5 (mg/L) (biochemical oxygen demand))	SS (mg/L) (suspended solid)	T-N (mg/L) (total nitrogen)	T-P (mg/L) (total phosphorus)	Coliform (MPN /100mL)
Black water	1086	-	7905	-	-	-
Greywater	208	151	63	24,2	4,9	4,7×105
Domestic wastewater	583	243	223	48	9	3,7×107
	145,67	72,67	34,00	32,69	-	2,48×105
	96-135	64-95	90-140	31-37	16-32	>9000
Urban wastewater	60-604	31-380	41-792	11-95	1,4-19	-
	500	250	300	40	9	108- 109
	200	100	50	20	4	-
QCVN standard A	30	75	50	20	4	3000
QCVN standard B	50	150	100	40	6	5000

2.3.3 Wastewater treatment plants

Basically, wastewater treatment plants replicate treatment of water in nature through machines and equipment, to enhance speed of treatment processes with suitable design and control (EPA 1998). Like water treatment plant (or drinking water treatment plant), according to composition of wastewater, wastewater treatment plants are not similar in detailed but they have different combinations of physical, chemical, and biological processes. Wastewater are more pollutants than raw water, so wastewater treatment plant has larger and more complicated operation than water treatment plant. (Public Education Committee of the PWEA.). Depending on purpose, wastewater is treated by different combination for specific target of output treated water (Public Education Committee of the PWEA). For example, if treated wastewater is disposal to environment, it is indispensable to meet quality standard to prevent environmental pollution. In case treated wastewater is applied water reclamation, the wastewater is indispensable to meet other quality standard for a specific application. Like water treatment plant, the wastewater treatment plant should produce treated wastewater for specific use with reasonable cost. (Public Education Committee of the PWEA; Schutte 2006, 16-24.)

Although there are different outputs for treated wastewater, generally, fundamental purposes in some stages during process for discarding treated wastewater are similar. Taking samples of some types of wastewater of TABLE 1 above to illustrate, oxygen demand (biochemical and chemical), suspended solids and amount of coliform are often far from the QCVN standard, so controlling these parameters are basic jobs. The fundamental purpose of each stage in water treatment is as follows: preparing for effective operation, removing solids, decomposing bacteria, and conducting additional filtration (and disinfection), corresponding to preliminary treatment, secondary treatment, and tertiary treatment. (LibreTexts. 17.3B: Wastewater and Sewage Treatment; Kumar 2016.)

Preliminary treatment is primarily focused on removing materials, especially large solids, to ensure efficient operation of subsequent treatment stages. The main objective of the treatment steps is to sequentially apply different processing methods to progressively increase the percentage of pollutants removed, such as solids and BOD, which may vary depending on the water composition. Primary treatment, often referred to as solids removal, eliminates approximately 50-60% of solids and 20-35% of BOD. Secondary treatment, also known as bacterial decomposition, involves biological methods and removes about 75-85% of solids and BOD. Tertiary treatment utilizes advanced treatment technologies to remove over 95-99% of all impurities and disinfect most of microorganisms present in the water. (LibreTexts. 17.3B: Wastewater and Sewage Treatment; Kumar 2016; Kesari et al. 2021, 9-12.)

Preliminary treatment process is sometimes operated as a process belong to primary treatment, but it is a process with specific purpose. Preliminary treatment has fundamental purpose to remove materials which may reduce efficiency of following process or damage equipment of the wastewater plant. The process does not just apply physical methods. It applies physical, chemical, and biological methods basing on targeted materials. The process may settle a collection system including influent pumping, screening, shredding, grit removal, flow measurement, pre-aeration, chemical addition, and flow equalization. (Spellman 2003, 532.)

Primary treatment process mainly applies physical treatment to remove large amount of suspended solids in wastewater (50-60%) and an standard amount of BOD (20-35%) (LibreTexts. 17.3B: Wastewater and

Sewage Treatment; Kumar 2016). Sedimentation tank is a conventional settling for primary treatment process. During the process, settleable solids stays in sedimentation tank when cleaner effluent flows to next process. (EPA, 1998; Spellman 2003, 540-541.). Secondary treatment process applies biological treatment as main method. The process uses bacteria to decompose organic matter into stabilized, low energy compound, so dissolved organic and colloidal contaminants can be converted to more stable solids for removal. The process can remove 85% organic matter, increase total percentage of solid and BOD removal as 75-85%. (LibreTexts. 17.3B: Wastewater and Sewage Treatment; Kumar 2016.)

Three universal techniques applied in secondary treatment process are trickling filter, activated sludge process and ponds (oxidation ponds or lagoons). Main principle of biological methods is utilization of suitable bacteria with suitable environment and suitable food. During the process, influent escapes from primary treatment process is mixed with activated sludge containing suitable aerobic bacteria. With more oxygen from air and enough food from effluent, aerobic bacteria decompose organic matter in influent effectively. The converted organic matters are settled, and cleaner effluent moves to next process, when the activated sludge with copious bacteria circulates in the process to readily mix with new influent. (EPA, 1998.)

Tertiary treatment is generally use as a synonym for advanced wastewater treatment, although they do not have precisely the same meaning. Tertiary treatment can be simplified as third treatment after primary treatment and secondary treatment. (Spellman 2003, 595.). With approach that treated wastewater is a product for specific use, tertiary treatment is the step to design and shape the product. To remove impurities which cannot be removed by previous process, such as residual solids, nitrogen and phosphorus, tertiary treatment process applies advanced treatment methods and process. This may explain reason that tertiary treatment and advanced treatment are used as the same concept. Tertiary treatment process can remove from 95% to more than 99% contaminants and operate effective disinfection, so treated wastewater may almost be potable. (Spellman 2003, 595.). From that, it is no doubt that tertiary treatment can make treated wastewater meet quality standard of specific water reclamation. Tertiary process or advanced process can be physical, chemical, and biological process. Depending on purpose, tertiary treatment can remove most of impurity with membrane technology or can remove a specific contaminant such as phosphorus with chemical precipitation. (Spellman 2003, 595; Kemira 2020, 119-120.)

However, the fact is that treated wastewater from tertiary treatment is only accounted a small percentage over the world even if advanced process has outstanding effectiveness (UN-Water 2017, 125). The reason is that advanced treatment is very expensive. The cost of updating conventional process with advanced processes, the cost of operation and maintenance are extremely expensive. Sometimes, expense of retrofit a conventional process can set up two secondary treatment processes. Besides, drinking water treatment factory is smaller and simpler than wastewater treatment factory. So, instead of building a tertiary process, building a new drinking water process and a new secondary process should be more profitable. Installing advanced treatment process is indispensable with circumspect research and prudent solution to increase ratio of benefit-to-cost. From that, application of advanced treatment process for wastewater may be reasonable and profitable. (Spellman 2003, 595.)

2.4 Water reuse

Four following quotes are about water reuse: “Water reclamation is the treatment or processing of wastewater to make it reusable with definable treatment reliability and meeting water quality criteria. Water reuse is the use of treated wastewater for beneficial uses, such as agricultural irrigation and industrial cooling.” (Asano 2007, 10). “Water reuse (also commonly known as water recycling or water reclamation) reclaims water from a variety of sources then treats and reuses it for beneficial purposes such as agriculture and irrigation, potable water supplies, groundwater replenishment, industrial processes, and environmental restoration.” (EPA 2023a). “Water reuse refers to the process whereby wastewater is reclaimed from a variety of sources and treated to a standard appropriate for a second purpose.” (Climate-ADAPT 2021). Water reuse refers to “using water more than one to expand a community’s available water supply” (American Water Works Association 2016).

The aforementioned explanations of water reuse showcase certain discrepancies. In specific scenarios, there has been a tendency to utilize terms such as "reused," "recycled," and "reclaimed" interchangeably, although in alternative cases, they have been employed with distinct meanings. The term "wastewater" lacks a standardized definition in the field of water treatment, which emphasizes the need to establish agreed-upon definitions within the scope of this paper. (UN-Water. 2017, viii.)

In this paperwork, in the context of water reuse, wastewater refers to untreated water that has been used by communities for a variety of reasons. For the purpose of unifying word usage in this thesis, water reuse is used as the technique of using water several times to increase a community's available water supply while decreasing water waste .(American Water Works Association 2016.). Similarly, the terms "water recycle" and "water reclamation" are used interchangeably to refer to the reuse of purified wastewater for beneficial purposes such as municipal, agricultural, and industrial uses (EPA 2023a; Asano 2007, 10). Similarly, the terms "recycled water" and "reclaimed water" are used interchangeably to describe treated water that meets particular quality criteria and is intended for beneficial uses such as municipal, agricultural, and industrial (EPA 2023a; Asano 2007, 10).

Water reuse is classified according to its various types and functions. It incorporates unplanned water reuse and planned water reuse which bases on planning situation of water reuse by human. Planned water reuse also includes non-potable water reuse and potable water reuse which derives from purpose of reuse. Potable water reuse is further subdivided into indirect water reuse and direct water reuse which depending on presence of a environmental buffer in reuse process. These notions will be clarified further in the following sections of this article. (EPA 2023a.)

2.4.1 Unplanned water reuse

Unplanned water reuse (de facto) occurs when two separate communities, one located upstream and the other downstream of a surface water source, such as a river, utilize untreated surface water as a raw water source for drinking water production in the downstream community (American Water Works Association 2016). Prior to this, the upstream community discharges treated wastewater back into the same water source. Clearly, this procedure transpired spontaneously and as an outcome of stochastic natural events, without planning of human. Flow of water in de facto reuse is illustrated by FIGURE 3. (American Water Works Association 2016.)

This system requires a minimum wastewater treatment system in each community to ensure that the treated wastewater does not cause environmental pollution. The treated wastewater then mixes with the surface water and undergoes natural environmental processes to minimize pollution. Subsequently, it flows downstream and can contribute as a raw water source for the downstream city. The system is illustrated through FIGURE 4. Wastewater treatment plants are essentially human-engineered systems that mimic and replicate the natural processes of water self-purification or self-treatment that occur in rivers and lakes. (American Water Works Association 2016.)

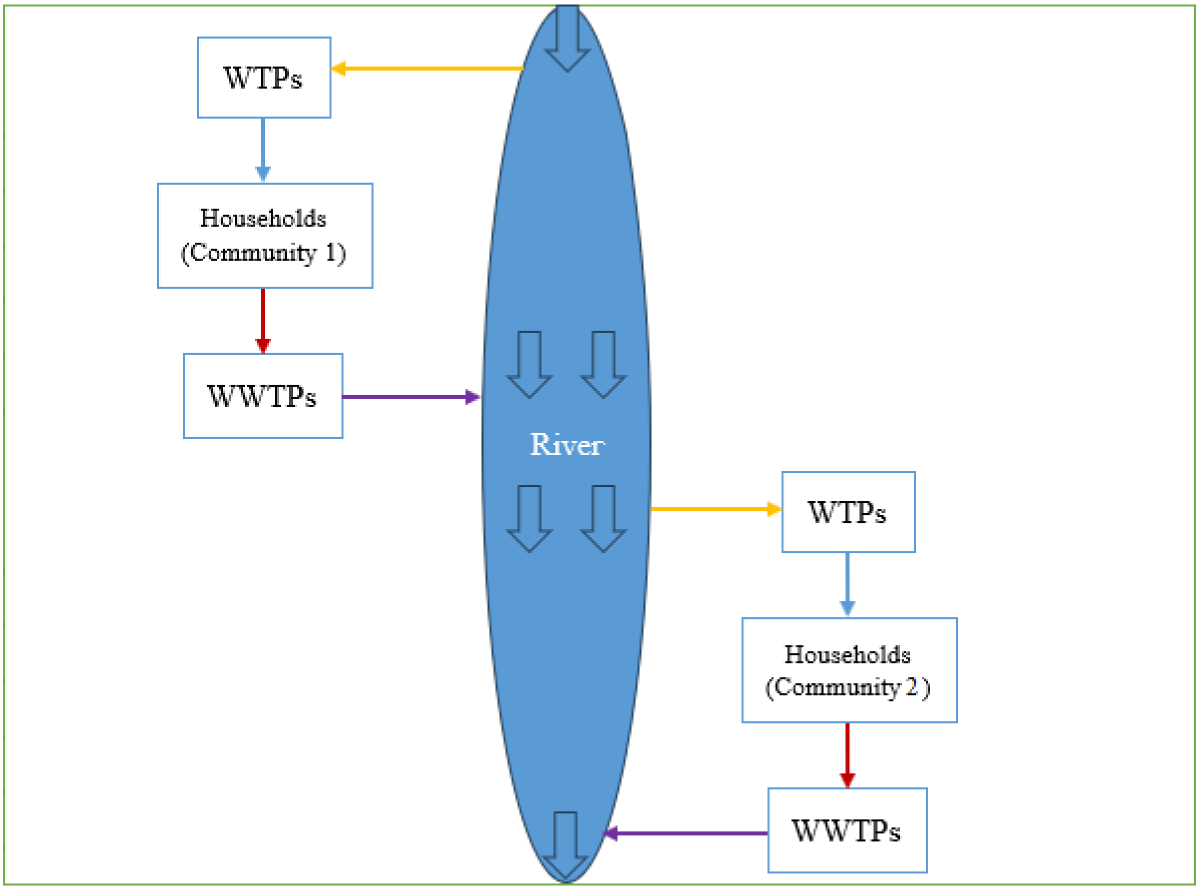

FIGURE 3. Flow schematic of de facto reuse (big blue arrow: direction of the water flow, yellow: raw water, blue: drinking water, red: wastewater, violet: Treated water to be released into the environment) (American Water Works Association 2016)

2.4.2 Planned water reuse

Planned water reuse comprises the creation of water treatment systems with the primary goal of effectively repurposing reclaimed water. Frequently, communities strive to enhance water efficiency by re-using water within their community before releasing it back into the environment. Instances of planned water reuse include irrigation of agricultural and landscaping areas, the use of reclaimed water in industrial processes, the preservation of safe drinking water supplies, and the management of groundwater resources. Municipal wastewater, industrial process and cooling water, stormwater, agricultural runoff and return flows, and produced water from natural resource extraction activities are all potential sources of water for reuse. These water sources are treated appropriately to meet specified "fit-for-purpose specifications" for their intended next usage. "Fit-for-purpose specifications" relate to the treatment requirements. It is required to purify water from a certain source to the appropriate quality level, while also protecting public health, environmental protection, or meeting specific user needs. (EPA 2023a.)

Depending on the intended purpose of water usage, planned water reuse can be divided into two categories: non-potable reuse and potable reuse. Nonpotable reuse refers to "all water reuse applications that do not involve either direct or indirect potable reuse.". (Asano et al. 2007, 4.). For example, when reclaimed water is used for agricultural irrigation (non-potable reuse), it must meet quality criteria that protect plants and soils, ensure food safety, and protect farm workers' health. More intensive treatment techniques may be required to assure the safety and purity of water when it is intended for the generation of potable water supplies (potable reuse). (EPA 2023a.)

As mentioned previously, potable reuse necessitates more extensive treatment measures (EPA 2023a). Due to technological limitations and the scale of water treatment facilities, a significant portion of wastewater can be suitable for nonpotable reuse. In fact, according to a compilation of significant events related to water reclamation and reuse worldwide in the book "Water Reuse" by Asano, the majority of water reuse is allocated for nonpotable purposes such as agricultural and landscape irrigation, as well as industrial applications. (Asano et al. 2007, 60.). Additionally, Asano presents data on domestic water use in the United States from various sources, suggesting that nonpotable applications like outdoor uses and toilet flushing account for over half of total domestic water consumption (Asano et al. 2007, 1171-1175).

While potable water is still used for activities that do not require strict water quality, such as toilet flushing, there is significant potential for nonpotable reuse. However, to implement nonpotable reuse effectively, the use of two separate plumbing systems is required: one for distributing potable water and another for reclaimed water. The rationale for using dual plumbing systems is that reclaimed water can substitute potable water for nonpotable applications both outdoors, such as landscape irrigation, and indoors, including fire protection and toilet flushing. To date, the primary focus of water reclamation and reuse has been on nonpotable applications such as agricultural and landscape irrigation, industrial cooling, and in-building uses like toilet flushing in large commercial buildings. Furthermore, the presence of harmful agents, especially pathogens, in nonpotable water still needs to be regularly identified and assessed to ensure long-term safety for its intended use. (Asano et al. 2007, 30-32, 902-903.)

Potable reuse is a water treatment procedure that involves using wastewater from a community as a safe and dependable supply of drinking water. Rather from being released into the environment, as in traditional wastewater treatment systems, treated wastewater is returned into the water supply system, resulting in a closed-loop system as demonstrated in figure 4. (WateReuse Association 2015, 5-8; American Water Works Association 2016.). There are two types of potable reuse: indirect potable reuse (IPR) and direct potable reuse (DPR). The utilization of an environmental buffer is the primary distinction between these two types. An environmental buffer is used in indirect potable reuse to allow for a longer amount of time for water quality restoration in the natural environment. This buffer serves as a protection, offering further treatment and filtration as the water passes through natural processes like percolation through soil and groundwater replenishment before being retrieved for drinking water. (WateReuse Association 2015, 5-8; American Water Works Association 2016.)

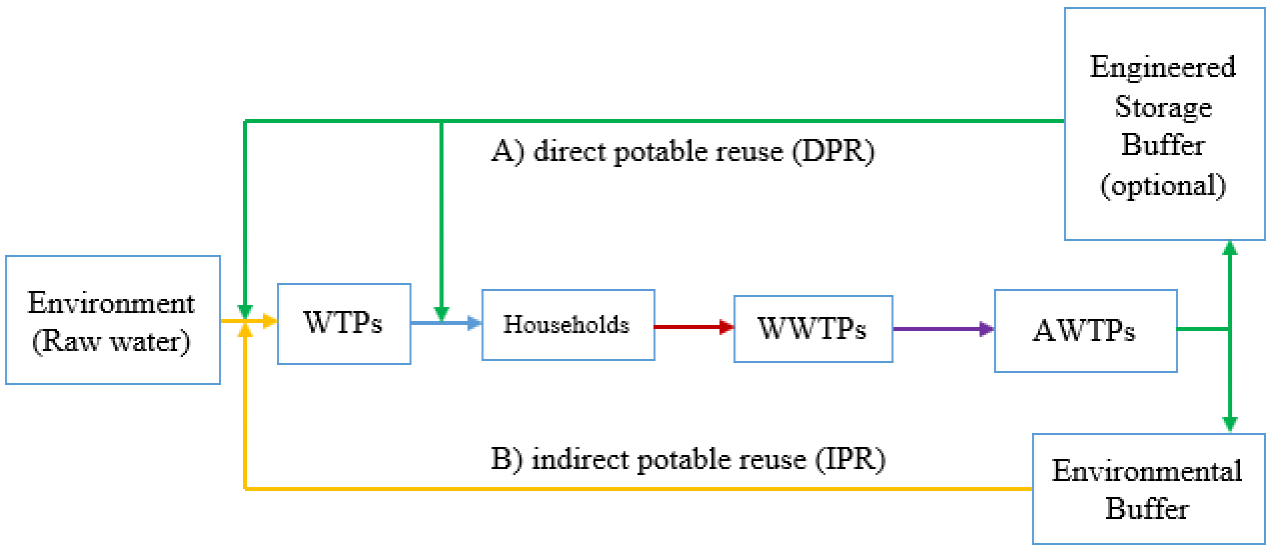

FIGURE 4. Closed-cycle water management of planned potable reuse (yellow: raw water or treated water with similar quality, blue: drinking water, red: wastewater, violet: treated wastewater, dark green: advanced treated water) with: A) direct potable reuse and B) indirect potable reuse (adapted from Verkhusha 2020, 28; WateReuse Association 2015, 6; Lafforgue & Lenouvel 2015)

Direct potable reuse, on the other hand, does not use an environmental buffer. In the first case, advanced water treatment includes a comprehensive set of effective technologies and operational procedures for treating wastewater to the required standards. As a result, the highly treated water can be immediately delivered to the community for drinking purposes or used as a source material for manufacturing drinking water in order to meet the community's water demands. Potable reuse in the second situation makes use of an engineered storage buffer. The designed storage buffer allows for faster water restoration and is less dependent on the state of the natural environment at the time. (WateReuse Association 2015, 5-8; American Water Works Association 2016.)

It is not possible to build a potable water reuse system exclusively on the limitless cycling of wastewater. This impossibility stems from two basic causes of water loss. Firstly, within a community, consumptive uses and leakages from wastewater collection systems result in not all provided drinking water being converted to wastewater. For example, evaporated water from human body escapes the cycle of wastewater. (Verkhusha 2020, 3-4 [Tchobanoglous, Burton, & Metcalf & Eddy, Inc., 1991, 16].). Secondly, the creation of semi-liquid or liquid treatment byproducts (e.g., sludge, brine, etc.) during the wastewater and advanced treatment process, the process indicates that not all collected wastewater can be turned into reclaimed water. As a result, including at least one extra source of raw water is required to compensate for losses caused. (Verkhusha 2020, 3-4 [Khan, 2013a, 3; Khan, 2013c, 13; NWRI, 2015b, 2].)

Overall, potable reuse is a novel way to maximizing water resources by treating and reusing wastewater, either indirectly or directly, hence improving water sustainability and decreasing dependency on traditional freshwater sources. To clarify more about indirect potable reuse, the injection of purified water into an environmental buffer, such as a groundwater aquifer, surface water reservoir, lake, or river, before the blended water is mixed into a water delivery system, is known as indirect potable reuse (IPR). Figure 5 depicts a flow diagram of indirect potable reuse. (American Water Works Association 2016; WateReuse Association 2015, 5-8.)

Water in indirect potable reuse systems follows a similar course as water in other systems. To generate drinking water, raw water is collected from a source and treated at a drinking water treatment facility. After being utilized, the drinking water be-comes community wastewater. The wastewater is treated in two stages: primary and secondary treatment at a wastewater treatment plant, followed by advanced treatment in an advanced wastewater treatment facility. The advanced treated water that results is subsequently routed to an environmental buffer. Water is held here, and natural processes and time allow for its recovery. Similar to raw water at the beginning of the system, once the water has attained the required quality for manufacturing drinking water, it is transported to a drinking water production facility to be processed into drinking water for the community. (American Water Works Association 2016; (WateReuse Association 2015, 5-8.)

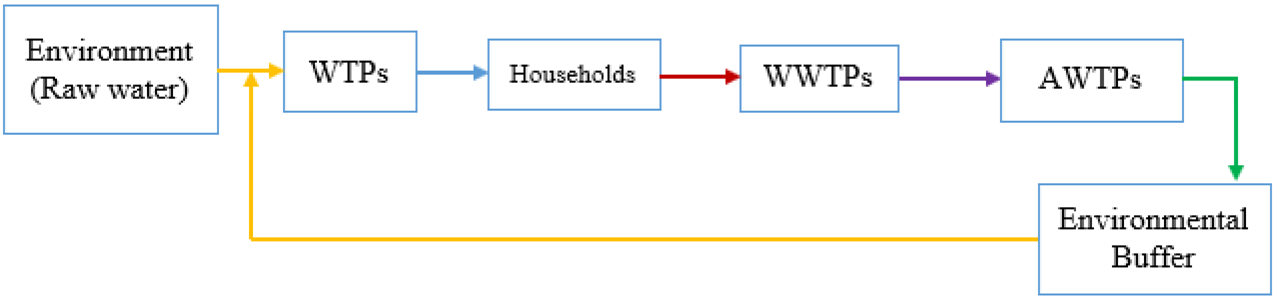

FIGURE 5. Flow schematic of indirect potable reuse (yellow: raw water or treated water with similar quality, blue: drinking water, red: wastewater, violet: treated wastewater, dark green: advanced treated water) (American Water Works Association 2016)

The environmental buffer's aim is to offer storage, transportation, and, in some situations, an additional protective barrier to protect public health. However, it is crucial to highlight that storing highly treated water in the environment, if not properly stabilized or mixed with other water sources, can introduce contaminants and deteriorate water quality. Metals dissolving from the groundwater aquifer, for example, or the presence of microbiological and other pollutants in surface impoundments may pose a risk. A groundwater aquifer, surface water reservoir, or another suitable water body such as a lake, river, or natural or manmade wetlands can serve as an environmental buffer. (WateReuse Association 2015, 5-8; American Water Works Association 2016.). In some cases, treated water may have to stay in an environmental buffer over six months to relieve public fears about ‘toilet to tap’ concept (UN-Water 2017, 56).

According to Asano's book "Water Reuse," a majority of the research done on direct and indirect potable water reuse is equally applicable to unplanned indirect potable reuse (de facto indirect potable reuse). This occurs naturally when water sources containing wastewater discharges are used as a source of drinking water. This indicates the feasibility of incorporating indirect potable reuse into standard water management procedures on a large scale. Please keep in mind that water reuse operations must always follow strict regulations and norms to protect public health and the environment. (Asano 2007, 30-32.)

Multiple barriers must be used as indicators to ensure public health. Multiple barriers are used for reclaimed water in indirect potable reuse applications, including: source control of wastewater collection system discharges, robust and redundant conventional treatment processes, robust and redundant advanced treatment, incorporation into a natural system (e.g., a water supply storage reservoir), water treatment before distribution in the potable water system, and monitoring at various points within the system.

Although each barrier provides some level of protection, no single barrier is flawless. As a result, relying too heavily on one barrier at the expense of another may increase the danger of contamination. (Asano 2007, 1308-1313.)

To clarify more about direct potable reuse, direct potable reuse (DPR) entails injecting purified water directly into an established water supply system, either with or without the use of a designed storage buffer, but without an environmental buffer. The term "direct" in direct potable reuse (DPR) refers to the process of treating and purifying wastewater to a quality level acceptable for immediate use as drinking water without the need for an intermediary environmental buffer or an extended time of natural restoration. This implies that the water is treated quickly and then made available as drinking water. (WateReuse Association 2015, 5-8; American Water Works Association 2016.)

There are two techniques of adopting DPR (FIGURE 6), both of which include applying sophisticated treatment to used water. However, these approaches differ in terms of where the mixing takes occur. In one approach, purified water is combined with raw water supplies (such as surface water or groundwater) before being treated further at a drinking water facility. The other method is to blend the purified water directly into the potable water distribution system downstream of the drinking water plant, which is known as pipe-to-pipe or direct-to-distribution DPR. To ensure public health, multiple barriers should be applied like case of indirect potable reuse. However, no related information has been found out. (WateReuse Association 2015, 5-8; American Water Works Association 2016.)

The Goreangab Water Reclamation Plant in Windhoek, Namibia, is the most notable DPR project (EPA & CDM Smith 2017, 2-6 [EPA, 2012a]). Windhoek was the first city to adopt long-term potable reuse without an environmental buffer. Windhoek's experimental DPR project started in 1969 and was enlarged to 5.5 MGD in 2002. (EPA & CDM Smith 2017, 2-6 [EPA, 2012a].). It can meet approximately half of the city's potable water demand (EPA & CDM Smith 2017, 2-6 [NRC, 2012a]).

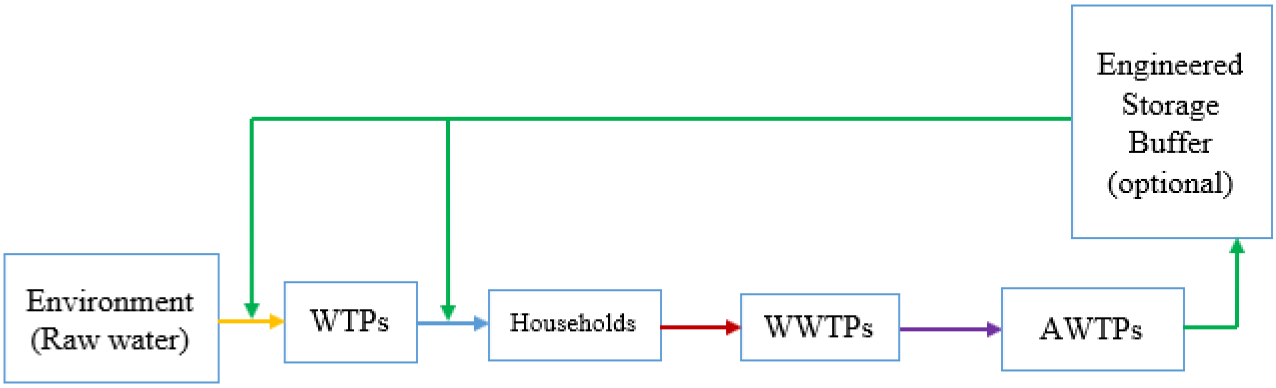

FIGURE 6. Flow schematic of direct potable reuse (yellow: raw water, blue: drinking water, red: wastewater, violet: treated wastewater, dark green: advanced treated water) (American Water Works Association 2016)

2.5 Circular economy

The circular economy is a framework for systemic solutions to global concerns such as climate change, biodiversity loss, waste, and pollution. It is founded on three design principles: eliminate waste and pollution, circulate products and resources (at their best value), and rejuvenate nature. The linear economy, also known as the take-make-waste economy, is a system in which resources are harvested to manufacture items that finally end up as garbage and are discarded. In a linear economy, products and materials are often not exploited to their full potential and, as the name implies, always travel in one direction - from raw material to waste. It is a polluting system that affects natural systems and is a driving force behind global issues such as climate change and biodiversity loss. (Ellen Macarthur foundation a, b.)

Based on two previous definitions, it is evident that both indirect potable reuse and direct potable reuse represent circular economy systems. On the other hand, de facto or traditional water management strategy may align with a linear economy approach if there is a lack of research and implementation regarding the application of treated wastewater. Case studies in next sector demonstrates and proves that Ho Chi Minh city applies de facto as water management strategy when Singapore applies indirect potable reuse as water management strategy. (Ellen Macarthur foundation a, b.)

3 HO CHI MINH CITY AND SINGAPORE, CASE STUDIES OF WATER MANAGEMENT

Ho Chi Minh city (HCMC) and Singapore are two cities in Southeast Asia. When Ho Chi Minh city is a city of Vietnam, a lower middle-income country, Singapore is a most richest and advanced country in region (MINISTRY FOR FOREIGN AFFAIRS OF FINLAND 2015, 11,15). HCMC is limited in environmental protection during urbanization process (The International Trade Administration. 2022). In the meanwhile, Singapore is one of the few countries which are sucessful in environmental protection during succesful urbanization process (The International Trade Administration. 2020). Urban water cycles of two cities are demonstrated in section 3.1 and 3.2 and compared in section 3.3.2. Besides some differences between two cities, they have some similar natural condition such as high raining rate. Some similarity in natural condition is stated and proved in section 3.3.1. Besides some similarities in natural condition, two cities are compared some other aspects related to water management such as water management strategy, water sector organization and citizens's perpective in section 3.3. From those comparisions, some approachs are ready for section 4.

3.1 Ho Chi Minh city

Although HCMC is one of the biggest and developed cities of Vietnam, high population and urbanization leads to many issues. Water pollution is one of the largest problems when the number of wastewater treatment plants are not enough for demand. Moreover, the urban drainage system of the city has many limitations. Limited drainage system leads to serious impact from flooding condition. The government stated that upgrading the drainage system and some other facilities is urgent to reduce effect of tidal flooding. Some general information of HCMC is introduced first, then, urban water cycle of HCMC is drawn out to identify issues. (The International Trade Administration 2022.)

3.1.1 General information

Ho Chi Minh City (HCMC) is one of the most densely populated cities in Vietnam, accommodating approximately 9,166,840 residents within an area of approximately 2,095 km^2. The population density is notably high, reaching around 4,375 people per square kilometer. (GENERAL STATISTICS OFFICE.). The city comprises 24 districts, including suburban areas such as Cu Chi, Hoc Mon, Binh Chanh, Nha Be, and Can Gio, the latter being a coastal district (Bual 2023). HCMC experiences a substantial amount of rainfall, averaging 1,949 mm annually, distributed over 159 wet days, which constitutes around 43% of the year. The wet seasons occur from May to November, with comparatively drier months in April and December. (GOVERNMENT ELECTRONIC PORTAL 2011.).

Regarding wastewater management, HCMC generates nearly 3 million m^3 of wastewater on a regular basis. To address this issue, wastewater treatment plants are built to treat wastewater before discarding to the environment. However, just approximately 12.6% of the wastewater is treated through three active wastewater treatment plants: Binh Hung factory with a capacity of 141,000 m^3/day, Binh Hung Hoa factory capable of treating 30,000 m^3/day, and Tham Luong-Ben Cat plant with a capacity of 15,000m3/day. (Ngoc Diem 2022.)

3.1.2 Urban water cycle in Ho Chi Minh city

Ho Chi Minh City (HCMC) achieved a significant milestone in 2016 by providing cleaned tapped water to all residents through the public water supply system (Ha 2017). As stated by SAWACO (Saigon Water Corporation), HCMC relies on two main water sources for the public network: surface water (from Dong Nai River, Saigon River, and Dong Canal) and groundwater. However, the city is making efforts to minimize groundwater exploitation to reduce its environmental and human impacts. (Tran 2022.). As reported by SAWACO, Surface water accounts for 94% of the raw water used for producing drinking water within the system, with 60.5% coming from Dong Nai River, 25% from Saigon River, and 8.5% from N47 Canal (a branch of Dong Canal) (Hoang 2022a). Raw water is extracted using pumps and transported through pipelines to water treatment plants to produce treated water. Challenge of surface water source is more and more polluted year by year. (Ha 2017; Tran 2022; Hoang 2022a.)

Groundwater, or well water, constitutes the remaining portion and is gradually being reduced, with plans to reduce to 100000 m^3/day in 2025. In 2022, HCMC extracts 264581 m^3/day. (Hoang 2022b.). Groundwater extraction has adverse effects on the environment, contributing to land subsidence, groundwater pollution, and other related issues. Beyond the public water supply system, some residents and businesses still rely on self-dug groundwater wells. Businesses must register with SAWACO to obtain permits for groundwater use, while controlling groundwater use in residential areas remains challenging. SAWACO and the authorities can only promote the replacement of groundwater with tap water. The quality of groundwater in HCMC often fails to meet safety standards, and prolonged use can have negative health implications. Following is the description of the urban water flow in Ho Chi Minh City (FIGURE 7). Please note that the information about the domestic water supply in Ho Chi Minh City is synthesized from various sources and may have some discrepancies in detail. (Hoang 2022b; Tran 2022.)

Ho Chi Minh City relies on two main water sources for its domestic water supply: surface water (from Dong Nai River, Saigon River, and Dong Canal) and groundwater, which is treated to provide drinking water to the residents (Tran 2022; Hoang 2022a). The public water supply is extracted from water sources and treated by the Saigon Water Corporation (SAWACO) before being distributed through the public water supply system and pipelines. For instance, privately exploited groundwater, used by households and businesses, is not considered as public water supply. Groundwater is used in small quantities and is seen as an emergency source when surface water is not available. However, the city is actively reducing groundwater exploitation due to its adverse environmental impacts, such as land subsidence and groundwater pollution. (Tran 2022; Hoang 2022b.)

The basic flow of water in the city is as follows: Water is pumped from surface water and groundwater sources through a lengthy pipeline system to water treatment plants. Here, the raw water undergoes water treatment to become drinking water, supplied to residents as tap water. Tap water cannot drink directly. Boiling is a simple method for potable safety. After using the tap water, households generate wastewater, categorized as either blackwater (from toilets containing human waste and urine) or greywater (from activities like bathing, dishwashing, and laundry). Blackwater is introduced into the household's septic tank, which then is discharged into the city's sewage system. Greywater is often discharged into the city's sewage system. (Pham & Kuyama 2013, 3-4.)

There are three scenarios for wastewater discharge. In the first scenario, domestic wastewater is discharged into the city's sewage system through a pipeline system, which then releases the pre-treated wastewater into the environment. In the second scenario, some residential areas have wastewater treatment plants where domestic wastewater flows through separate pipelines, segregating greywater from blackwater. After being collected by the treatment plant, the wastewater is either discharged into the sewage system or sent to a centralized wastewater treatment plant. After treatment, the wastewater is released into the environment. In the third scenario, in certain slum areas along the riverbanks, domestic wastewater is often directly discharged into the environment without any treatment. (Pham & Kuyama 2013, 3-4; World Bank 2013, 26, 52, 62; Chu 2019; Vietnamdaily 2019.)

Rainwater is a potential water resource and, at the same time, a significant challenge for Ho Chi Minh City. In the city, both wastewater and rainwater share the same sewer system. Rainwater flows into the sewer system after falling. During heavy rainfall, the accumulation of rainwater can lead to flooding, which has been a persistent issue for Ho Chi Minh City without a fully effective resolution. Aside from some rainwater being collected in reservoirs at water treatment plants or private rainwater storage tanks, there is no official plan for systematic rainwater harvesting as a supplementary water source for the city. While there are proposals for constructing regulating ponds and reservoirs, these primarily aim to mitigate flooding rather than harness rainwater as a substantial water resource. (Le & Le 2019; Son 2022.)

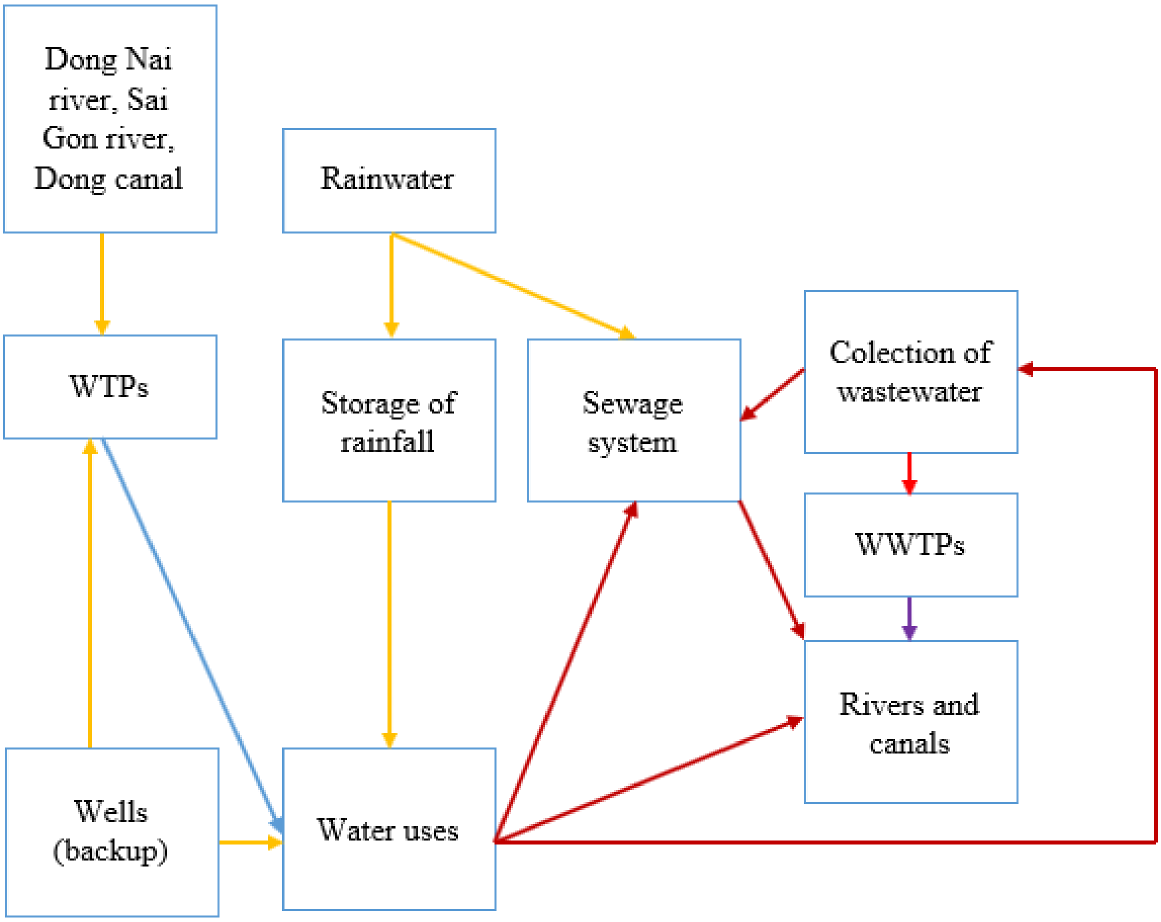

FIGURE 7. The urban water cycle in Ho Chi Minh city (red: wastewater, yellow: raw water, violet: treated water for disposal to rivers, blue: drinking water) (Adapted from Pham & Kuyama 2013, 3-4; World Bank 2013, 26, 52, 62; Chu 2019; Vietnamdaily 2019; Tran 2022; Hoang 2022a; Hoang 2022b; Le & Le 2019; Son 2022)

After public water supply and urban water cycle are reviewed, some private water uses of citizen are introduced following. Groundwater is still used by some households in the city as private groundwater wells, especially in non-central districts (Tran 2022). Besides, rainwater is predominantly used for domestic purposes, especially in suburban areas where access to the public water supply is limited in the past, such as District 7, Nha Be, and Can Gio (Le & Le 2019). Rainwater holds significant potential as a water resource because of high raining rate. According to one research, rainwater in HCMC even meets the national standard for potable water (QCVN 01:2009/BYT – National technical regulation on drinking water quality) (Le & Le 2019 [Nguyen et al. 2015]). However, another study titled "Domestic use of rainwater in Ho Chi Minh City, Vietnam: exploring the barriers from the citizens' perspective" by Hang and Thuong, conducted through a survey with 270 valid responses, found that 15.6% of respondents believed rainwater is 'very polluted,' and 34.55% considered it 'polluted.' Only 0.4% and 6.91% of respondents regarded rainwater quality as 'very good' and 'good,' respectively. Approximately 42.5% of respondents had no specific opinion or remained neutral about the quality of rainwater. (Le & Le 2019.) In contrast, according to SAWACO's reports, the quality of piped water in HCMC does not meet the national standard for potable water due to the old pipe system (Le & Le, 2019 [Dinh 2016]). Hang and Thuong's study also highlighted a knowledge gap among citizens regarding water quality and the available scientific data (Le & Le, 2019).

In Ho Chi Minh City, the raw water resource is increasingly affected by severe pollution, leading to negative impacts on the drinking and domestic water quality for many households. Particularly, areas with industrial activities, export processing zones, and strong manufacturing operations contribute significantly to the pollution problem. Direct discharge of untreated industrial wastewater into surface water sources like rivers and lakes has led to unforeseen consequences for people's livelihoods and health. Additionally, the Ministry of Health advises against consuming tapped water directly from the faucet and recommends boiling it to ensure safe usage. This may not be convenient and may lead to insecure feeling with taped water for many households. Consequently, people have sought alternative solutions to ensure access to clean drinking water and safeguard their health. (WEPAR 2021, Ban nhân dân hàng tháng.)

Two common approaches to safeguard from anxiety of polluted water are bottled water and private water filtration systems. Using bottled water as a replacement for boiling-then-cooling water has gained popularity and trust among many individuals. Bottled water can be consumed directly without boiling. It is produced by private facilities and is usually available in 20-liter bottles. However, one concern with bottled water is the difficulty in controlling the water quality across different production facilities. Some facilities may provide unqualify bottled water. (WEPAR 2021.). Household Water Filtration Systems is another common approach. This is an approach to purify tap water of households by installing water filtration systems for drinking purposes. The tap water is connected to the water filtration machine which filters the tap water into safe drinking water for the residents' use. According to a feature in the Nhan Dan monthly magazine in December 2022, most residents in large urban areas expressed dissatisfaction when asked about the quality of clean drinking water. Statistical data indicates that the Vietnamese water filtration market has been experiencing significant growth and vibrancy. Water filtration machines have become essential household appliances to safeguard health. (Ban nhân dân hàng tháng 2022.)

3.2 Singapore

Singapore is a island in Southeast Asia. It is a city, a country and a state (Ministry of Foreign Affairs Singapore 2023). Singapore is a country and has achieved significant accomplishments such as achieving the richest and most advanced country in Southeast Asia with GDP per capita ranking 8th in the world in 2013 (MINISTRY FOR FOREIGN AFFAIRS OF FINLAND 2015, 11). Moreover, the country has succeeded in developing the economy in parallel with environmental protection (The International Trade Administration 2020). However, the water resource of the country is limited. The truth is that it faces challenges in terms of water security. Surface water, which is one of Singapore's primary water sources, is imported from Malaysia. (Seah 2020; Lafforgue & Lenouvel 2015.). Singapore's progress is intricately tied to its continuous efforts to achieve water self-sufficiency and reduce reliance on external sources (Seah 2020; Lafforgue & Lenouvel 2015).

3.2.1 General information

Singapore is a sunny, tropical Southeast Asian island (Ministry of Foreign Affairs Singapore 2023). It has a population of 5,637,000 people living in an area of 720 square miles (Department of statistics Singapore 2022). As a result, the density is approximately 7900 people/km^2, making it one of the highest in the world. Singapore has a high rainfall rate, with an average of 2165.9 mm and approximately 167 rainy days each year (45.8% of the year). The city experiences various wet seasons from November to January, as well as dryer months in February. (Meteorological Service Singapore 2010.). Singapore has five NEWater plants that create high-quality water, as well as five desalination units that produce drinkable water from seawater (PUB 2022c; PUB 2022a). Although natural water resource is limited, the city exploits all sources of water to satisfy its demand (Seah 2020).

3.2.2 Urban water cycle in Singapore

Singapore employs a comprehensive water management approach called the "Four National Taps," overseen by Singapore's national water agency PUB. The four water sources are imported water, water from local catchment, NEWater, and desalinated water. (PUB 2022d.). First national tap, imported water is surface water that Singapore imports from the Johor River in Malaysia under the 1962 Agreement, satisfying 40% of its water demand (PUB 2022e; Lafforgue & Lenouvel 2015). Second national tap, water from local catchment involves harvesting rainwater. Rainwater falling over a significant portion of Singapore is not wasted but collected through a network of rivers, canals, and drains, eventually flowing into 17 reservoirs. The water in these reservoirs is then treated at water treatment plants to become safe drinking water for the water supply system. Singapore has continuously expanded the water catchment area, and since 2011, it has been able to collect rainwater over approximately 473 km^2, covering two-thirds of its land area (710 km^2). (PUB 2022b.). The country plans to further expand the water catchment area to cover 90% of its land area in the future (PUB 2022b; PUB 2022e; Lafforgue & Lenouvel 2015).

Third national tap, NEWater involves reusing treated wastewater, known as NEWater. Singapore has a separate underground pipe system for collecting wastewater, which is then sent to wastewater treatment plants and then sent to NEWater plants. (PUB 2022b.). Currently, Singapore has five NEWater plants that treat wastewater for non-potable reuse and indirect potable reuse. The NEWater plants use a combination of microfiltration/ultrafiltration, reverse osmosis (RO), and ultraviolet disinfection to transform wastewater into ultra-clean, high-grade reclaimed water. After treatment, the highly treated wastewater is used for non-potable purposes, such as industrial and air conditioning use. During the dry season, Singapore also practices indirect water reuse by pumping treated wastewater into reservoirs to dilute with raw water. Subsequently, the water in the reservoirs is treated at water treatment plants to become potable drinking water. (Seah 2020.). Forth national tap, desalinated water involves a water source obtained by filtering seawater to make it suitable for drinking. Currently, Singapore operates five desalination plants. Desalination of seawater requires a significant amount of energy. Singapore is continuously testing and implementing new methods to reduce the energy consumption from the current 3.5 kWh/m^3 to 1.5 kWh/m^3 and ultimately to 1 kWh/m^3 in the long-term. (Seah 2020;.PUB 2022a.)

Singapore's water management aims to create a closed-loop urban water cycle, and the process is well-defined in FIGURE 8. Seawater undergoes treatment at desalination plants to become potable tapped water for the residents. The water from the other three sources is treated at water treatment plants to produce tapped water for drinking purposes. After use, the drinking water becomes wastewater and is conveyed through a separate underground pipe system for wastewater to water reclamation plants (WWTPs in FIGURE 8). (Seah 2020; Lafforgue & Lenouvel 2015.)

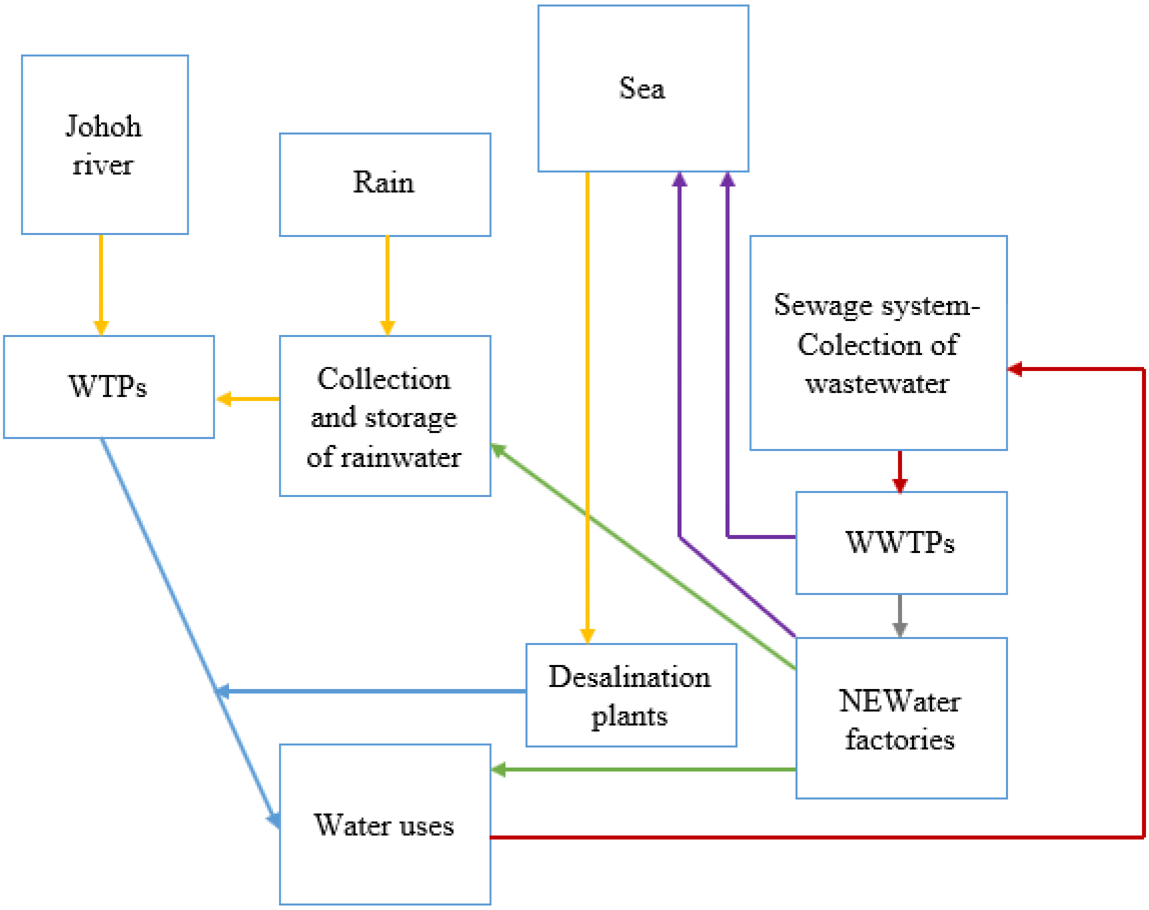

FIGURE 8. The urban water cycle in Singapore (red: wastewater, yellow: raw water, grey: unqualify treated water for disposal to sea, light green: highly-quality treated water for non-potable uses, light green: quality treated water for NEWater production, blue: drinking water) (Adapted from Seah 2020; Lafforgue & Lenouvel 2015)

The treated used water from the reclamation plants includes two types: one suitable for NEWater production, which is directed to NEWater plants, and one unsuitable type, which is discarded into the sea. At the NEWater plants, the treated water is further purified to create NEWater, which is primarily used in industries requiring water of higher quality than drinking water. During the dry season, NEWater is pumped into reservoirs, acting as environmental buffers, and blended with rainwater. Any treated water that does not meet the stringent quality standards for NEWater during the treatment process at the

NEWater plants is discharged into the sea. The blended water from reservoirs is then treated at drinking water plants, restarting the cycle in the closed-loop system. (Seah 2020; Lafforgue & Lenouvel 2015.)

3.3 Comparison

From 3.1.2 and 3.2.2, Ho Chi Minh city (HCMC) and Singapore have different water management strategy. Obviously, when Singapore reuses wastewater in a closed-loop system, water treatment in HCMC does not meet the demand (Seah 2020; Nhân dân điện tử 2021). If water treatment in HCMC meets the demand, wastewater will be discarded with recent water management strategy (Nhân dân điện tử 2021). This means, in the context of HCMC, there remains significant potential for enhancement and development. Two cities are compared in various aspects to derive relevant lessons for HCMC to overcome its current challenges effectively. The selected aspects for comparison encompass natural conditions, water management strategies, water sector organization, and citizens' viewpoints. Data and information are collected from section 3.1 and 3.2. These aspects are briefly summarized in TABLE 2. (Seah 2020; Nhân dân điện tử 2021.)

TABLE 2. Comparison of Ho Chi Minh City and Singapore (adapted from GOVERNMENT ELECTRONIC PORTAL 2011; Meteorological Service Singapore. 2010; Seah 2020; Le & Le 2019).

Natural condition	Ho Chi Minh city	Singapore
Rain rate	average 1949 mm/year	average 2165.9 mm/year
Area	2095 km^2	720 km^2
Population	9166840	5637000
Density	4375 people/km^2	7829 people/km^2
Water management strategy	De facto	Indirect potable reuse
Water source	2	4
Water sector organization	SAWACO only manages drinking water supply	PUB, a national organization manages entire water cycle
Citizens’ perspective	Not high	High

3.3.1 Natural condition

Ho Chi Minh City experiences high rainfall, with an average of 1949 mm per year and approximately 159 rainy days (43% of the year). In comparison, Singapore receives higher rainfall, with an average of 2165.9 mm and about 167 rainy days (45.8% of the year). Both cities have relatively similar weather patterns, characterized by distinct wet seasons (from May to November in Ho Chi Minh City and from November to January in Singapore) and drier months (April and December in Ho Chi Minh City and February in Singapore). (GOVERNMENT ELECTRONIC PORTAL 2011; Meteorological Service Singapore. 2010.)

The average annual rainfall in Ho Chi Minh City is about 90% of Singapore's average rainfall. Therefore, the amount of water that Ho Chi Minh City can harvest on the same unit of land area will not be as much as Singapore. However, Ho Chi Minh City has a larger land area of 2095 km^2, while Singapore's land area is only 720km^2. (Department of statistics Singapore 2022; Văn phòng ủy ban nhân dân TPHCM.). Moreover, the quality of rainwater in Ho Chi Minh City meets the standards set by the Ministry of Health for potable water (QCVN 01:2009/BYT – National technical regulation on drinking water quality). A study conducted in 2013 at 12 rainwater monitoring stations analyzed the concentrations of ions such as Na^+, stiffness, NO_3^-, NH_4^+, SO_4^{2-}, and Cl^- in the rainwater samples (Le & Le 2019 [Nguyen et al. 2015]).

Nevertheless, one issue affecting the quality of rainwater is environmental pollution leading to acid rain. The rate of acid rain is estimated to be about 20-30% in HCMC (VietNamNet & Thanh Nien 2009). A report on rainwater quality monitoring in HCMC in 2013 by a group of students found that rainwater in industrial areas of the city may require neutralization due to its low pH and high acidity. Despite this, the group also acknowledged that the overall quality of rainwater in HCMC is still suitable for various uses. (Tran et al. 2013.). Acid rain is also present in Singapore, but the use of rainwater there remains unaffected (Lei 2020). Therefore, the presence of acid rain in HCMC may increase the cost of rainwater treatment, but it may not have a significant impact on overall water treatment expenses (Tran et al. 2013; Lei 2020).

Based on the natural conditions mentioned earlier and the similarities with Singapore, it appears that developing a rainwater harvesting system in HCMC is suitable both in terms of rainfall quantity and rainwater quality. However, it is advisable to establish the rainwater harvesting infrastructure away from industrial areas to collect rainwater with low acid content, which can help reduce the cost of rainwater treatment (Tran et al. 2013). Additionally, implementing a well-planned construction of rainwater storage facilities can contribute to mitigating flooding issues in the city, which is a significant concern for Ho Chi Minh City (Le & Le 2019).

Constructing a large-scale rainwater harvesting and storage system requires high investment costs and land area (Nguyen et al. 2007, 72, 81). However, the operational costs after completion are lower compared to the operation of water reclamation plants because rainwater is of good quality and can be directly connected to the existing water supply system (Le & Le, 2019). It is essential to pay attention to mosquito breeding control in the rainwater harvesting system, as dengue fever caused by mosquitoes is a serious issue in HCMC. If rainwater reservoirs become favorable breeding grounds for mosquitoes, it could pose a significant threat to the city's residents. Therefore, proper mosquito control measures must be implemented to ensure the safe and efficient operation of the rainwater harvesting system. (Thanh 2023; Hunt & Gee 2021.)

Essentially, besides large-scale advanced membrane technologies like Singapore, desalination requires a water source of either seawater or brackish water to be filtered into potable water (Seah 2020). Therefore, the Can Gio Sea in Can Gio District, HCMC, can provide an abundant raw water source for desalination. However, desalination demands a considerable amount of energy, and both HCMC and Vietnam, in general, are currently facing electricity shortages, particularly during the dry season. Nevertheless, Vietnam and HCMC have significant potential for solar power exploitation. If solar power, especially rooftop solar, is well developed, there will be no concerns about electricity shortages. (Xuan 2023.). Considering the natural conditions, it seems feasible to develop desalination in the region. However, the cost of desalinated water is typically twice as expensive as conventional water supply (in the US) (WateReuse Association 2015, 16). In the case of Singapore, desalinated water is about five times more energy-intensive compared to NEWater (Seah 2020, 45). Thus, desalinated water could contribute to an increase in the cost of public water supply (WateReuse Association 2015, 16; Seah 2020).

To summarize, the natural conditions of Ho Chi Minh city share similarities with Singapore, making it feasible to develop and operate rainwater catchment and desalination systems to expand water sources. Rainwater catchment also presents a long-term solution to mitigate flooding in HCMC (Le & Le 2019). Desalination seems suitable accoring to natural condition, but advanced technology and cost of desalination are barriers (WateReuse Association 2015, 16; Seah 2020). However, further in-depth research and analysis are necessary to assess the practical feasibility and address potential challenges that may arise in the implementation process.

3.3.2 Water management strategy

Ho Chi Minh City (HCMC) is currently part of an unplanned water reuse system or de facto. Using the example of the Dong Nai River, which runs through the city, there are numerous industrial areas, agricultural zones, and new urban developments along the river basin that utilize water from the Dong Nai River for production activities and daily living. Subsequently, the wastewater is discharged back into the river. Additionally, the Dong Nai River basin experiences significant waterway traffic with busy boat transportation. HCMC, being downstream, relies on and treats the raw water from the downstream portion of the Dong Nai River to supply drinking water to its residents. As a downstream city, the control of raw water quality sourced from the Dong Nai River for HCMC is challenging due to potential pollution from upstream industrial and domestic activities, as well as incidents such as oil spills from vessels. (Hoang 2022.). All wastewater from HCMC is discharged into the Saigon River. However, the Saigon River later converges with the Dong Nai River, and their combined flow eventually reaches the sea. No community utilizes the downstream portion of the Saigon River after HCMC as a raw water source. Therefore, based on the aforementioned definition, HCMC is not considered an upstream city in an unplanned water reuse system. (Hoang 2022; SGGPO.)

Singapore has clearly adopted an indirect potable reuse approach, evident through its diverse water sources, water treatment plants, advanced wastewater treatment facilities, and the use of reservoirs as environmental buffers. The public is well-informed about the origin of their drinking water and supports this practice. (Seah 2020.). All these factors demonstrate Singapore's excellent water management practices. Additionally, despite not owning the main water source from the Johor River, Singapore has alternative sources such as seawater and reliable rainwater supply, which can serve as emergency backups. (Seah 2020.). Conversely, HCMC heavily relies on the Dong Nai river as its primary water source. Unfortunately, this water resource is experiencing increasing pollution year after year (Vo 2007). To address this issue, HCMC should consider exploring alternative water sources or revising its water management strategy (Seah 2020; Vo 2007).

3.3.3 Water sector organization

Article “Closing the urban water loop: lessons from Singapore and Windhoek” provides one similar point of two cities which leads to their success in field of water management. They are similar about water sector organization. Both cities have their organization to manage entire urban water cycle of their cities and they are all experts in the field of water treatment. (Lafforgue & Lenouvel 2015; Seah 2020, 42.). Ho Chi Minh City (HCMC) is serviced by SAWACO, a water sector organization responsible for managing the entire water supply of the city. SAWACO has achieved its target of providing 100% clean water to the population, indicating its success in delivering safe drinking water. However, due to its narrow focus on clean water supply, SAWACO may overlook other aspects of water management. Without an integrated organization overseeing the entire water cycle in HCMC, innovative approaches to water management could be challenging. (Ha 2017; Tran 2022; Hoang 2022a.)

For example, SAWACO plans to switch to a new water source to avoid contamination and intends to construct a new water reservoir there (Nguyen & Ha 2021). While this is suitable for ensuring water supply, it might not be the most efficient approach from a water cycle perspective. Building water reservoirs at strategic locations in HCMC could facilitate rainwater harvesting and contribute to flood reduction. Another issue is the lack of consistent infrastructure planning and synchronized investments. Some areas have completed drainage systems without corresponding wastewater treatment plants (like the Nhieu Loc-Thi Nghe canal project), while others have finished wastewater treatment plants but lack proper sewage collection systems to transport the wastewater to the plants (as seen in the Tham Luong-Ben Cat project). (Nguyen & Ha 2021; Ngoc Diem 2022.)

To gain trust and confidence from the public, swift and resolute action is crucial. Otherwise, there is a risk of facing more significant challenges, and public faith in the water management authorities may continue to diminish. Despite the potential development of SAWACO into a highly specialized organization overseeing the entire water sector, distrusting SAWACO from public may remain as an issue. This is evident from the increasing prevalence of household water filtration systems, as people lack confidence in SAWACO's ability to provide sufficient clean water. (Ban nhân dân hàng tháng.)

3.3.4 Citizens’ perspective

As main consumers, citizens are significant links in water management because they decide to follow or oppose water policies from government. The perspective of the Singaporean for water is high, so the right policies may be more favorable for success. Their policies enhance their water perspective through education and regulation. (Seah 2020.). Perspective of citizens in HCMC about water is limited. Article "Domestic use of rainwater in Ho Chi Minh City, Vietnam: exploring the barriers from the citizens' perspective" proves that there is a knowledge gap among citizens regarding water quality and the available scientific data. (Le & Le 2019.)

4 DISCUSSION

Based on the current reality of increasing water pollution in Ho Chi Minh City (HCMC), the author proposes three approaches to address the issue: changing water sources, adding new water sources, and developing or adopting more advanced water treatment technologies capable of purifying increasingly polluted water in both the present and the future. Regarding the first solution, the city is already implementing a water source change by shifting the water intake point upstream of the Dong Nai river (Ngoc Diem 2022). In terms of adding new water sources, HCMC can learn from Singapore's well-established achievements in water management, which have been integrated with socio-economic development while continuously striving to conserve water (Seah 2020). Singapore, with a dense population and some basic weather similarities to HCMC, serves as a relevant example. From comparison in previous section, natural condition of Vietnam is suitable for develop rainwater catchment and desalination. However, the economic, social, and technological disparities between the two cities present significant challenges. The third approach involves adopting more advanced water treatment technologies capable of handling increasingly polluted water. If being successful, this solution would lay the foundation for further technological advancements in water reuse from treated wastewater. (Seah 2020; Lafforgue & Lenouvel 2015; Department of statistics Singapore 2022; Le & Le 2019; Văn phòng ủy ban nhân dân TPHCM.)

Based on the assessment of developing additional water sources and drawing insights from Singapore's experiences, the differences between HCMC and Singapore must be considered. The most apparent disparities lie in their economic and technological levels. Singapore is a developed country with a high GDP, employing advanced membrane technologies for wastewater treatment, whereas HCMC lacks such advanced technologies and currently treats less than 13.2% of its total wastewater (MINISTRY FOR FOREIGN AFFAIRS OF FINLAND 2015, 11; Seah 2020; Nhân dân điện tử 2021). Although it is not known whether the city has the necessary funding for construction, HCMC is planning to call for investments to build a total of 12 wastewater treatment plants which can treat around three million m^3 of wastewater per day, to enhance the city's capacity to treat urban wastewater both quantitatively and qualitatively (Nhân dân điện tử 2021). Furthermore, HCMC has set goals to construct additional water treatment plants to increase water supply capacity to 3.63 million m^3 by 2025, in response to the city's population growth and development needs (Thu & Khanh 2022). HCMC has planned to develop an urban area with a water consumption level of approximately 3.6 million m^3 and the capacity to treat around 3 million m^3 of wastewater. The city has also proposed constructing a 5-million- m^3 water reservoir, capable of providing clean water to city residents for up to 7 days as a precaution against heavy water pollution. (Nguyen 2021.).

Clearly, construction projects are actively planned and underway. The challenge lies in coordinating, planning, and operating these projects coherently and efficiently in the future. Therefore, it is essential to establish an organization responsible for managing the entire urban water cycle of HCMC to integrate future projects into an efficient, closed-loop urban water cycle. Considering Singapore's experience, they have been continuously researching and developing technologies for many years. When NEWater was established in 2003, it showed Singapore's technological readiness. However, Singapore still unified all water management under a single national agency, PUB, to ensure seamless operations. Hence, having an organization dedicated to managing HCMC's entire urban water cycle is indispensable, as it is crucial for transformation and development, based on lessons learned from Singapore. Consequently, the HCMC government should promptly establish a new organization under the jurisdiction of HCMC, specifically tasked with planning and monitoring the construction of water-related facilities, to ensure a coherent and well-planned indirect potable reuse for the future. This organization would also eliminate unnecessary constructions, such as new water source’s reservoir, thereby conserving resources for essential and sustainable projects, like rainwater reservoirs if the organization makes enough research to compare effectiveness of two options. (Seah 2020; Ngoc Diem 2022.)

Based on the available information, the current situation presents an opportunity for HCMC's water sector. Firstly, the 2020 Environmental Protection Law is the first legal document to address the concept of a circular economy and includes provisions on circular economy (Lan 2021). Building three additional water sources in a suitable manner would create a closed-loop system similar to Singapore's, aligning with the principles of a circular economy. The encouragement of circular economy applications by the government also prompts water supply companies to pay more attention to water reclamation. From that, wastewater could be seen as a new materials and water reuse has space for development. Speaking of water supply companies, the second favorable aspect is the industry's growth and promising prospects from 2017 to 2020, with an annual compound growth rate of 43% for industrial water and 35% for clean drinking water. (Hieu 2020.). However, this growth pertains to the entire country, and it is possible that water sector investments in other cities may be more favorable than in HCMC. Therefore, a more detailed analysis of HCMC's water sector growth is required to have a complete optimistic outlook. Additionally, the third advantage lies in the potential for revenue collection from water treatment fees charged to citizens and businesses. (Nhân dân điện tử 2021.). Charging fees will boost the water sector's budget and create more capacity for developing new water sources (Nhân dân điện tử 2021). Although higher water prices may not be well-received by the public, they may increase awareness about water conservation. Furthermore, the survey on barriers to rainwater harvesting revealed that the primary reason for rainwater usage is to save water costs (Le & Le 2019).

Besides, about water reuse, Phu My Hung, an upscale residential area in District 7 in HCMC, installed a wastewater treatment system which had separated pipelines for stormwater and wastewater. This enabled them to apply wastewater reclamation by utilizing treated wastewater for irrigation purposes and converting waste sludge from the wastewater treatment process into fertilizer for plants. (The World Bank 2013, 52.). Consequently, implementing water reclamation in HCMC is feasible. However, to achieve high effectiveness, the key lies in coordinating well-planned construction and development. The separation of pipelines is crucial in the application of water reclamation in Phu My Hung, and to ensure the successful installation of new pipeline systems, a rational planning approach is necessary. Therefore, having a water section organization responsible for managing HCMC's entire urban water cycle is essential and indispensable. Singapore also utilizes PUB to ensure coherence in water planning and management, which proves to be a pivotal factor in their success. (The World Bank 2013, 52; Seah 2020.)

The potential and feasibility of changing water sources require further exploration, considering the information and knowledge mentioned above. These discussions provide potential considerations, along with the experiences of Singapore, but may not contain enough data and reasoning to conclude a fully feasible and practical plan for Ho Chi Minh City. However, from analysing Singapore as a case study, establishment of a new water section organization which manages entire urban water cycle in HCMC is indispensable. Some in-depth and practical studies about rainwater catchment implementation of HCMC and about application of urban wastewater in HCMC are also important.

5 CONCLUSION

With a belief that water reuse requires cooperation from all citizens, the thesis aims to establish a seamless logical framework encompassing the fundamental aspects of water, water and wastewater treatment, and water reuse. It then conducts a comparative analysis of water management strategies between Ho Chi Minh city (HCMC) and Singapore to draw successful lessons on water reuse from Singapore. Based on these lessons, the thesis identifies suitable approaches to apply and develop water reuse in HCMC.

In conclusion, HCMC should adopt the approach of indirect potable reuse, similar to Singapore, by developing three new water sources through rainwater catchment, wastewater reclamation, and desalination due to their suitability to the local natural conditions. Additionally, this approach fosters a sustainable development pathway for the water sector. Among these options, rainwater catchment deserves priority as it not only expands water supply but also contributes to flood reduction, a pressing issue in HCMC. Besides, wastewater reclamation deserves following priority because it expands water supply and applies circular economy. Most importantly, the city's government should promptly establish a water section organization responsible for managing the entire urban water cycle of HCMC. This organization will specialize in planning, coordinating, overseeing construction, and future operations, ensuring the seamless integration of all relevant water sections to establish the foundation for an indirect potable system.

However, since the analyses are fundamental, further research is indispensable for specific application, including three main approach. Firstly, conducting in-depth studies to assess the feasibility of implementing rainwater catchment in HCMC, comparing costs and benefits with other water source projects in the city, recently, studies about this topic are limited. Secondly, identifying appropriate and profitable applications for wastewater reuse, suitable and qualified reseachs in this approach may convert wastewater from waste into money. Thirdly, conducting research on pipeline systems, effiency pipeline systems affect quality of water like a dirty dish may spoil food. (Schutte 2006, 12-23; Le & Le, 2019). These additional efforts will provide more comprehensive insights and ensure the success and practicality of water reuse implementation in HCMC.

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