THESIS

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Assessment of Water Management Strategies in Vientiane Capital of Lao PDR

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Lists of Abbreviation

APHA: American Public Health Association

BOD: Biochemical oxygen demand

$BOD_{5:}$ Five-day biochemical oxygen demand

COD: Chemical oxygen demand

CWTP : Chinaimo water treatment plant

COD_{cr}: chemical oxygen demand chromium

CU: Colour Unit

DNA: Deoxyribonucleic acid

DO: Dissolved oxygen

DWTP: Dongmakkhai Water Treatment Plant

EC: Electrical conductivity

EPA: Environmental Protection Agency

IWRM: Integrated Water Resource Management

JICA: Japan International Cooperation Agency

KWTP: Kaolieo Water Treatment Plant

NPNL: NAMPAPA Nakhone Luang

NTUs: Nephelometric turbidity unit

pH: potential of hydrogen

PHC: Population and Housing Census

RNA: Ribonucleic acid

TON: threshold odor number

TTN: threshold taste number

UNESCO: The United Nations Educational, Scientific and Cultural Organization

VC: Vientiane City

WEPA: The Water Environment Partnership in Asia

WHO: World Health Organization

WWTP: wastewater treatment plant

Chapter I: INTRODUCTION

1. Introduction

Water is one of the most important substances on Earth. To survive, all plants and animals need water. There wouldn't be any life on earth without water, as water is essential to human everyday life (ENHEALTH, 2010). Water is used by humans for different daily tasks, including cooking, bathing, doing laundry, cleaning dishes and cutlery, maintaining clean homes and communities, using swimming pools for recreation, and gardening and maintaining plants. Humanity settled near water points in the earliest stages of civilization (Lenntech, 2017). Economic and social development is all about water, which is used for food production, environmental management, employment creation, and health maintenance, among others. Despite the importance of water, more than 663 million people around the world do not have access to clean drinking sources (Water Supply and Sanitation Program, 2014).

The management of water resources is defined as a planning, construction, and operation of water resource utilization systems centered on quantity and quality parameters (The World Bank, 2019). It entails structures, infrastructure, and policies that support water management as a tool within its own right. Water resource management ensures adequate water quantity and quality for various sectors, manages environmental risks like floods, drought, and pollution, and supports ecosystems and ecosystems. The issue of how houses, water, economy, and ecosystems are related calls for a holistic approach towards sanitation that respects synergies and accommodates trade-offs (The World Bank, 2019). Nowadays, municipal sanitation and wastewater management has turned into a problematic matter. sustainable environmental development in the developing countries. As of 2015, 39.4% of the global population had access to safe and properly managed sanitation services (WHO, 2017). In the same time, that social and economic developments are seen in the Asian countries, they also come with serious water pollution issues. The urban areas' growing population has led to the growing need for drinking water and its supply (WEPA, 2015).

Lao PDR is a landlocked country in Southeast Asia. It borders Myanmar, China and Vietnam are to the northwest, Thailand to the west, Cambodia to the south, and Lao PDR is the administrative area with about 3,920 km^2 inhabited by roughly 800,000 people, Vientiane Capital is the largest city. Vast urbanization is causing problems presently such as scattered house building due to increase in population, constant traffic jams and inadequate public infrastructure **(**Department of Home Affairs of Vientiane Capital, 2015).

Objective

The objective of this thesis is to carry out the thorough investigation of the effectiveness and sustainability of water management strategies in Vientiane, the capital of Laos PDR. Through the multi-dimensional assessment, the study seeks to evaluate the water management projects considering the dimensions of infrastructure development, water resource use, environment protection, and social and economic impact. This study would undertake a critical evaluation of the approach currently adopted to know the strengths, weaknesses, opportunities, and threats that are the main aggregator of the challenges of water management in Vientiane. In the end, we aim at identifying and giving insights and solution that will result in a water management policies and practices enhancement so as we can have a more resilient and sustainable water supply and user system in the context of Vientiane in the future.

Chapter II: LITERATURE REVIEW

2.1. General knowledge about water management

The concept of water management is the provision of control and distribution of water resources to prevent damage done to people and properties while still optimizing the longevity of their life span. The damage by floods can be reduced by proper dams and levees operations. Irrigation water consumption management systems optimize utilization of limited agricultural water resources. Water budgeting and surface and subsurface drainage system studies are elements of drainage management. Human water management sometimes necessitates changing practices, like the rate of groundwater withdrawal or the water allocation among various uses (GRT, 2021).

The treatment of wastewater in the sanitation system is an important environmental service that is closely connected to water management. Inadequate sanitation practices in Lao PDR contribute to the water pollution in the country in a general way and urban areas. The main water source for urban supply is surface water because most towns are along the rivers. Groundwater, on the other hand, caters for the rural population. In Vientiane, the capital city, on-site disposal system of both human waste and black water is commonly applied without treatment or with the treatment that is poorly functioning in most urban areas (Chanthavilay et al.2017). The increase of pollution and the constant deterioration of drainage water quality is now a big challenge for the management of Vientiane's water resources as it is becoming a more and more urban city.

2.1.1. Integrated Water Resource Management.

According to Jain and Singh (2003) One of the way of implementing the approach called Integrated Water Resource Management (IWRM) is through a geographic unit (called basin or watershed). The objective of integrated water management (IWRM) is to minimize economic and social welfare along with the equitable distribution in a sustainable way to maintain the precarious balance. This is achieved through coordinated integrated development and management of water, land and associated resource (Jain & Singh 2003).

Integrated Water Resources Management also means the process of making decisions and taking actions that are multi-perspective and consider all the possible viewpoints on how water should be managed. These choices and actions refer to the events such as basin planning for rivers, setting up expert groups, building new capital facilities, controlling reservoir outflows, protecting floodplains, and developing/imposing new laws and regulations, respectively. The multi-pronged approach is due to competition for water and complicated institutional wardens (Grigg, 1996).

2.1.2. Components of Integrated Water Resources Management.

Five elements make up integrated water resource management (Grigg & Neil S, 1996):

+ Water Resource Management: Land and water, the upstream and downstream streams, ground water, surface water, and coastal resources, are all part of managing water in a basin or at a watershed level (Steusloff,2010). The functions of managerial instruments will enable the functioning of institutions. These tools include design tools for allocating resources as well as evaluation and integration tools. The rivalry for the limited water resources is on the rise in the as the pressure on the global water resources increases. This calls for an effective water management strategy to address these issues. In a nutshell, the strategy involves eco-human equilibrium which implies that it is time to move from the artificial sectoral approach to water management to the real interdisciplinary model which is holistic.

+ Purposes and Services: Integrated water resources management considers water management agencies with separate objectives as one of the perspectives. Three factors are considered while managing water: the area of water body, the amount and the quality of the surface and the ground water. Navigation, recreation, storm, and flood control, water quality services and wastewater services are managed by water agencies along with navigation, navigation and water for fish and the environment as well as wildlife. Analyzing ground and surface water sources, studying water balances, utilizing wastewater, and assessing environmental impacts of the distribution and utilization alternatives are all parts of maximizing supply (Mitchel 1990).

+ Disciplines of Knowledge: Circularity of Integrated Water Resources Management requires interdisciplinary knowledge. Through the diverse knowledge from several disciplines such as engineering, law, finance, economics, politics, history, sociology, psychology, life science, and mathematics an opportunity can be created, a decision made, and an action taken. For instance, sociology covers people; rather, engineering excellence would pay attention to physical infrastructure systems (Timmerman et al.2008). The water management has transformed from a sector focus into a more comprehensive perspective. An overall strategy must be applied for the creation of the best alternatives and decision making on water management (Timmerman and Langaas, 2004).

+ Government and Interest Groups. The intergovernmental relationships of a state-to-state, interagency, and regional nature are examples of intergovernmental relations that consists of a government agency operating at the same level. The states and the federal government, by the same token, as well as municipal and state governments, was representation of different layers of government. Likewise, interest groups consist of both pro and anti-resource development groups as well as pro and anti-preservation groups The task of these interest groups is to promote and facilitate IWRM and they are not guided as far as how they are supposed to do it (UNESCO, 2013). The working group knows about the concerns of the participants and the challenges they are currently facing. Besides, they know about their water systems, but they don't have a clue about the management options, consequences, or decision-making frameworks.

+ Stakeholders Group: Inherent in basin management is the need to know the different stakeholders who participate in decisions on water and resource management of the basin and are likely to be affected by these decisions. After this is realized, strategies for involving the diverse stakeholders at the right levels of basin management can be devised (GWP & INBO, 2009). In order to ensure the sustainable use of water resources, IWRM stresses the importance of involving stakeholders within one hydrographic basin: different actors which include the authorities, institutions, the public and private sectors, and civil society, with a particular emphasis on women and marginalized groups.

2.2. Water Quality

The quality of the water in surface waters and groundwater is a result of both human actions and natural processes. Living organisms, a large amount of non-dispersed matter, and dissolved chemicals are naturally present in water. These components are the very backbone of clean water because they carry out life-sustaining biogeochemical cycles. Naturally occurring contaminants are so rarely the cause of water quality issues that can be a real threat to humans (Van Halem et al., 2009). To illustrate, groundwater has been a primary source of fresh water for about 77 million people in Bangladesh where nearly 90% of the population depends on groundwater. Arsenic has been proven to have been in contact with this population (Smith et al., 2000).

However, According to WHO (2008) there are also several factors such as mining, forestry practices, electricity generation, agricultural output, and power generation that will impact the chemical, biological, and physical attributes of water and pose a threat to human health and environmental integrity. Water pollution is largely triggered by industrial and agricultural processes, as well as human dwellings. Activities that release untreated human and animal waste, poor treatment of industrial residues, incorrect agricultural practices, and solid waste that has not been disposed of properly are among the negative aspects of these activities.

Industrial dumping into the water of an estimated 300–400 million tonnes of heavy metals, solvents, toxic sludge, and other waste is occurred each year (UN, 2016). The main chemical water pollutant in all ground water aquifers worldwide is nitrate from agriculture (Morris et al.2003). The runoff from agriculture using manure and fertilizers is the utmost cause of water pollution in the USA; the croplands account for about 40% of the nitrogen pollution and 30% of the phosphorus pollution (Revenga, 2000).

2.2.1. Key Components of Water Quality

The uses of either potable purposes or municipal and industrial processes are depending on water quality. For example, the EPA (2023) has specified limits on over 90 chemicals that can be in drinking water. This helps to safeguard drinking water and prevent the intake of contaminants. The consequence of that is the development of diseases that necessitate medical care.

As stated by Sensorex (2022), the water quality in the industrial units plays a determining role for the entire production system. Water quality parameter is basically of physical, chemical, and biological types. The attributes of physicochemical properties include colour, taste, odor, temperature, turbidity, solids, and electrical conductivity. Chemical parameters encompass pH, acidity, alkalinity, chlorination, hardness, dissolved oxygen, and biochemical oxygen demand. Biological parameters encompass bacteria, algae, as well as viruses. Dissolved oxygen is a fundamental parameter for assessing water quality since low levels may suggest high pollution and organic contaminants that oxidize oxygen. Having these values known is very important for major applications.

There are three types of water quality parameters physical, chemical, and
biological (Hassan Omer, N. 2020):

Types of water quality parameters		
Physical parameters	Chemical parameters	Biological parameters
Turbidity	pH	Bacteria
Temperature	Nitrogen	Algae
Taste and odor	Dissolved oxygen	Viruses
Solids	Biochemical oxygen demand (BOD)	Protozoa
Electrical conductivity (EC)	Chemical oxygen demand (COD)	
	Sulfate	
	Chloride	
	Copper and zinc	
	Phosphorus	

Table 1: Parameters of water quality **(**Hassan Omer, N. 2020).

+ Physical parameters of water quality:

1. Turbidity: Turbidity is a measure of the clarity of water. It characterizes light's ability to go through water. The suspended substance in water, including clay, silt, organic matter, plankton, and other particle matter, brings about this phenomenon (Alley ER, 2007). That the water is turbid is undesirable, and it can raise the treatment costs. This can supply shelters for the harmful microorganisms to hide, damage the fish gills and adsorption of heavy metals and pollutants. Suspended particles act as a thermometer, and higher turbidity makes the water warmer than the usual conditions and, therefore, there is less food available due to increased water temperatures (Kiprono SW, 2017). The nephelometric turbidimeter measures the turbidity by the NTUs (nephelometric turbidity unit), these units are equivalent to 1 mg/L of silica in suspension. Waters over 5 NTU are recognized as turbid by an ordinary person and more than 100 NTU indicate the water to be muddy. Given its low tur-bidity as it is filtered through soil, groundwater usually has natural turbidity (APHA, 2005).

2. Temperature: Temperature regulates palatability, viscosity, solubility, odor, and chemical interactions. The endpoint is that temperature is the factor affecting the processes of sedimentation and chlorination, as well as biological oxygen demand (Davis ML, 2010). It is also the mediator of biosorption of dissolved heavy metals in water. (Tchobanoglous G et al. 1985) addresses that the majority of people would rather have water within the temperature range of 10-15 °C.

3. Taste and Odor: The foreign substance like organic materials, inorganic compounds, or dissolved gases can cause taste and odor in water. Materials can be harvested from natural, domestic, or agricultural resources (DeZuane J, 1997). Using distilled water of no odor, dilute sample A with sample B until the odor is barely perceived at a total volume of 200 ml (Tchobanoglous G, 2003). The unit of odor or taste is expressed in terms of a threshold number as follows:

TON or TTN = (A + B) / A (Spellman FR, 2013)

TON is the threshold odor number, and TTN is the threshold taste number.

4. Solids: As for water activity, solids in water either dissolve or disperse into suspension (Tchobanoglous G, et al. 2003). These two kinds of solids can be differentiated by using a fiberglass filter that the water sample is forced to run through (Tchobanoglous G, et al. 2003). The suspended solids are held back on the top of the filter. On the other hand, the dissolved solids diffuse preferentially pass the filter with water. If the filtered portion of the water sample is placed in a small dish and then evaporated, the solids as a residue. This material is usually called total dissolved solids or TDS (APHA, 2005).

5. Electrical conductivity (EC): The term electrical conductivity (EC) of water is an index of how well an electrolytic solution is able to carry electric current (Tchobanoglous G, et al. 2003). As the ions in solution carry this electrical current, the conductivity increases as the concentration of ions rises. Hence, it is one of the main factors taken into consideration when analyzing the water quality for irrigation and firefighting (APHA, 2005).

+ Chemical parameters of water quality:

1. pH: pH is one of the most important parameters for assessment of water quality. It's the negative logarithm of the hydrogen ion concentration. It is a ratio measureless which detect

the strength of an acid or a base (Hammer, 2011). However, the pH of water measures the acidity and basicity of it. As Alley (2007) claims, hydrogen ion (H^+) content of acidic water is higher, while the hydroxyl ions (OH^-) content of basic water is higher.

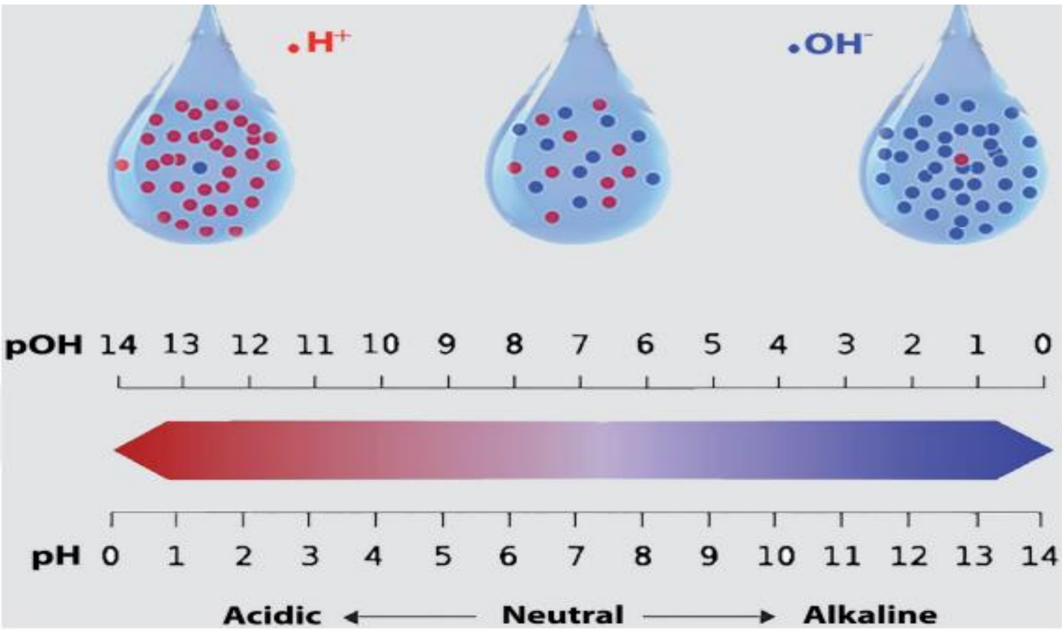

Figure 1: pH of water (Hassan Omer, N. 2020)

As shown in Figure 1, pH goes from 0 to 14, being the 7 one neutral. A pH level lower than seven represents acidity, while a pH above seven is basic. At the temperature of 25°C, in pure water, pH is about 7.0. The atmospheric carbon dioxide gas is the cause of normal rainwater being slightly acidic as it has a pH value of around 5.6. For drinking water and its use at home, the pH should be within the range 6.5 - 8.5 (WHO, 2011).

Too high and too low pH levels can be dangerous to the utilization of water. High pH impacts the taste and efficiency of which chlorine disinfection requires additional treatment (APHA, 2005). The concentration of oxygen in water increases along with the pH rising. Acid water will corrode and dissolve metals as well as other items (DeZuane J, 1997).

2. Nitrogen: There are four types of nitrogen in water and wastewater i.e., organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen. Most nitrogen present in sewage-polluted waters comes from organic matter and also ammonia, which microbes decompose to nitrites and nitrates (Tchobanoglous G, 2003). Nitrogen is a rate-limiting nutrient and a fundamental element of plant growth (APHA, 2005).

3. Dissolved oxygen, DO, acting as one of the most critical measures of water quality, is

considered in streams, rivers, and lakes. The most relevant testing for water pollution is this one (APHA, 2005). Quality increase with rise in dissolved oxygen concentration. Oxygen is very temperature sensitive and weakly soluble in water. An illustration: the saturation concentration is about 4.6 mg/L at 0°C and 9 mg/L at 20°C (Tchobanoglous G, 2003).

Temperature, salinity and pressure have an impact on the amount of actual dissolved oxygen in water. Public health is not affected by dissolved oxygen concentrations, but some individuals may find the taste of water with low or no dissolved oxygen to be unpleasant. The three most common methods to determine dissolved oxygen are the colorimetric technique (which is both rapid and inexpensive), the conventional Winkler titrimetric technique and the electrometric method (APHA, 2005).

4. Biochemical oxygen demand (BOD): Bacteria and other microbes will consume organic substances as food. As they go through the process of metabolizing organic matter, they consume oxygen (APHA, 2005). The microbes decompose the organics into simpler compound such as CO_2 and H_2O that the microbes use the energy released for growth and reproduction, the DO in the water is consumed when this process happens in water. If the oxygen is not added into the water either naturally or artificially, the concentration of DO will decrease as the microorganisms consume the organic molecules in the water, it means. The "biochemical oxygen demand" (BOD) is an expression of this need for oxygen (Tchobanoglous G, 2003).

   The BOD that the microbes eat will increase with the quantity of organic matter in the water. The strength of wastewater is calculated on BOD, where strong wastewater has high BOD value, and the weak one has low BOD value. Generally, the full degradation of organic material is carried out by microbes in 20 days or more. The ideal BOD is the amount of oxygen needed in a given volume of water to complete the oxidation or stabilization of the biodegradable organic materials (Mara D, 2003).

   BOD_5 implies the five-day biochemical oxygen demand. Consumption of oxygen by microorganisms involved in decomposition of organic matter is accumulating every day until the final BOD is reached, often in 50 to 70 days (California State University,2024).

5. Chemical oxygen demand (COD): One metric used for measuring all organics, both biodegradable and non-biodegradable, is the chemical oxygen demand (COD). In contrast

of BOD, chemical oxygen demand (COD) is the amount of oxygen required to break down the organic material via oxidation. The test is chemical in nature and can yield results in as little as two hours with the use of powerful oxidizing agents (potassium dichromate), sulfuric acid, and heat (Tchobanoglous G, 2003). For the same sample, COD values are consistently greater than BOD values.

COD_{cr}: The Dichromate Chemical Oxygen Demand test measures the oxygen equivalent of the amount of organic matter oxidizable by potassium dichromate in a 50% sulfuric acid solution (E3S, 2024).

6. Sulfate: Sulfate ions (SO_4^{2-}) are present in both natural water and wastewater. The occurrence of high sulfate content in natural water is almost always associated with leaching of Epson salt or sodium sulfate (Glauber's salt) which are the natural deposits (Davis ML, 2010). If levels in drinking water are high concentrated it can cause objectionable tastes or unwanted laxative effects; but there is no significant danger to public health (Davis ML, 2008).

7. Chlorine: Groundwater, streams, and lakes naturally contain chloride; nevertheless, freshwater has a comparatively high proportion of chloride. (about 250 mg/L or more) may be the indication of wastewater pollution (Chatterjee A, 2001). Chlorides are a versatile class ion that enter the surface waters from multiple sources: chloride containing rock, agricultural runoffs, and wastewater.

   Chloride ions (Cl^-)in drinking water is not going to produce health impairment. Yet, if the numbers of chloride are too high one may still find the water unpleasantly salty in a taste. The chlorides, in the common salt were shown not to be harmful to humans (WHO, 1996).

8. Copper (Cu) and zinc (Zn): are non-toxic if they occur in small quantities but have harmful effects if exceedingly high found (APHA, 2005). In fact, both of them are not a matter of only health of human beings but also of flora and fauna (WHO, 1996). They render undesirable tastes in water so; the water may become unfit for consumption. They are sieved and taken through the same procedures as iron and manganese in assessment (APHA, 2005).

9. Phosphorus: The problem of phosphorus may be as a result of bad farming practice, runoff from urban areas, lawns and leaking septic systems or sewage treatment plant discharges.

The excess of phosphorus may lead to accelerated growth of the algae, aquatic plants and decrease the levels of dissolved oxygen– this process is known as eutrophication. Excess amounts of phosphorus can also lead to algae blooms that are toxic and harmful to both humans and animals(EPA, 2023)

+ Biological parameters of water quality:

1. Bacteria: Bacteria are microscopic living organisms that have only one cell with three basic cell shapes: rod, sphere, and spiral. New mature cells can form and divide into two new cells in less than half an hour (Tchobanoglous G, 1985). Bacteria can proliferate swiftly under ideal circumstances, aiding in the detection and enumeration of bacteria in a water sample. Various species of bacteria are dependent on their food being metabolized (Wiesmann U et al, 2007).

   Aerobic bacteria need oxygen for metabolism while anaerobic bacteria live in anaerobic surroundings. Some facultative bacteria live either in the absence or in the presence of oxygen. Bacteria reproduce and grow very slowly at low temperatures, with each 10°C increase doubling the rate of reproduction and growth. More than often, most bacteria have an optimal temperature of about 35°C. The bacteria cause typhoid, paratyphoid fever, leptospirosis, tularemia, shigellosis, and cholera which are waterborne diseases dangerous (Mara D, 2003). In these cases, due to the absence of proper sanitary techniques, gastroenteritis outbreaks of such diseases can occur.

2. Algae: Algae are microscopic plants that possess pigments employed in photosynthesis, such as chlorophyll. They are autotrophs, they obtain their sustenance by utilizing solar energy to take inorganic components and convert them into organic matter. They take up carbon dioxide and release oxygen while the process (Mara D, 2003).

   They are very important for the operation of the stabilization pond for wastewater treatment (Tchobanoglous G, 2003). Taste and odor problems are normally associated with the noxious organisms of algae in water supplies. Some algal species are particularly harmful to the environment and public health. For example, poisoning of domestic animals such as cattle by drinking contaminated water with blue-green algae has been reported (Mara D, 2003).

3. Viruses: The smallest forms of life that possess all genetic material such as DNA or RNA necessary for self-reproduction are called viruses (Tchobanoglous G, 1985). Even a high-resolution electronic microscope cannot see them (Mara D, 2003).Viruses resemble parasites since they need a host to be alive. They are permitted to bypass the filtration that block the bacteria passing through (Nathanson JA, 2004). Infectious hepatitis and poliomyelitis are known to be caused by water borne viral infections. Water treatment plant uses disinfectant that can kill most of water born viruses (Mara D, 2003).

4. Protozoa: Protozoa are the single-celled microscopic animals (Tchobanoglous G et al, 1985), feed on solid organic particles, bacteria, and algae, and act as prey to predator animals at the higher trophic levels (Nathanson JA, 2004). The aquatic protozoa are those that are floating on water and sometimes are called zooplankton (Nathanson JA, 2004). They create cysts that cannot be inactivated by disinfection measures (Tchobanoglous G et al, 1985).

Chapter III: MATERIALS AND METHOD

3.1. Study area.

Currently, Vientiane Capital obtains its raw water supply from the Mekong River and the Nam Ngum River which are the two major sources of water source. There are four (4) treatment plants now existing (JICA, 2015). Figure 2 indicates both the areas of research and the location of water treatment plants.

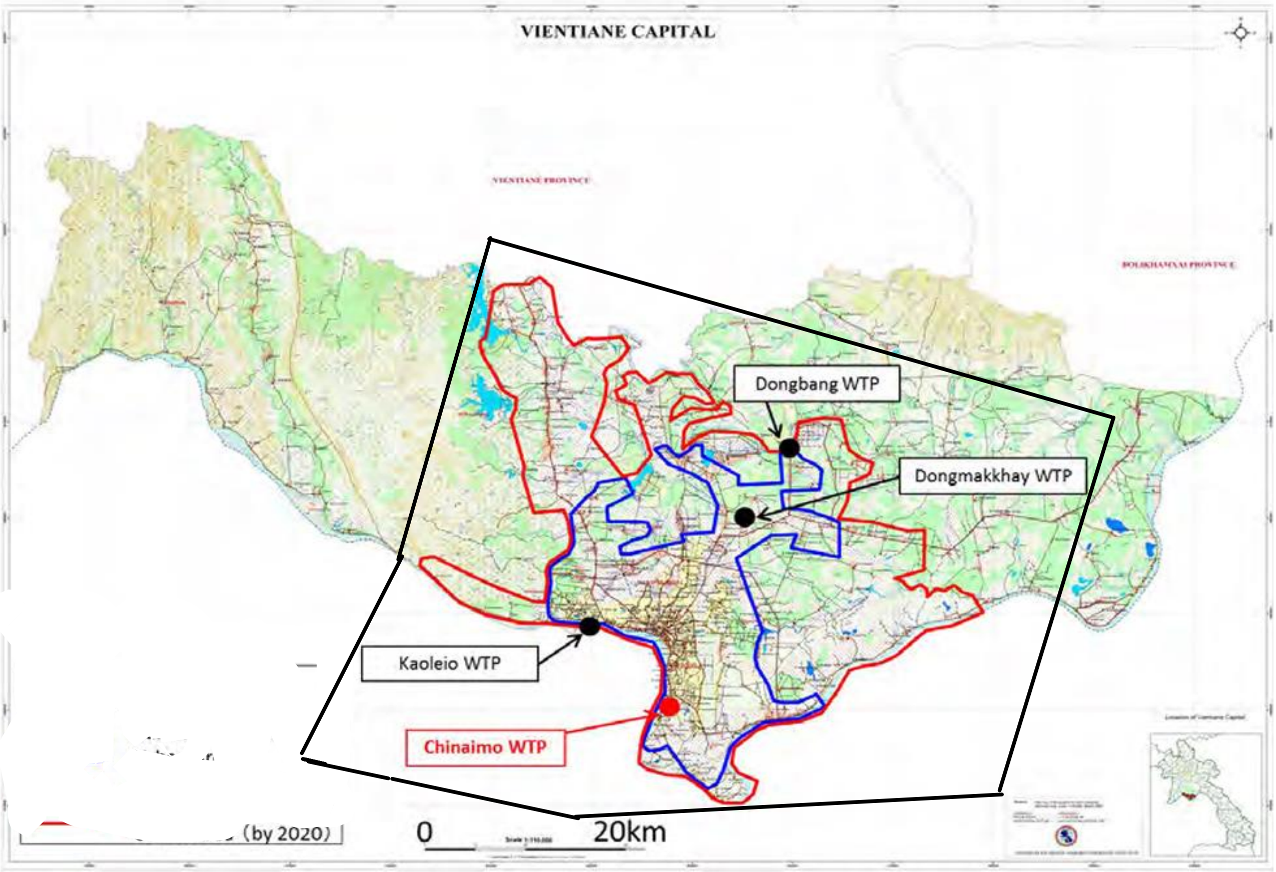

Figure 2: Location Map of the Research Area (JICA, 2015)

The research area covers the capital city of Vientiane, while the WTPs include Chinaimo, Kaolieo, and Dongmakhai. Among this crowded urban scene, these WTPs are vital in facilitating access to clean and drinkable water for the city dwellers. Chinaimo and Kaolieo are Mekong River water users; Dongmakhai uses the water from the Nam Ngum River. WTPs like this play a crucial role in collective water requirements ensuring availability of safe drinking water for the growing urban population. Nevertheless, the fact that Dongbang is not included in the analysis as a result of insufficient and poor data shows the relevance of more powerful and true data collection methods to the development of effective water management strategies for cities like Vientiane.

3.1.1. Vientiane Capital Overview.

The capital of Lao PDR Vientiane Capital lies on alluvial plain along the left bank of Mekong River from east to west. The capital's area is approximately 3.920 km^2, with the terrain situated at an elevation of 160–170 m above sea level. The city comprises nine districts; the population is around 820.900 people (Ministry of planning and investment, 2015).

Vientiane Prefecture covers an area of 3,920 km2, as shown in the figure below, and is divided into 9 districts including Chanthabuly District, Sikhottabong District, Xaysettha District, Sisatanak District, Naxaithong District, Xaythany District, Hatxaifong District, Sangthong District, Maypakngum District.

Figure 3: Map of Cities in Vientiane Capital (JICA,2015)

The capital is made up of the following districts:

No	District	Population
1	Chanthabuly	69,187

2	Sikhottabong	120,999
3	Xaysetha	116,92
4	Sisattanak	65,712
5	Naxaithong	75,228
6	Xaythany	196,565
7	Hadxayfong	97,609
8	Sangthong	29,509
9	Mayparkngum	49,211

Table 2: The districts of Vientiane Capital (PHC, 2015)

The majority of these nine districts Sikhottabong, Chanthabuly, Sisatanak, and Xaythany District, which cover 1,116 km^2 in southern Vientiane—are categorized as "urban areas," with the remaining four districts being classified as "rural areas." (PHC, 2015) The following districts make up the province's urban area:

Number	District	Population (2015)
1	Chanthabuly	69,187
2	Sikhottabong	120,999
3	Xaysetha	116,92
4	Sisatanak	65,712

Table 3: Districts of the urban area in Vientiane Prefecture (PHC, 2015)

3.1.2. Water Resources in Vientiane.

In the Vientiane Prefecture there are two main rivers. Both Nam Ngum and Mekong River drainage basins cover the whole area. The capital is located to the south and the west of the Mekong River which is the main river that borders the country on the Thai side. A key use of the Mekong is for both agricultural and drinking water supplies. The Mekong River is the origin of the Nam Ngum River, which is the second largest river (JICA, 2015).

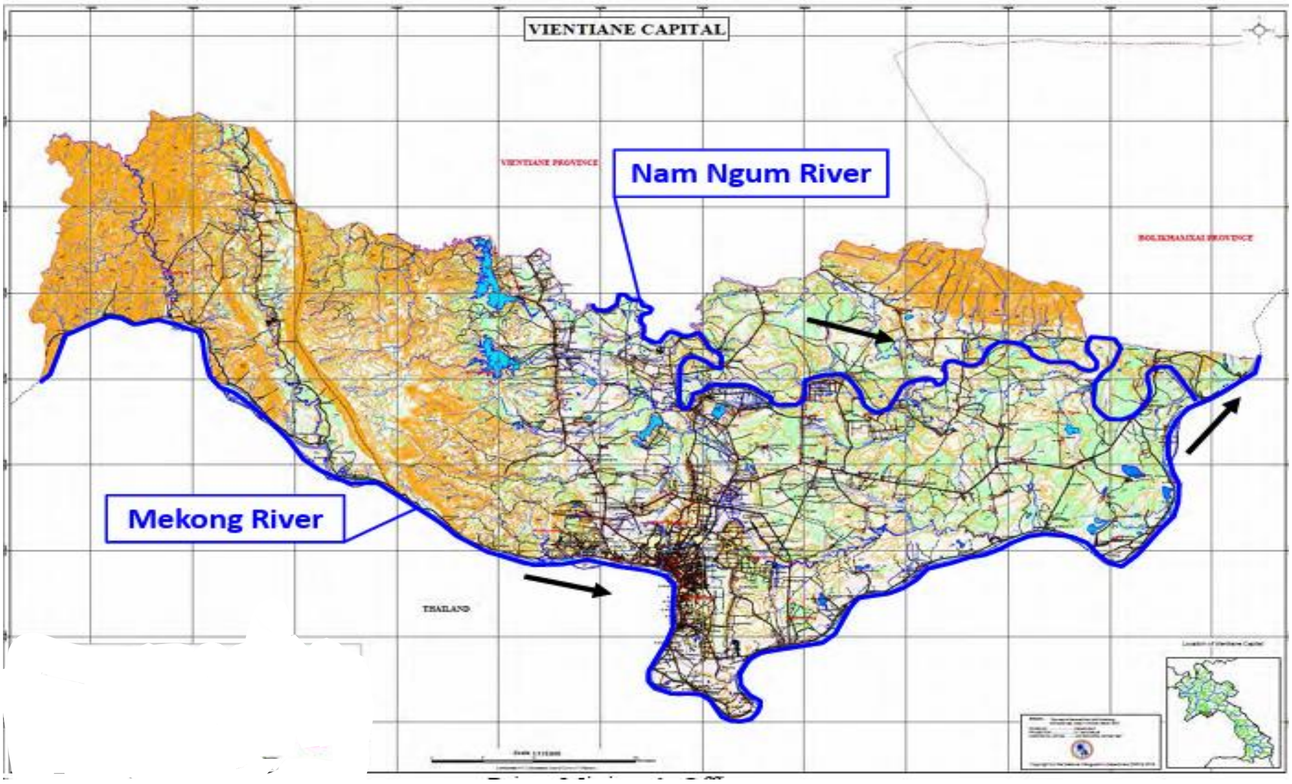

Figure 4: Map of Vientiane with Mekong and Nam Ngum River (JICA, 2015)

It finally spills out into the Mekong River at the eastern end of Vientiane Prefecture, having flown through Xaythany and Mayparkngum districts, an east-west flow. The Nam Ton River forms the west borderline between the districts of Sangthong and Naxaithong, but it runs from north to south(JICA, 2011).

The Nam Ngum River joins the Mekong River in the east side of Vientiane Capital. The average flow rate of the Mekong River shows that there is significant difference between rainy season and dry season. In 2010, the minimum water discharge of low years, only 912.24 m^3/s or 78,817,589.33 m^3/day, was recorded in March, and the maximum water discharge in the same year was 8908.79 m^3/s or 769,715,950.80 m^3/day in September. In the Mekong River, water depth has also significant fluctuations of over 10 meters between dry season and rainy season. As for water quality in the Mekong River, turbidity is generally high, especially in rainy season. The highest turbidity recorded in the past was over 3,000 NTU (JICA, 2015).

3.1.3. Domestic Water Usage.

All the water was used only for irrigation, nothing was used for drinking purposes because the local folks have a habit of buying bottled water. As per Xayyavong and Babel (2010), the quality of bottled water in Lao PDR met most of the criteria insisting on drinking water, but for the pH, some samples failed to comply. We used shallow free well water and small quantities of supplied water in cooking. From most of the wells cleaned dishes, cars and vegetables were washed. Most of the villagers changed the water from the deep well to that of the shallow one believing that that which came from deep well was of better quality than that which came from the shallow well (Makino et al., 2016).

3.1.4. Current Water Management Practices in Vientiane.

Particularly, Vientiane, the capital of Laos, faces an issue of municipal wastewater management due to lack of suitable sanitation and wastewater treatment systems, including a sewerage network system. Most of the wastewater from domestic, commercial, and industrial areas in Vientiane is directly discharged into receiving waters, such as drainage canals, streams, marshes, lakes, and finally the Mekong River. Domestic wastewater is treated by using only on-site wastewater disposal and basic treatment facilities, such as pour-flush and septic tanks (Tilley ELüthi C et al. 2008).

However, these treatment facilities are usually badly designed, constructed, maintained, and operated. The grey water produced from the kitchen, bathroom, and laundry still has not been treated before discharging into the environment. This problem is highlighted in the fact that wastewater from average households has an effluent BOD concentration of 100 to 110 mg/L for septic tanks, whereas the BOD concentration of grey water discharged without treatment varies from 200 to 230 mg/L (JICA, 2017). Those concentrations are higher than the national standard of discharged BOD concentrations from households (BOD < 30 mg/L) based on the National Environmental Standard in Laos (WREA, 2017).

On average, many technologies of municipal sanitation and wastewater treatment in developing countries have been put into practice and been adopted from those in developed countries depending on local conditions, climate-geography aspect, and financial mechanism and capability (Ujang, Z.; Henze, M. 2006). Specifically, trickling filter and aeration techniques can be used in developing countries. The trickling filter process is a known biofilm system that is widely adopted in many countries around the world. The biofilm mentioned is a biological growth developed on the surface of filter media, known as a bio-filter, in biological wastewater processes (Ujang, Z.; Henze, M. 2006). Aeration is the activated sludge process in which air is pumped into a tank to stimulate microbial growth in the wastewater. The operation of the trickling filter and aeration processes can be performed for on-site, decentralized, and centralized wastewater treatment units (US EPA, 1980).

These days, the quality of the water from natural resources is one of the major problems for many countries worldwide. Sewerage is now viewed as an essential challenge in the Vientiane Capital that is particularly observed in urban areas within the city where substantial growth and expansion are anticipated. Future similar developments will dirty more natural water reserves if the city does have an efficient sewage system (Chanthavilay et al. 2017).

3.1.5. The existing sewerage system and wastewater disposal site

According to The World Bank's (2014) surveys, over 95% of the wastewater producers in the examined area discharged their black waters into septic tanks or soak pits. Additionally, the assessments showed that only a small percentage of the black waters are transported to the treatment plants by the vacuum trucks. The majority of the black waters from these facilities were either seeped into the ground or dumped into the drainage system. Afterwards, the grey waters are immediately and without any pretreatment emptied into the drainage network.

The annual report on water works (NAMPAPA Nakhone Luang, NPNL, 2018) has revealed that tap water average 255,750 m3/d was produced from prefecture's water treatment plants. Consumption of drinking water supply has been on the rise for the last decade and the capital Vientiane is provided with the water supply for 75% of the population living inside the water supply zone. Nevertheless, the water supply needs to continue to expand, upgrade and strengthen the existing networks. Vientiane city is provided with no separate sewer and treatments plants for waste at the center, so water waste and rain are discharged into the open canals by both the open and the closed drains. The drainage system is arranged into subcatchments with two natural main collector paths collecting the storm water and wastewater from Vientiane city (JICA, 2011).

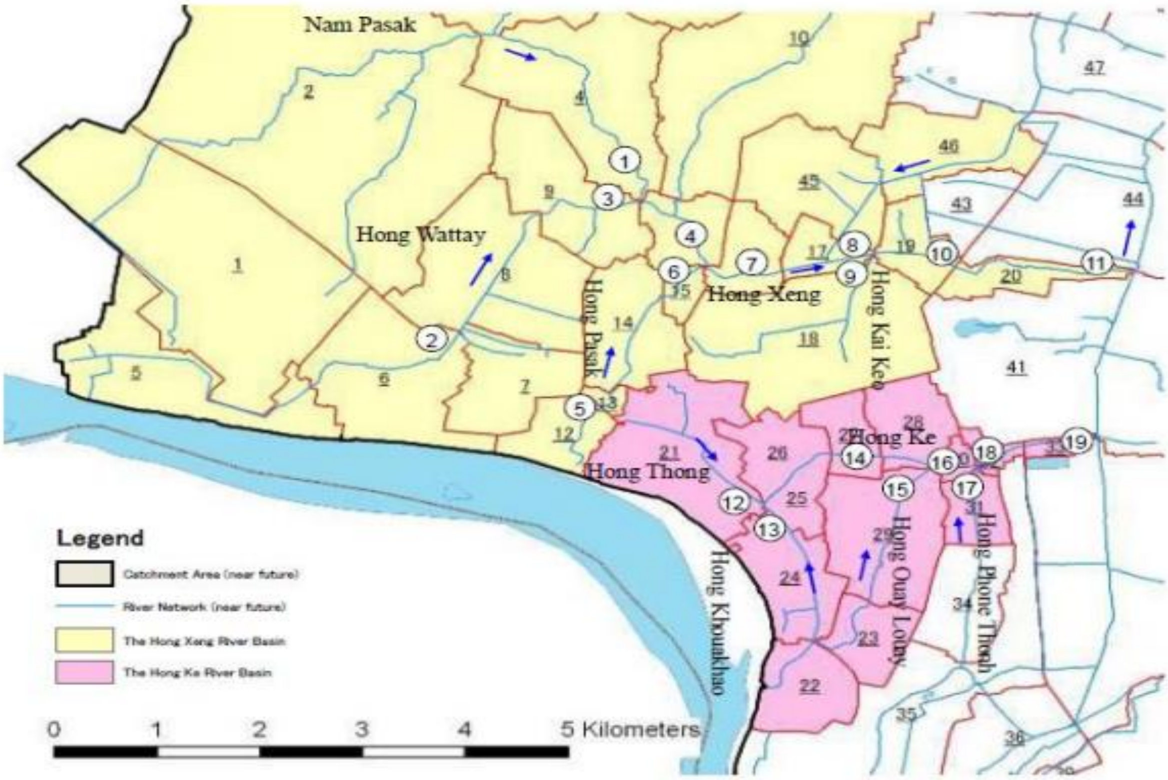

Figure 5: Map of canals in Vientiane City (JICA, 2011)

As shown in figure 5 The Hong Xeng system (yellow part), consisting of Hong Kai Keo, Hong Pasak, Hong Wattay, and Nam Pasak, drains catchments in the north of Vientiane City and flows into the Mak Hiao River. The Hong Ke system (pink part), consisting of Hong Phone Thanh, Hong Ouay Louay, Hong Thong, and Hong Khoua Khao, drains wastewater into That Luang Marsh (JICA, 2011).

3.1.6. Facilities of wastewater system.

In Vientiane, black water from toilet is regulated to be discharged through septic tank. According to the "Standards of Septic Tanks for Household" (Department of Public Works and Transport, VC,2016), single treatment septic tanks (which accept black water from toilet) or combined treatment septic tanks (which accept black water form toilet and grey water form kitchen) must be used before discharging water into public water bodies. The volumetric sizing should be based on a hydraulic retention time of 24 hours and 200 l/day cap water use, excluding filter media and sludge volume for 2 years. Septic tanks are typically built from concrete or bricks, with carrier media sometimes added for anaerobic biodegradation. The exact number and condition of septic tanks in Vientiane are unknown. In 2005, 73% of households in Vientiane were connected to septic tanks, while 19% were connected to pit latrines. The remaining 8% likely did not have such facilities

(JICA, 2017).

More than 95% of the houses and buildings in the survey zones that were sampled were found to have sanitary facilities like soak pits or septic tanks as per (JICA, 2011). Although the data reveal that desludging is not a routine under a size and proper maintenance task. The phenomenon that these facilities gather night soils only, the untreated outflow of other household wastewaters is the primary source of water contamination in canals. Nowadays, black water to which bathrooms, kitchens and laundry works are not treated is flushed into sewerage canals.

The Vientiane City wastewater strategy assumes a 50-60% reduction ratio of BOD_5 in septic tanks' effluents, with a BOD_5 concentration of 100-110 mg/L. The survey by JICA in 2017 revealed a wider range of discharged wastewater quality, from 21 to 312 mg/L BOD_5, 44 to 1,500 mg/L CODcr, and 32 to 101 mg/L nitrogen. The original goal of producing treated wastewater with less than 60 mg/L BOD_5 is not achieved. Even with a cleaned filter bed of a Community Based Sanitation (CBS) device, the BOD_5 of the effluent is around 100 mg/L and the COD is around 290 mg/L. Anaerobic treatment alone is almost impossible to keep the effluent BOD_5 below 60 mg/L (JICA, 2017).

3.2. Methodology.

The main purpose of this study is to determine how water quality conditions have changed before and after treatment from the major water treatment plant in our capital. Through this analysis, the study is aimed at ascertaining the efficiency of the given water treatment process in terms of water quality enhancement and provision of safe and drinkable water to the residents of the capital. The water quality parameters like turbidity, pH levels, dissolved oxygen concentration and different types of contaminants before and after treatment will be analyzed in this study which will determine the efficiency of the treatment plant in improving the overall water quality in the region. Hence the analysis of any significant differences and trends in water quality conditions will aim to inform future water management strategies and to be part of the continuous efforts to improve water quality and to ensure access to clean and sustainable water resources in the capital city.

In this study, the method of document analysis will be engaged to gain an understanding of the water management strategies in Vientiane, Lao PDR's capital. Document analysis presents an excellent opportunity for exploring numerous documents, reports, programs and policies concerned with water management practices that are relevant to the study area. The systematic review process that involves having the information extracted from sources which include government reports, policy documents, and materials from NGOs as well as academic publications, allows for a clear comprehension of the current status of water management in Vientiane. Besides that, this technique provides considerations from many sources to impart a single storyline of water management techniques and their impact on the development of sustainable Vientiane. The results of document analysis will help in developing concrete policy recommendations and the research community could utilize them towards resolving complex problems related to water management in the city.

3.2.1 Major Water Supply Facilities of Vientiane.

The total design production capacity of the existing water treatment plants is 280,000 m^3/day, Among the four water treatment plants, Chinaimo WTP and Kaoleio WTP are being overloaded by 10,5% and 2,5% on annual average, respectively. Chinaimo WTP and Kaoleio WTP extract additional raw water from Mekong River by using floating pump facilities at the existing intake sites (NPNL Annual Report, 2019).

Name of WTP	Source	Design Capacity (m^3/day)	Intake Volume (m^3/day)	Production Volume (m^3/day)	Treatment Loss (%)
Chinaimo	Mekong River	80,000	90,062	80,628	10.5
Kaolieo	Mekong River	60,000	62,359	60,771	2.5
Dongmakhai 1	Nam Ngum River	20,000	21,438	20,453	4.6
Dongmakhai 2	Nam Ngum River	100,000	84,942	77,039	9.3
Dongbang	Nam Ngum River	20,000	6,083	5,476	10.0
Total		280,000	258,801	244,367	5.6

Table 4: Major Water Supply Facilities of Vientiane (NPNL Annual Report, 2019)

This (table 4) indicates the design capacities, intake volumes, treatment losses, production units of (WTPs) Chinaimo, Kaolieo, Dongmakhai 1, Dongmakhai 2 and Dongbang along with their water resources. Cinaimong and Kaolato may use the water from Mekong River, but Dongmakai 1, Dongmakai 2, and Dongmangbe are completely dependent on Nam Ngum

River. Range of actual design capacity is 20000 to 100000 m3/day. In a few cases, plants' inflows don't match design norms, which implies either to high demand or operating variations. Practically, it is the intake volume that members of the group would be able to reach and not the production. Failure losses are anything from 2.5 % to 10.5 %. Differing the output of certain wastewater treatment plants, the average daily production by all such plants exceeds 244,367 m3, which makes it 5.6% lower than the average figure for a Treatment Lost .

The total design production capacity of the existing water treatment plants is 280,000 m^3/day, Among the four water treatment plants, Chinaimo WTP and Kaoleio WTP are being overloaded by 10,5% and 2,5% on annual average, respectively. Chinaimo WTP and Kaoleio WTP extract additional raw water from Mekong River by using floating pump facilities at the existing intake sites (NPNL Annual Report, 2019). According to the historical records of water quality analysis performed by NPNL, the finished water from the WTPs is maintained to meet the national drinking water quality criteria even during the overloaded operation (JICA, 2015).

3.2.2. General information of WTP in Vientiane Capital.

1. Nam Papa Nakhone Luang (NPNL), a state-owned corporation created in 1971, owns and operates the Chinaimo water treatment plant (CWTP). NPNL operates four water treatment plants, including this one. It was built in 1980 with a capacity of 40,000 m^3/d. In 1996, the capacity was increased to 80,000 m3/day (Khambay, 2015).

   As reported by NPNL annual report in 2013, the Mekong River serves as a raw water source. The treatment process's main components include hydraulic mixing, a manual cleaning collector system, fine sand, and up flow water backwash with air scour. In 2013, CWTP supplied an average of 85,053 m3/d of tap water (exceeding the design capacity) to 44,966 homes in seven municipalities in Vientiane capital.

2. Nam Papa Nakhone Luang (NPNL), a state-owned water utility corporation in Lao PDR, owns and operates the Dongmakkhai Water Treatment Plant (DWTP) since 1971. NPNL operates four water treatment plants, including this one. It was built in 2006, with Capacity of 20,000 m^3/day (Park, 2015).

In 2013, DWTP supplied 22,656 m^3/d of tap water to 11,073 homes in Vientiane capital (NPNL, 2013). The Nam Ngum River serves as the DWTP's water source, and it is located 10 kilometres from the water treatment facility. The treatment procedure involves hydraulic mixing, manual sedimentation basin cleaning, a single-medium deep-bed filter with coarse sand, and up flow water backwash with air scour (Park, 2015). The Dongmakkhay water supply system expansion is underway with a concessional loan from the Export-Import Bank of China. The project includes a new intake at Nam Gum River, raw water transmission pipelines, a water treatment plant with a capacity of 100,000 m^3/day, clear water transmission pipelines, and a SCADA system (used for controlling, monitoring, and analyzing industrial devices and processes (SCADA, 2024). The project is part of an EPC contract between MPWT and China Yunnan Construction Engineering Group Co., Ltd (JICA, 2015).

3. According to NewTap in 2015, The Kaolieo water treatment plant (KWTP), owned by NPNL, was built in 1964 with a capacity of 20,000 m^3/d. It was expanded in 2008 to 60,000 m3/d. Raw water is extracted from the Mekong River using hydraulic mixing, sedimentation basin, fine sand filter, and up-flow water backwash with air scour. In 2013, 32,834 households in Vientiane capital received 67,010 m^3/d clean water daily from the KWTP (NPNL, 2013).

   Kaoleio Water Treatment Plant (KWTP) in Vientiane employs solid alum, polymer and calcium hypochlorite for the treatment of water. These chemicals are imported to Thailand where they are then mixed using hydraulic jumps thus ensuring proper distribution and preventing algae growth. The plant employs the vertical baffle type channel for improving the water flow. Sedimentation tanks are rectangular, and sludge collection is done monthly during the dry season and daily during the rainy season. The plant uses two filtration types: fine sand and coarse sand with a deep-bed filtration capacity of 60,000 m3/d. The process is done within 1 to 2 days, where water wash and air scouring activities occur. These processes help to prevent water pollution and to meet the high standard of water quality in Vientiane (NewTap, 2015).

3.2.3. Water treatment process schematic.

1. The Chinaimo water treatment plant (CWTP): Extraction of raw water from the Mekong River, followed by pumping of the raw water, introduction into the pipeline for static mixing with alum and hydraulic jump for pre-chlorination, subsequent flocculation using baffled channel-type systems, sedimentation in rectangular units with mechanical sludge collectors, filtration through rapid sand filters, disinfection through post-chlorination, transfer to clean water tanks, and finally, elevation using high lift pumps within the building. There is no sludge treatment process at CWTP. Sludge generated from sedimentation and backwashing is drained directly to Mekong River (Khambay, 2015).

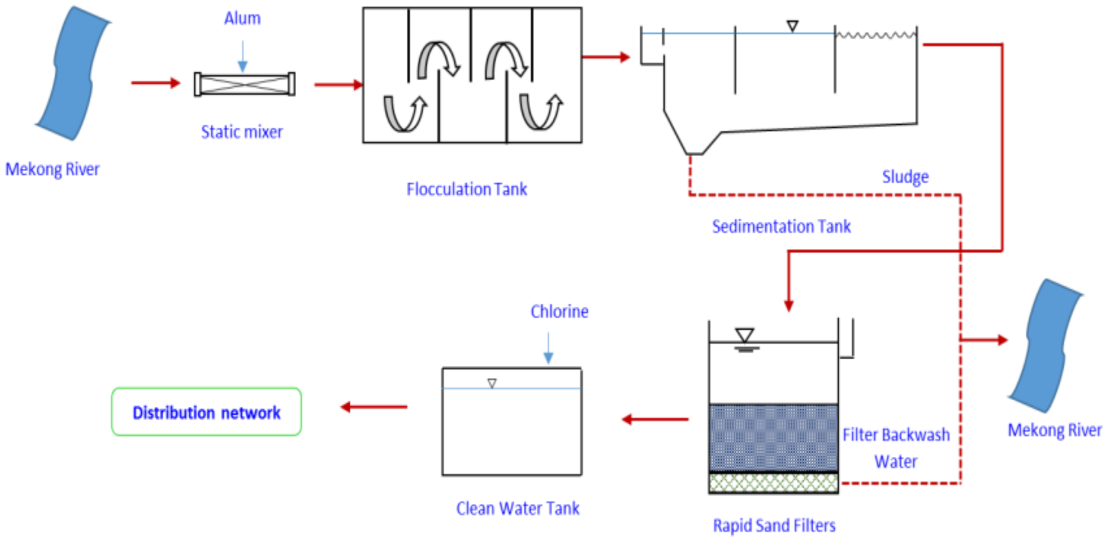

Figure 6: Water Treatment Process at CWTP (Khambay, 2015).

At the Chinaimo Water Treatment Plant (CWTP), water treatment involves imported chemicals from Thailand, including solid alum as a coagulant, calcium hypochlorite for pre-and-post chlorination, and polymer for coagulant aid. The process begins with alum injection into raw water and chlorine in the receiving tank. Pre-chlorination is used to prevent algae growth in flocculation and sedimentation basins. Lime is omitted due to high alkalinity concentrations. CWTP uses a vertical baffle channel type for flocculation and a rectangular tank for sedimentation. The sedimentation tank has a hydraulic retention time of 2.7 hours, exceeding the typical range for conventional basins. The filtration system uses a single media deep-bed filter with coarse sand media. Backwashing is conducted using water backwash with air scour, facilitated by a dedicated backwashing pump (Khambay, 2015).

2. Dongmakkhai Water Treatment Plant (DWTP): Extraction of raw water from the Nam Ngum river is followed by pumping the raw water, then subjecting it to hydraulic mixing with alum and pre-chlorine. Subsequently, the water undergoes flocculation in a baffled channel type system, followed by sedimentation in a rectangular unit, which requires manual cleaning. Next, the water is passed through rapid sand filters containing coarse sand and undergoes a water wash with air scouring. Following filtration, disinfection with chlorine is carried out, after which the treated water is stored in a clear well before being pumped to the desired location through a high lift pump building (Park, 2015)

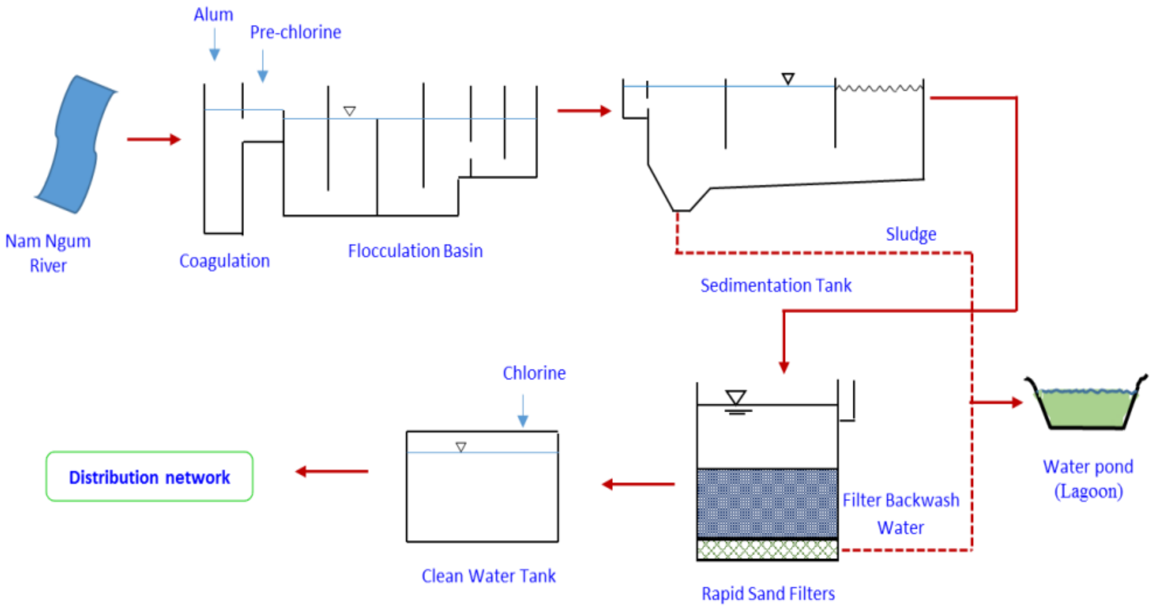

Figure 7: Water Treatment Process at DWTP (Park,2015)

The water treatment process in DWTP involves the use of imported solid alum as a coagulant and calcium hypochlorite ($CaOCl_2$) for pre and post-chlorination, sourced from Thailand. These chemicals are injected into the receiving well (mixing basin) through hydraulic jumps. Chlorine is additionally injected during pre-chlorination to prevent algae growth in flocculation, sedimentation, and filter basins. During periods of higher turbidity in the wet season, chlorine is injected into the effluent weir of sedimentation to prevent algae growth in filter basins. DWTP features vertical baffle channels and a 25-minute hydraulic retention time in the flocculation tank. The rectangular sedimentation tank operates with a surface loading rate of 40 m^3/m^2, with settled solids cleaned manually on a regular cycle. The detention time for DWTP is 2.2 hours, differing from the conventional basin range of 1.5 to 3.0 hours. Filter media include conventional fine sand, dual media, and single sand deep bed filters, with preference given to dual media and single sand deep bed filters for their effective removal of solids. The filter media used is single-medium deep-bed (coarse sand) about 100 cm deep with a 1.0 mm effective size. Two types of filter washing systems are employed: fluidized-bed backwash with surface wash and water backwash with air scour (Park,2015).

3. Kaolieo water treatment plant (KWTP): According to NewTap in 2015 the process of the treatment is extraction of raw water from the Mekong river precedes raw water pumping, followed by hydraulic mixing with alum and pre-chlorine. Next in the process is flocculation in a baffled channel type system, succeeded by sedimentation in a rectangular unit requiring manual cleaning. Subsequent treatment involves passing the water through rapid sand filters, after which disinfection with chlorine occurs. The treated water is then stored in a clear well before being pumped to the desired location through a high lift pump building.

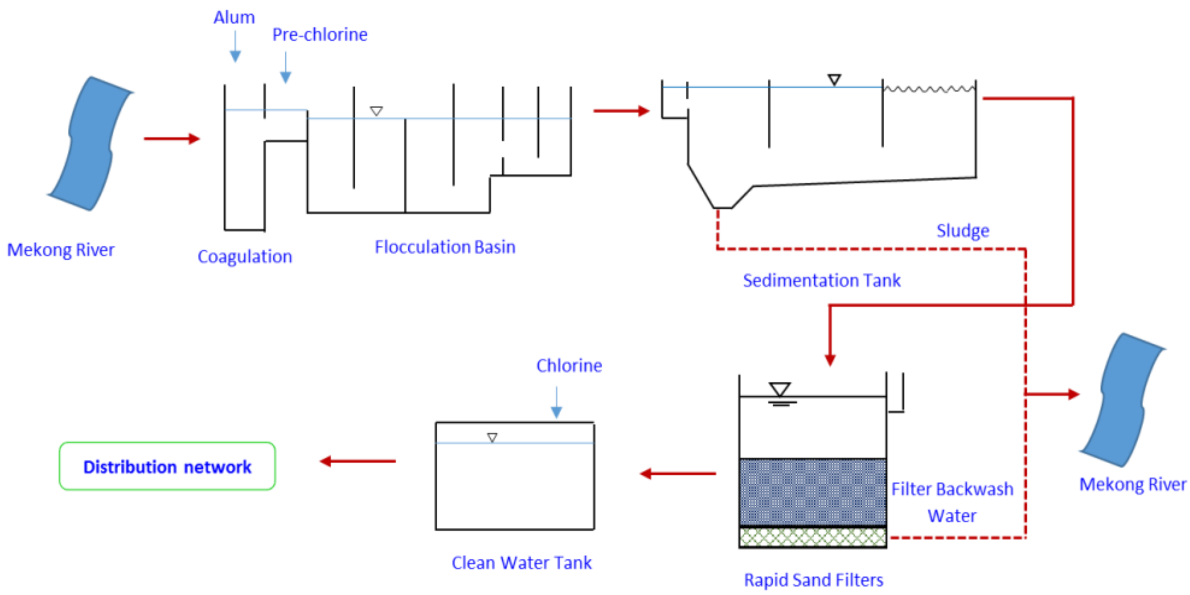

Figure 8: Water Treatment Process at KWTP (NewTap, 2015)

At KWTP, three chemicals are used in the water treatment process: solid alum for coagulation, polymer for flocculation aid, and calcium hypochlorite for pre and post chlorination. These chemicals are imported from Thailand and are used during rainy seasons due to high turbidity in raw river water. The coagulation process involves dissolving solid alum and calcium hypochlorite in a solution tank before transferring to the storage tank. The pH value of water controls the nature of coagulation. Polymer is injected into the entrance part of the flocculation basin. Chemical rapid mixing is done by hydraulic jump, preventing algae growth in flocculation and sedimentation basins. Alkaline chemicals (lime) are not used due to high alkalinity concentrations. The flocculation tank is designed with a vertical baffle channel type, with a hydraulic retention time of 23.7 minutes (NewTap, 2015).

Chapter IV: RESULTS OF DOCUMENT ANALYSES

Three water treatment plants (WTPs) in Vientiane have water quality testing facilities. Within them, the laboratory the Chinaimo WTP plays a key role and is equipped with a spectrophotometer and an atomic absorption spectrophotometer (JICA, 2015).

The former's raw water source is the Mekong River, which may reach turbidity levels of 4,000 NTU during the wet season. The latter takes water from the Nam Ngum River. The Nam Ngum River's turbidity is rather consistent, peaking at 200 NTU. Regardless of turbidity, treated water from all WTPs meets drinking water quality criteria (JICA, 2021).

No.	Item	Unit	NPNL Standard	Chinaimo WTP	
				Raw	Treated
1	Turbidity	NTU	<5	3.0	1.0
2	Color	CU	<5	4.0	1.0
3	Odor	-	Not offensive	Soil	Normal
4	Taste	-	Normal	-	Normal
5	pH (value)	-	6.5-8.5	8.5	8.1
6	M. Alkalinity ($CaCO_3$)	mg/l	-	108.0	96.0
7	Sulfate ion (SO_4)	mg/l	<250	<2	<2
8	Chloride ion	mg/l	<250	13.5	7.7
9	Fluoride ion (F^-)	mg/l	<1.0	1.44	0.06
10	Total Hardness ($CaCO_3$)	mg/l	<300	96.0	84.0
11	E. Coli	MPN/100 ml	0	5/5	0/5
12	KMnO4 consumed	mg/l	-	14.7	6.9
13	Residue Chlorine (Cl_2)	mg/l	0.2-2.0	X	0.7
14	Iron (Fe)	mg/l	<0.3	0.63	N.D.<0.03
15	Manganese (Mn)	mg/l	<0.1	0.41	N.D.<0.01
16	Aluminum (Al)	mg/l	<0.24	0.09	0.01
17	Cyanide ion (CN^-)	mg/l	<0.5	0.005	0.001
18	Total Dissolved Solids (TDS)	mg/l	-	168.0	171.0

Table 5: Water Quality Analysis Items and Results of Raw and Treated Water at CWTP (NPNL report 2019)

The data above (Table 5) indicate the raw and processed water at Chinaimo Water Treatment Plant water quality. The main parameters we are going to focus on are turbidity and colour which have the value of 3.0 NTU and 4.0 CU. Following the treatment process the value will decrease to 1.0 NTU and 1.0 CU, showing the improvement of the treated water clarity and appearance. The other parameters as well including alkalinity, total hardness, and levels of sulphate, chloride, fluoride, and total dissolved solids (TDS) meet or fall within the reasonable values, which in turn prove the in-place of the treatment processes. On the other hand, certain ions such as iron, manganese, aluminium and cyanide show some decreases however, they might still end up being in the treated water, at rather lower levels. Furthermore, the fact that you cannot detect the E. coli in the treated water indicates proper disinfection. Overall, test data prove that the Chinaimo WTP plant is successful in restoring raw water to a safe drinking water level within regulatory margins (NPNL report 2019).

No.	Item	Unit	NPNL Standard	Kaoleio WTP	
				Raw	Treated
1	Turbidity	NTU	<5	3.0	0.0
2	Color	CU	<5	2.0	1.0
3	Odor	-	Not offensive	Soil	Normal
4	Taste	-	Normal	-	Normal
5	pH (value)	-	6.5-8.5	8.3	8.1
6	M. Alkalinity ($CaCO_3$)	mg/l	-	112.0	102.0
7	Sulfate ion (SO_4)	mg/l	<250	<2	<2
8	Chloride ion	mg/l	<250	10.52	7.84
9	Fluoride ion (F^-)	mg/l	<1.0	1.74	0.08
10	Total Hardness ($CaCO_3$)	mg/l	<300	94.3	86.5
11	E. Coli	MPN/100ml	0	5/5	0/5
12	KMnO4 consumed	mg/l	-	18.4	6.61
13	Residue Chlorine (Cl_2)	mg/l	0.2-2.0	X	0.6
14	Iron (Fe)	mg/l	<0.3	0.60	0.03
15	Manganese (Mn)	mg/l	<0.1	0.22	0.04
16	Aluminum (Al)	mg/l	<0.24	0.09	0.01
17	Cyanide ion (CN^-)	mg/l	<0.5	0.003	0.001
18	Total Dissolved Solids (TDS)	mg/l	-	165.0	171.0

Table 6: Water Quality Analysis Items and Results of Raw and Treated Water at KWTP (NPNL report 2019)

The Table 6 shows the result of a water quality analysis of both raw and treated water from the Kaoleio Water Treatment Plant (WTP). In term of turbidity, the treated water meets the standard with the value not exceeding 5 NTU, and a record one was 3.0 NTU, showing the water being a little cloudy. The results also show satisfactory levels of water colour, as the effluent has only 2.0 CU, which is significantly less in comparison with 5.0 CU, the set standard The smell and taste range be within normal ranges for both of raw and treated water at indicating no offensive smell or taste. pH values for treated water vary with the optimum of 6.5-8.5, and this has a recorded value of 8.3. But on the downside, chloride and chloride ions and fluoride ions concentrations in the treated water are all under the standard levels, which could indicate good removal during the process. Total hardness levels are kept below 300 mg/l as per the standard, with a treated water measurement of 94.3 mg/l. To emphasize, the treated water was testified to no signs of E. coli, securing its microbiological safety. In addition to these parameters, including $KMnO_4$ consumed, residue chlorine, iron, manganese, aluminium, cyanide and total dissolved solids (TDS), those also meet their desired standards, indicating effective treatment processes at Kaoleio WTP (NPNL report 2019).

No.	Item	Unit	NPNL Standard	Dongmakhai WTP		
				Raw	Treated 1	Treated 2
1	Turbidity	NTU	<5	6.0	0	0
2	Color	CU	<5	10.0	1.0	1.0
3	Odor	-	Not offensive	Soil	Normal	Normal
4	Taste	-	Normal	-	-	-
5	pH (value)	-	6.5-8.5	7.9	7.8	7.9
6	M. Alkalinity ($CaCO_3$)	mg/l	-	72.0	74.0	64.0
7	Sulfate ion (SO_4)	mg/l	<250	2.4	<2	<2
8	Chloride ion	mg/l	<250	11.5	6.8	8.3
9	Fluoride ion (F^-)	mg/l	<1.0	1.34	0.06	N.D.<0.05
10	Total Hardness ($CaCO_3$)	mg/l	<300	69.0	62.0	64.0
11	E. Coli	MPN/100ml	0	4/5	0/5	0/5
12	KMnO4 consumed	mg/l	-	16.9	5.8	6.3
13	Residue Chlorine (Cl_2)	mg/l	0.2-2.0	X	0.2	0.4
14	Iron (Fe)	mg/l	<0.3	0.05	N.D.<0.03	N.D.<0.03
15	Manganese (Mn)	mg/l	<0.1	0.24	N.D.<0.01	0.04
16	Aluminum (Al)	mg/l	<0.24	0.09	0.01	0.01
17	Cyanide ion (CN^-)	mg/l	<0.5	0.002	0.001	0.001

18	Total Dissolved Solids (TDS)	mg/l	-	98.0	99.5	97.2

Table 7: Water Quality Analysis Items and Results of Raw and Treated Water at DWTP (NPNL report 2019)

The Table 7 shows the comparison of water quality parameters between the raw and treated water at Dongmakhai Water Treatment Plant (DWTP) where the effluent treated water numbers for DWTP-1 and DWTP-2 are also included. Treated water from both WTPs shows a significant number of parameters making their improvements against raw water fast. The discharge of water to rivers has been successfully completed, and the dissolved material levels have decreased to below 5 NTU in both the treated water outlets, which meet the required standard. Besides, that, the colour levels drop drastically and the level of 5 CU is used to assess the result. No odor is offensive and the taste is normal in all water samples that were through the analysis. the water's' pH values for both WTPs are within the 6.5-8.5 equilibrium range. The level of alkalinity goes on decreasing from 72.0 mg/l in source water to 64.0 mg/l at the end of treatment processes at Dongmakhai WTP2. Another set of parameters in the form of sulphate ion, chloride ion, fluoride ion, total hardness, E.coli, $KMSO_4$, residual chlorine, iron, manganese, aluminum, cyanide ion, and total dissolved solids (TDS) also meet requirements in DWTP1 and DWTP2 of Dongmakhai and were within acceptable levels (NPNL report 2019).

Chapter V: CONCLUSION AND RECOMMENDATIONS

In, Conclusion the case of the Chinaimo, Kaoleio, and Dongmakhai Water Treatment Plants in Vientiane is an example of a process that can result in safe drinking water and become the role of the conductor. It doesn't make any difference whether the different raw water sources are seasonal in clarity or not, all of the extracted water still has water levels which are either equal to or passing water quality standards for drinking water. The factors related to turbidity, color, pH, alkalinity, chloride, fluoride, and total hardness as well as the microbiological indicators such as E. coli all show a tremendously marked improvements after the treatment, which demonstrates that the water quality and the lack of impurities has been significantly improved. Furthermore, the conformity with a series of different parameters during all the WTPs treatment stages highly implies the robustness of treatment facilities.

The research provides some recommendations for the enhancement of the water treatment and quality in Vientiane. As follows, water treatment facilities need to determine and manage water quality parameters as well such as turbidity and color to ensure safe consumption. Constant monitoring and calibration of laboratory apparatus contribute to the precision of measurements made. Second, treatment processes should be optimized in order to reduce ions such as iron, manganese, and aluminum, whereas emerging contaminants and possible pollutants from water sources like the Mekong and Nam Ngum Rivers should be monitored. In the third place, the partnership with local authorities together with the community representatives can bring in knowledge about water quality improvement and conservation, which in turn will encourage the residents to be water savers. Through this collaboration the sustainability of Vientiane's water supply can be ensured in the long run.

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