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Water analysis for agriculture in Hanoi

A comparison with national standards

Bachelor's Thesis

Environmental Engineering

May 2016

MAMK
University of Applied Sciences

DESCRIPTION

	Date of the bachelor's thesis 26/05/2016
Author(s) Tuan Nguyen	**Degree programme and option** Environmental Engineering – T871SN
Name of the bachelor's thesis Water analysis for agriculture in Hanoi – A comparison with national standards	

Abstract

Water quality is a significant issue especially in developing countries like Vietnam but it has not received adequate consideration. The main objective of this thesis is to study the water quality of four inner Hanoi's rivers and suggest a wastewater treatment method suitable to treat water for reusing in agriculture.

Theories on water quality, particularly water constituents that affect the water capability to be reused in agriculture and aquaculture, were reviewed. A Water Quality Index model developed by a national organization was used to further assess the water quality.

The subject of study was water in four inner Hanoi's rivers, which regularly had wastewater from domestic, industrial and crafting villages discharged into. Data from various sources along these rivers were collected from secondary source, and were compared with National Technical Regulations on Surface Water Quality and National Technical Regulation on Irrigatied Agriculture as well as calculated through a Water Quality Index model.

The results indicated heavy pollution in term of organic matters, microbial pathogens, heavy metals (Pb, Cd, Cr, As, Hg), oil and grease, and micropollutants. Water Quality Index calculations resulted in all four rivers unsuitable for use in any purposes. As the wastewater development plan by the authorities are a long way from complete, a constructed wetland system imitating natural reed bed namely Vertical Flow Bed was suggested. This is a design for decentralized wastewater treatment that is suitable for small scale peri-urban Hanoi farmers to treat wastewater from the rivers to reuse in their traditional agricultural and aquacultural practices.

Subject headings, (keywords)

Decentralized wastewater treatment, Hanoi, constructed wetland, reed bed, water pollution, water quality assessment

Pages	Language	URN
47 pages + 7 pages appendices	English	

Remarks, notes on appendices

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CONTENTS

1 INTRODUCTION

For centuries, Vietnam's economy has been agriculture-oriented. The economic reform 'Doi Moi' in 1986 has facilitated economic development toward industrialization and modernization. Hanoi, as the capital and political headquarter of Vietnam, has quickly developed into a large urbanized city. Along with the fast development, Hanoi has become a population-densed area with a population of over 3.2 million within an area of 303.93 km^2, which is 10627 people/km^2 as of 2013 (Statistical Yearbook 2013). Much of the food supply for this populated city comes directly from farmers living in the peri-urban area (Shields 2013).

The Red River basin is the largest and most important river system flowing through Hanoi to the ocean. The river system is generally clean at the upstream but gradually polluted once reach the city (National Environmental Report 2012, 111). The reasons for the degradation of the middle-stream part of the river system that flows through the inner city are domestic, crafting-village and industrial activities (Viet-Anh 2005, 17; Vietnam EPA Report 2008, 49).

Peri-urban farmers have traditionally been using these surface water sources as the main irrigation channels for agricultural activities. In fact, water use in Vietnam is dominantly for agriculture and aquaculture (84% and 4% respectively, National State of Environment 2010, 69). The Red River basin alone provides 45% of total irrigation water for the nation (National Environmental Report 2012, 14). Additionally, some previous irrigation channels within the city have been completely converted into drains and sewers (Van 2009, 19).

FIGURE 1: Irrigation and vegetable washing using polluted water (Thang, 2016)

A thesis study by Tung (2014) stated that polluted water sources are risky to use for irrigation. National Environmental Report (2012) also proposed a conclusion that "in almost every rivers, lakes and canals, all parameters represent organic pollution have exceeded maximum limits for B-type surface water (National Technical Regulations on Surface Water Quality, see Appendix 1). The water quality in upstream rivers is generally good, but middle- and downstream parts of the river system is seriously polluted with many times exceeding National Technical Regulations in term of BOD_5, COD, Coliform, total Nitrogen and total Phosphorus." Oblivious to this statement, the farmers are increasingly using these sources for daily irrigation of fresh vegetable, crops and aquaculture. Fig. 1 (2016) presents real life practices of using polluted water for irrigation and vegetable washing.

Logically, high population leads to high food consumption demands, which in turn is forcing the farmers to increase agro-production by the application of these irrigation channels as well as chemical fertilizers and plant protection chemicals. There were estimated to be 658,000 farmers using wastewater to irrigate 43,778 ha of land according to Raschid-Sally et al. (2008). This agricultural practice in such scale does not only pose great health risks to people living in the city but is also harmful to the environment.

2 SCOPE AND OBJECTIVE OF THESIS

Due to such unhygienic agriculture practices, hygiene and food safety are becoming one of the biggest challenges in Hanoi. Acknowledging the health risks upon Hanoians, Vietnamese environmental activists are tackling on this issue together. One of the pioneers in environmental protection, the Institute of Environmental Science and Engineering, Hanoi University of Civil Engineering has approved to provide supervision for my thesis and practical training. My supervisor is Assoc. Prof., PhD. Viet-Anh Nguyen, director at the institute.

At first, the topics for thesis and practical training were to monitor and manage some ponds from a private site in the suburb of Hanoi. After having found that the pond quality - which source is coming directly from groundwater aquifer - to meet all national criteria for irrigation water, my supervisor has suggested to change the topic to water quality assessment for certain irrigation channels in Hanoi and treatment suggestions.

From his suggestion, the scope of this thesis was formed. That is to explore the situation of river water quality in Hanoi in term of suitability for irrigation and risks in irrigation water quality toward human. The connection between theory and practical statistics will be made and the water from various rivers will be assessed. National and international regulations and guidelines will be used as references. And finally, a theoretical suggestion of reed-bed system will be provided.

The objective of this thesis is then to make a scientific statement concerning the use of dirty water for irrigation of farms in peri-urban of Hanoi, as well as to provide a more economical, ecological, secure and viable water treatment method for individual farmers to cope with this problem.

3 METHODOLOGY

Water quality assessment refers to the measurement and assessment of the condition of water to meet the relative requirements for the organisms relying on the water for their survivability, as well as for human needs. In a water quality assessment, there are, but not limited to, certain stages that must be conducted. The first step involves data acquirement to build a sufficient database for research purpose.

Both primary (self-made data) and secondary (data collected externally) resources are acquired. The database will be built, then processed and a more suitable version for the Thesis' purpose will be selected. All selected and relevant data will be presented in the Appendices for reference.

With a manageable size of data to work with, the next step is to produce results. There are two different approaches to this. The first approach looks at the water quality of these sampling sites according to national regulations with international standards as references. The second approach aims to calculate the Water Quality Index (WQI) to provide an overall picture of the pollution level of assessed sites.

The results will serve two purposes (1): to show the client, and more general, the interested parties about the risky irrigation practices and (2): to be the base for the suggestion of the reed bed system - an ecological water treatment design. The theory of reed bed systems will be studied in order to suggest a theoretical design for wastewater treatment model that is ecological, efficient, economic and viable to help the farmers practice more hygienically. This report's structure consists of Introduction, Scope and Objective, Methodology, Theoretical Framework, Water Situation in Hanoi, Results, Discussion, Proposal for Alternative Method and Further Work.

3.1 Data collection

The first step involves gathering relevant data for different rivers of inner Hanoi. The data is collected from both primary and secondary sources. Primary resources are the samples directly taken from irrigation point sources and analysed through laboratory work for certain water quality indicator as mentioned in the national regulation QCVN 39:2011/BTNMT (from now referred as QC39). Secondary sources come from various research documents and presentations available on the internet and through private recommendations, all of which will be cited accordingly in References and Appendices.

3.1.1 Primary resource

There were two samples taken from a private farm, located alongside Red River near Thanh Tri Bridge. Farms around have been known to use Red River water for irrigation of fruit orchards. However this private farm use groundwater from private dug wells, which withdraw water from an aquifer below the soil level. The location of this farm is marked in Fig 2. below in red symbol.

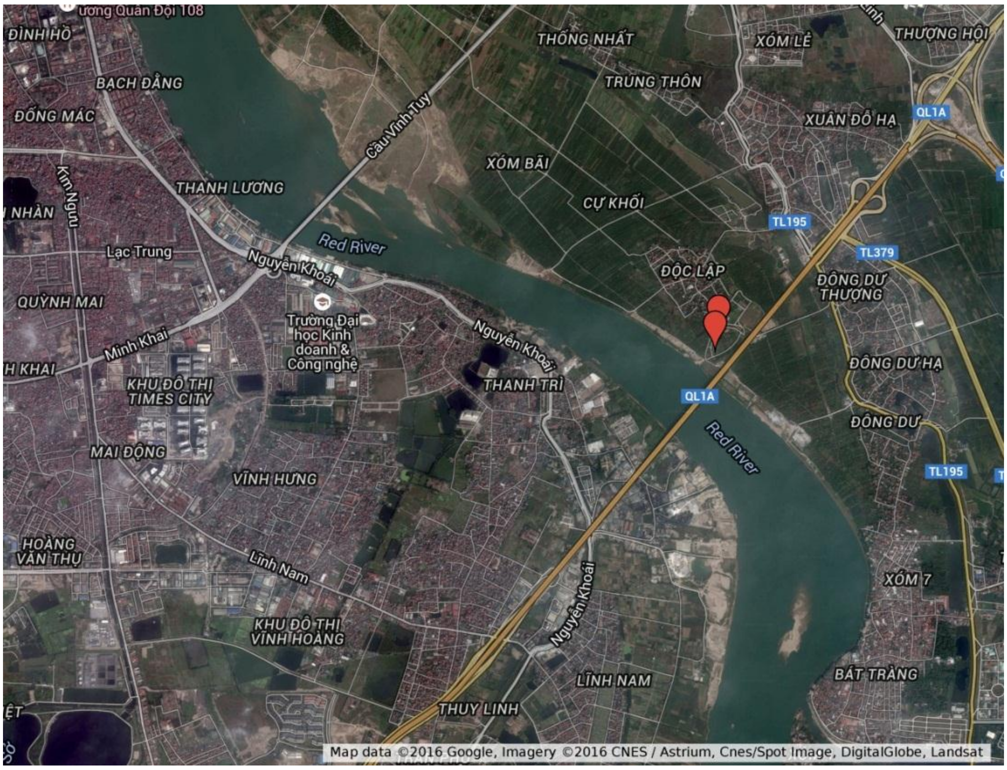

FIGURE 2: Sampling site at private farm location (Author, 2016)

Groundwater sample (G1) was taken directly from a groundwater pump that is constantly pumping water to a fishpond. The other sample – pond sample (P2) took water from the fish-pond at the depth of about 10 centimetres below water surface, and one metre away from the shoreline, as guided in QC39 (2011). However, the data collected from this source meet all parameters stated in this national technical regulation for irrigation water (See Appendix 1) and therefore will not be analysed within the scope of this thesis.

3.1.1.1 Sampling work

For each sample, the following preparations and requirements are met:

- 1x 3-litres clean plastic bottle with cap provided by laboratory service
- Marking of sample date, time, type and location
- Thoroughly sanitized hands or use plastic gloves and carefully take sample to keep most accurate results
- Keep airtight and minimize impact during transportation to laboratory
- Analyse as soon as possible to yield the most accurate results

3.1.1.2 Laboratory work

Some limitations during the laboratory work make the process of analysing errors less synchronous. The limitation from laboratory facility means that only simple parameters can be analysed by owns work. Other parameters require more advanced laboratory equipment and thus they are measured by an external accredited laboratory service namely Environmental Chemistry Laboratory, Technical Centre for Standard Quality Testing 1 (quatest1).

3.1.2 Secondary resources

The initial topic of this Thesis requires the need for specific resources, and thus, self-sampling actions must be taken. The results from own sampling have showed that it is not necessary to further investigating in the situation. Hence, the Thesis topic's scope has been widened to cover different irrigation channels for peri-urban farmers from Hanoi. Therefore, in order to reduce time, costs and effort, secondary data is compiled from online sources including two presentations, one Bachelor's Thesis and one research paper.

Table 1 shows the secondary sources as well as types of documentation, which the sources are withdrawn from, and sampling sites. Additionally, secondary sources concerning standards and guidelines will be presented as part of the study to give comparative analysis possibility.

Table 1: Sources of data and sampling sites (Author 2016)

River / Source	To Lich River	Kim Nguu River	Lu River	Set River
Group Presentation (Thuy, N. et al., 2014)	✓	✓		
Bachelor's Thesis (Ha, N., 2012)	✓	✓	✓	✓
Research Paper (Dao, C. A. et al., 2010)	✓	✓	✓	✓
Presentation (Furumai, H., 2009)	✓	✓	✓	✓

All of these sources seek compliance under national technical regulation QCVN 08:2008/BTNMT (from now referred as QC08) and therefore some parameters listed in QC39 (2011) are not present.

3.2 Data Selection

Initially, all data from various sources are gathered into a raw database, unorganized. This include various sampling points of different locations in inner Hanoi's rivers and their measured parameters as listed in QC08 (2008). The first categorization is devised from the acknowledgement of the most important inner Hanoi's river channels – To Lich River, Kim Nguu River, Lu River and Set River, and reported parameters.

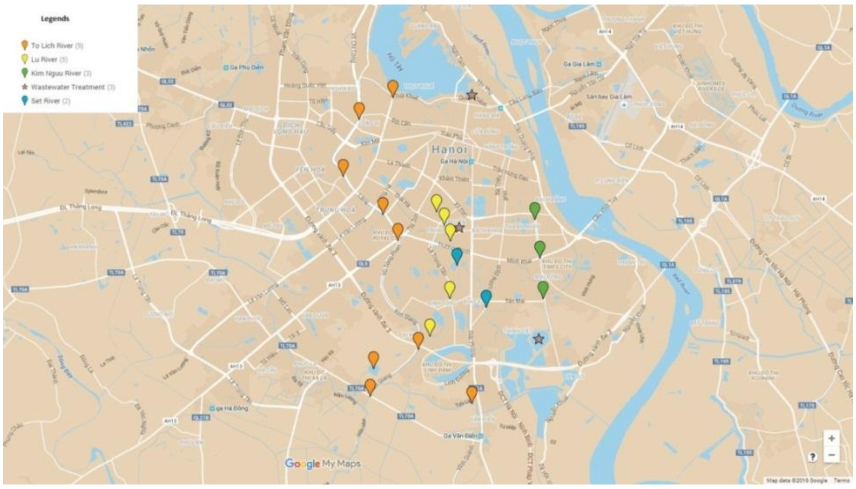

FIGURE 3: Sampling sites and wastewaster treatment plants of Hanoi (Author, 2016)

Due to the many sampling sites on these rivers, data is compiled in consideration with sampling locations and the data fulfils most parameters will be selected. There are nineteen (19) sampling locations, in which nine (9) from To Lich River, three (3) from Kim Nguu River, five (5) from Lu River and two (2) from Set River as presented in Fig. 3.

For parameters, a list is selected from QC39 (2011). This fifteen parameter list consist of pH, Dissolved Oxygen (DO), TDS, SAR, faecal coliform, 3 toxic ions (Cl, B, SO_4) and 7 heavy metals (Lead, Copper, Zinc, Chromium, Arsenic, Cadmium and Mercury). However, data is largely incomplete for certain parameters such as SAR and the toxic ions (Cl, B, SO_4). Therefore parameters from different guidelines and standards including QC08 (2008), FAO guidelines (see Appendix 3, 4) are also used.

3.3 Data Analysis to check compliance with National Regulations

QC39 (2011) requires a set of fifteen specific parameters as mentioned previously, some of which are mentioned in FAO Irrigation Water Quality Guidelines (see Appendix 3) and FAO Recommended Maximum Concentrations of Trace Elements in Irrigation Water (see Appendix 4) including: pH, TDS, SAR, six trace elements except Mercury (Hg), and some ions (Cl, SO_4 and B). QC39 is attached in this thesis as Appendix 2.

Additionally, parameters DO and faecal coliform are only present in QC39 but not FAO Guidelines. These parameters indicate the limits for values in which the irrigation water source could pose microbial pathogenic risks to human consumption. On the other hand, nutrient parameters such as Nitrate-Nitrogen (NO_3-N), Ammonium-Nitrogen (NH_4-N), Phosphate-Phosphorus (PO_4-P) and Potassium (K) stated in FAO Guidelines are not present in QC39.

QC08 (2008) on surface water quality cover most of the parameters listed in QC39, excluding only TDS. It also does not mention the macronutrient parameters in surface water, in which indicative quality is partially substituted by biological-related parameters such as Total Suspended Solids (TSS), Dissolved Oxygen (DO), Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD_5). In addition, QC08 provides parameters for pesticides of Organochlorine and Organophosphate origins as well as herbicides and radioactivity. This national technical regulation is attached as Appendix 1 below.

Tables and graphs comparing database to guidelines and regulations mentioned in this section will be presented in Results and Discussions. Additionally, Water Quality Index (WQI) theory will be explained in Theoretical Framework, with calculated WQI values presented in Results and Discussions.

4 THEORETICAL FRAMEWORK

In order to fully understand the meanings of national standards and water analysis techniques, theories on water quality, particularly irrigation water quality, must be explored. The first section introduces current environmental legislations in Vietnam, which will be the base for comparison to the data collected. Then theory on irrigation water quality is explored for most important indicators. Finally, Water Quality Index is presented as a tool for additional evaluation of water quality.

4.1 Environmental legislations

The environmental legislation history of Vietnam is young and has not received adequate consideration from the government. The first Environmental Protection Law had been issued in 1994, but not until 11 years later, in 2005 that the second revision of this law was updated (History of National Environmental Protection Agency 2009). The Vietnamese Congress issued the third and latest version of Vietnam Environmental Protection Law in 2014, which open up more opportunities for more sustainable environmental management practices of not only the authority but also the people (Environmental Protection Law - 55/2014/QH13).

Ministry of Natural Resources and Environment (MONRE) was founded in 1992, and is the main legal body for environmental legislations of Vietnam. For the purpose of this thesis, suitable regulations have been attached to the Appendices. Those are:

- QCVN 08:2008/BTNMT (see Appendix 1): National technical regulation on surface water quality;
- QCVN 39:2011/BTNMT (see Appendix 2): National technical regulation on Water Quality for irrigated agriculture

The main legislation that this thesis results and evaluations are based on is national technical regulation on water quality for irrigated agriculture - QCVN 39:2001/BTNMT (from now referred to as QC39). While QC39 is more relevant, QCVN 08:2008/BTNMT (from now referred to as QC08) reflects the consideration in which the Vietnamese government is paying to surface water quality of Vietnam. Currently there is no legal document for the safe use of wastewater in Vietnam (Lien et al.).

4.2 Irrigation Water Quality

Irrigation water quality refers to the characteristics of water that can potentially affect human through agriculture. According to several publications, a complete irrigation water quality considers the following factors: total salinity, water infiltration rate, pH, specific toxic ions concentration, microbial pathogens and excess nutrients (Ayers et al. 1985, Bauder et al. 2003). The addition of toxic pesticides and herbicides are also of major concern, as the values for these are restricted in surface water according to national technical regulation QC08 on surface water quality.

In agricultural activities, contaminated wastewater can cause from mild to severe physical skin effects while total salinity of the water can induce a crop yield loss. Similarly, pH range and toxic ions can affect the potential growth of plants, and might combine with total salinity to pose even more complicated and hazardous effects to produce yield. On the other hand, coliforms in irrigation water can anchor into raw vegetables and could pose great health risk if consumed.

QC08 (2008) and QC39 (2011) mention a wide range of water characteristics suitable for the assessment of these above factors. These characteristics must be understood in order to compile the most suitable database. The characteristics are explained through considered factors below.

4.2.1 Total Salinity

In agriculture, crops are affected by the salinity of irrigation water. Water with high salt content, when irrigated to the soil will evaporate leaving behind the minerals and salts. Thus, saline water can accumulate salt into the soil gradually. When the salt concentration in the soil rises, the ability of plants to extract water from the soil decreased due to osmotic pressure. As a result, plants can suffer from drought and reduced crop yield. Salinity resistance is higher in forage crops, then field crops, vegetable crops and fruit crops respectively (Fipps, 7)

The parameters to determine total salinity of water is either Electrical Conductivity of Water (EC_w) expressed in dS/m, or Total Dissolved Solid (TDS) expressed in mg/l. Only the latter is available in QC39 (2011). The equation below expresses the interrelation between EC_w and TDS.

$$ECw\ (dS/m) \times 640 = TDS\ (mg/l)$$

4.2.2 Water Infiltration Rate

When salt is accumulated in the root zone of soil, an input of water to a good water infiltration soil can leach the salt to a deeper level where it will keep accumulate until enough water pressure leach it downward. A good water infiltration rate thus helps reduce the salinity of the soil and as a result sustain an adequate level of water available for plant uptake. In the case of low water infiltration rate, the water is absorbed slowly into the soil, leading to stagnated water on the ground and aboveground layer. Without good drainage, most plants except those of aquatic culture are susceptible to diseases and pests.

Water infiltration rate is affected by two most common factors (18) – the total salinity and the proportion of sodium in relation to calcium and magnesium content. Water with high salinity can infiltrate better into the soil, while higher proportion of sodium can reduce overall infiltration rate.

The parameters to assess water infiltration rate are EC_w and Sodium Adsorbtion Rate (SAR).

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

SAR calculation formula, in which Na, Ca and Mg are expressed in mEq/l (milliequivalents of solute per litre of solvent). In certain cases where the water has high content of HCO_3^-, the availability of Ca decreases and an adjusted SAR calculation (SAR_{ADJ}) is applied.

To convert mg/l to me/l, the following formula is applied:

$$mEq/l = \frac{mg/l}{equivalent\_weight}$$

In which, *equivalent_weight* variable is the mass of one mol of the calculated substance or element.

In QCVN 39:2011/BTNMT, SAR value is a parameter, while Calcium (Ca) and Magnesium (Mg) ion concentrations are not presented as parameters and thus the concentration of Calcium and Magnesium in the medium is not restricted within the scope of this regulation.

4.2.3 pH

Parameter pH is an indicator of whether the water is acid or alkaline. This parameter is important due to the fact that nature tends to thrive in the most balanced condition, which for soil is slightly acidic to neutral soil condition. Therefore, most plants tend to survive best in the optimum pH range of 5.5 - 7. Perry (2003) sums up the important role of pH in his publication from University of Vermont, stating that the optimum pH range encourage soil bacterial activities, reduce nutrient leaching, keep nutrient available for plants, lock toxic elements and maintain the soil structure suitable for plant growth.

Acidity can additionally also cause corrosive damage to irrigation equipment. On the other hand, alkalinity can amplify the impact of reduced water infiltration rate. Alkalinity in water is most commonly caused by high content of high bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) These ions cause Calcium and Magnesium to form insoluble minerals, leaving Sodium as the dominant ion, affecting the SAR value (Bauder et al. 2003).

The pH value is a parameter in both QC08:2008/BTNMT and QCVN 39:2011/BTNMT.

4.2.4 Toxicity Ions

Trace elements are vital to plant growth in micro-quantity. High concentration of the elements, however, can be toxic and in severe cases, vital to plants. Often, perennial trees have lower tolerance to toxic ions in comparison with annual crops. FAO Guidelines (Ayers eet al. 1985) focus on sodium (Na), chloride (Cl) and boron (B) as the most considerable toxic ions. Their concentration in plant, though small, can cause negative impacts to crops.

Generally, these elements are concentrated where the plant's water evaporation is the largest, which are the leaf tips and edges (Ayers et al. 1985). Therefore, plant degradation signs such as marginal leaf burn and interveinal chlorosis could indicate ions toxicity. In annual crops, small uptake concentration might not show significant impact, but a high dose is possible to cause yield lost. This problem is more severe if irrigation water is sprinkled to plant leaves.

In QCVN 39:2011/BTNMT, the ions Chloride (Cl), Sulphate (SO_4), Boron (B), Arsenic (As), Cadmium (Cd), Chromium (Cr), Mercury (Hg), Copper (Cu), Lead (Pb) and Zinc (Zn) are mentioned parameters. A more complete list of toxic ions and their recommendation is presented by FAO in Appendix 4 (Ayers et al. 1985).

4.2.5 Microbial Pathogens

Food-borne diseases are sometimes associated with pathogenic organisms. These pathogens include bacteria (e.g., *Salmonella*), protozoa (e.g., *Cryptosporidium*), helminths (e.g., *Ascaris*) and virus (e.g., enteroviruses) (Pachepsky et al. 2011, 74). There are varieties of pathways in which pathogens can get into the human's body through consumption. In crop produce alone, pathogenic organisms can reach the fresh produce through plantation, plant care, irrigation and more. This thesis will only mention the possible risk of microbial pathogens to travel to human through irrigation water sources.

Treated wastewater sources are generally riskier to be used as irrigation sources among three main sources of irrigation water: surface water, treated wastewater and groundwater. Groundwater is generally the safest source in term of microbial activity due to the lack of dissolved oxygen in underground water bodies. It is common that wastewater, especially from urban activities, contains more pathogens and bacteria, and thus less safe (Pachepsky et al. 2011, 77).

Pathogens from irrigation water sources can adhere to plants, or internalize with the plants by colonize some of the plant tissues (Pachepsky et al. 2011, 85-86). From there, these organisms can survive for a variable period of time depending on the condition, making it easier to reach the endpoint of human consumption (Delaquis et al., 2007). Furthermore, food-borne disease outbreaks are increasingly recorded as associated with fresh produce such as vegetable, fruits and other products (Uyttendaele 2015, 336).

In reality it is difficult to isolate pathogens from irrigation sources, produce and patients, as well as there is difficult to find a clear sequence connecting these elements. Therefore, the relationships amongst these elements can only be inferred from real-life evidences. Pachepsky (2011) explains the relationship amongst these elements through fig. 4. The links A, B and C are straightforward, which means each of the latter event can be inferred backward, such as the investigation on produce to find the association with food-borne disease outbreak. Links D can be inferred through observation of environmental sources of contamination near produce stock, and link E can be inferred from the observation of increased clinical cases in areas using contaminated irrigation water.

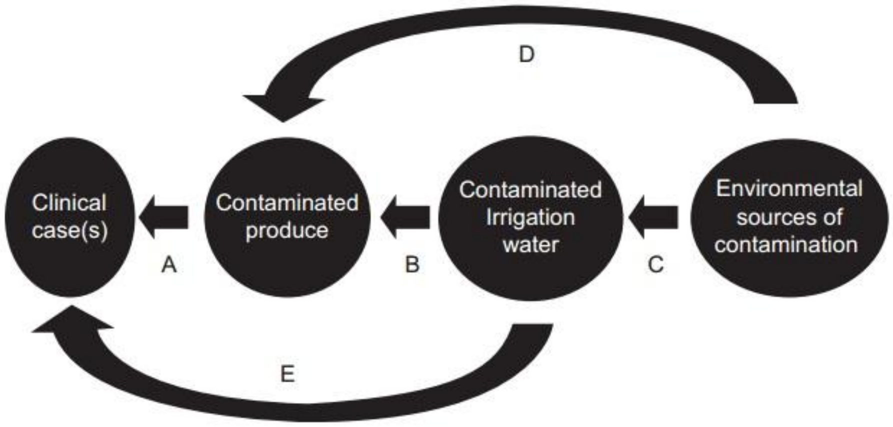

FIGURE 4: Inferences in research of irrigation water as a source of foodborne diseases caused by consumption of fruits and vegetables (Pachepsky *et al.* 2011)

QC39:2011/BTNMT provides the parameter for faecal coliforms. It is in accordance with most of the current guidelines and standards, which are still based heavily on microbial standards and parameters such as faecal coliforms as of 2015 (Uyttendaele et al. 2015, 348).

4.2.6 Excess Nutrient

Nitrogen, Potassium and Phosphorus are macronutrients vital for vegetation growth. However, if present in excess quantity in irrigation water sources, these nutrients can cause problems to produce yield. FAO (Ayers et al. 1985) have summed up the recorded effects of excessive Nitrogen on agriculture.

Excess Nitrogen in irrigation water has the same effects as Nitrogen fertilizer to plants' life cycle. During the immature stage, plants needs Nitrogen to grow, therefore Nitrogen availability in this stage is important to the development of plants. However, as the plants reach flower and fruiting stages, excessive Nitrogen can upset the plants, causing over-stimulation of growth, delayed maturity or poor quality yield. Excess Nitrogen in vegetation is also hazardous to livestock and animals. This nutrient can also encourage algae growth, which can potentially cause clogging and blocking of irrigation instruments.

Nitrogen most frequently occurring in irrigation water in the form of Nitrate (NO_3), but in wastewater it can occur as Ammonium (NH_4). In irrigation water standards and guidelines, Nitrogen is generally reported as Nitrate-Nitrogen (NO_3-N) or Ammonium-Nitrogen (NH_4-N), which means the total amount of Nitrogen in measured liquid.

Similar to Nitrogen, excess Potassium in water can encourage algae production, causing eutrophication. This type of pollution is due to excess nutrient discharged into stagnant or slow-run water sources. Peacock et al. (Irrigation Water Quality Problems, 4) states that Potassium and Phosphorus rarely exceed the capacity of the soil, unless nutrient-rich wastewater from human's discharge is retained in stagnant water body for an extended period of time.

In some situations, Magnesium present in excess quantity in water can affect plant growth. This is likely because excess Magnesium can cause less Calcium to be absorbed due to antagonistic effects, or the highly exchangeable capacity of Magnesium ions, which results in less available Calcium for plants (Ayers et al. 1985). An ideal Ca/Mg ratio of 1 means Calcium and Magnesium present in equal amount is better than a lesser ratio, especially in countering the salinity of the soil as well as providing plants with enough Calcium to counter the possible toxic effects of other ions such as Na and Mg. The effects of excess Magnesium on soil and water are not yet fully understood.

4.3 Water Quality Index (WQI)

The process of assessing surface water quality is complex and difficult to get a clear picture from the observed results, especially when addressed to interested parties without expertise in the field. There are so many parameters to assess, which are not only problematic individually, but also the interrelation of these parameters can cause a variety of combined effects as mentioned earlier. Scientists have come up with different methods for interpretation and modelling of data in order to convert complex parameters into much simpler form and readily understandable for interested non-expert parties such as the authorities, the project managers or land owners.

One way to do that is interpreting such complex parameters into a single value used as a general water quality index – also known as Water Quality Index (WQI). This model can be used for various parameters depending on the local and regional water situation as well as the purpose of modelling party. Basically, it converts individual parameters through mathematical calculations to quality value unit (Q-value), then involves the weighting factor to indicate the water quality impact capacity of the parameters, and finally the converted numbers are calculated for the final WQI value. The following sections explain the concept of Q-value, weighting factor, and also the diversity of parameters used for WQI.

4.3.1 Parameters and Q-value

In general, nine parameters are used include pH, DO, BOD_5, temperature (t^o), faecal coliform, total phosphorus (TP), total nitrogen (TN), turbidity and total solids (TS). Other parameters such as COD, TDS, hardness and specific ions concentration are sometimes used if the water is known to have characteristics that these parameters can indicate. However, only a number of most useful parameters will be used in a WQI, as the exploitation of more parameters may cause complexity and inaccuracy, contradict to the initial purpose of making a simple water quality index.

Dependent on the specific purpose in water quality assessment, different parameters will be selected for WQI calculation. These parameters will be converted to Q-values, usually ranging from 0 to 100, as water quality increases. The conversions of parameters to Q-values depend on their natural occurring level as well as monitored thresholds, limits and behaviour in the environment.

Appendix 5 (Oram 2014) presents a series of graphs showing Q-value conversion for many parameters. In some parameters such as turbidity, faecal coliform, BOD and nutrients, water quality (Q-value) decreases as these factors increase. For living-condition parameters such as pH and temperature (t^o), the Q-values are highest within a certain range, and decrease gradually as the condition shifts away from these ranges. Behave differently, the Q-values of TS and DO tend to rise as these parameters accumulate up to a peak – 50 mg/L for TS and 100 for DO – and will decrease if the concentrations continue to rise.

Table 2: Water quality index and interpretation (Author 2016)

Quality	Excellent	Good	Medium	Bad	Very Bad
Q-value & WQI Index	100 – 90	90 – 75	75 – 50	50 – 25	25 – 0

Q-values and their weighting factors are designed so that the range of the final WQI will fall between 0 and 100. These Q-values as well as final WQI can be interpreted through Table 2. To assess individual Q-values and WQI, interpretation from Table 2 can be used. In which, a parameter is considered excellent if its Q-value fall between 90 and 100, and will be considered bad if its Q-value falls between 25 and 50.

4.3.2 Weighting Factor

In some cases, the model will use weighting factors for each parameter, which represent the importance of individual compare to each other as well as to the WQI. The total sum of weighting factors of every considered parameter must equal 1, in other words, all the parameters in WQI represent 100% of the WQI final value.

Parameters that are better indicators of water quality will have higher weighting factor and influent more the final WQI. This weighting factor is also dependent on local water condition as the pollution sources are different. Commonly, Dissolved oxygen (DO) in water is one of the most important parameters in water quality analysis and therefore its weighting factor is usually larger than that of most other parameters. Water Research Center (Oram 2014) has a generic weighting factor for common parameters in WQI. This list is shown in Table 3.

Table 3: Common parameters and their weighting factors (Oram 2014)

Parameter	**Weight**	**Parameter**	**Weight**
Dissolved Oxygen	0.17	Total Phosphate (TP)	0.10
Faecal Coliform	0.16	Total Nitrates (TN)	0.10
pH	0.11	Turbidity	0.08
BOD	0.11	Total Solids (TS)	0.07
Temperature (t^o)	0.10	**TOTAL SUM**	**1.00**

In this list, DO weighting factor is 0.17 and is the highest of all parameters. Similarly, faecal coliform usually has high weighting factor (0.16) where blackwater is discharged directly to the water source. Temperature, TP and TN all share the same value for weighting factor and thus their water quality indication capacity individually accounts for 10% of the final WQI.

Total Solids and turbidity can also affect the water in term of concentration of various salts and minerals, or the ability of the water to biological self-cleansing.

4.3.3 WQI methods

There are different methods to calculate WQI, many of which are built upon the Pythagoreans means – rithmetic mean, geometric mean and harmonic mean. Walsh et al. (2012) sums up different WQI methods in Table 4.

Both weighting factor and no weighting factor are present for arithmetic mean-based, geometric mean-based and Solway modified weighted methods. Therefore, it can be seen that weighting factor may or may not be important in a WQI model, depending on specific use. From these based models, different organizations have developed their own water quality index calculation model, including variation in both Q-value rating curves, weighting factors and parameters.

Table 4: Methods for calculating WQI (Walsh et al. 2014)

No	Method	Aggregation function	Reference
1	arithmetic mean, no weighting factor	$I = \frac{1}{n}\sum_{i=1}^{n} q_i$	Prati et al., 1971; Sargaonkar and Deshpande, 2003; Frumin et al., 1997
2	arithmetic mean, with weighting factor	$I = \sum_{i=1}^{n} q_i w_i$	Brown et al., 1970, Prati et al., 1971
3	geometric mean, no weighting factor	$I = \left(\prod_{i=1}^{n} q_i\right)^{1/n}$	Bhargava, 1983
4	geometric mean, with weighting factor	$I = \prod_{i=1}^{n} q_i^{w_i}$	Brown et al, 1972 Couillard and Lefebvre, 1985
5	Solway modified weighted sum, no weighting factor	$I = \frac{1}{100}\left(\frac{1}{n}\sum_{i=1}^{n} q_i\right)^2$	Wepener et al., 2006
6	Solway modified weighted sum, with weighting factor	$I = \frac{1}{100}\left(\sum_{i=1}^{n} q_i w_i\right)^2$	Tyson and House, 1989; Gray, 1996; Bordalo, 2006
7	harmonic mean, no weighting factor	$I = \sqrt{\frac{n}{\sum_{i=1}^{n}\frac{1}{q_i^2}}}$	Dojlido et al., 1994; Cude, 2001
8	Min	$I = \min(q_1, q_2, \ldots q_n)$	Smith, 1990
9	Max	$I = \max(q_1, q_2, \ldots q_n)$	Couillard and Lefebvre, 1985

In Vietnam, there has exists some methods for the calculation of WQI (Environmental Monitoring Center 2011). Some of calculation methods are WQI model by Dr. Ton That Lang for Dong Nai River, WQI model by Dr. Pham Thi Minh Hanh and WQI model by Vietnam Environment Administration.

The first WQI model for Dong Nai River use arithmetic mean with weighting factor.

$$\text{WQI} = \sum_{i=1}^{n} q_i W_i$$

WQI: Water Quality Index

q_i: Q-value of parameter

W_i: Weight of parameter

Parameter	Weight
BOD	0.23
DO	0.18
SS	0.16
pH	0.15
TN	0.15
Total coliform	0.13

The second model by Dr. Hanh use exploratory factor analysis (EFA) method.

$$I_B = \left[\frac{1}{5} \sum_{i=1}^{5} q_i \times \frac{1}{2} \sum_{j=1}^{2} q_j \times q_k \right]^{1/3}$$

where:

I_B : the basic water quality index

q_i: Q-value for DO, BOD_5, COD, NH^+_4-N and PO_4^{3-}P

q_j: Q-value for SS and turbidity

q_k: Q-value for total coliform

Parameter
COD
BOD5
DO
Turbidity
TSS
NH^+_4-N
PO_4^{3-}P
Total coliform

4.3.4 WQI model used (Environmental Monitoring Center 2011)

The last WQI model mentioned in this section is the model used in the WQI calculations of this thesis. It is a model issued by Vietnam Environment Administration, a major environmental authority of Vietnam. The model considers nine parameters, and also temperature is additionally used in the calculation process. The first step involves calculations of Q-values for seven parameters: BOD5, COD, NH^+_4-N, PO_4^{3}-P, TSS, Turbidity and Total Coliform using the following formulas:

$$WQI_{SI} = \frac{q_i - q_{i+1}}{BP_{i+1} - BP_i}(BP_{i+1} - C_P) + q_{i+1} \quad (1)$$

$$WQI_{SI} = \frac{q_{i+1} - q_i}{BP_{i+1} - BP_i}(C_P - BP_{i+1}) + q_{i+1} \quad (2)$$

where:

WQI_{SI}: Q-value of parameter

BP_i: lower threshold concentration of monitored parameter at level i

BP_{i+1}: higher threshold concentration of monitored parameter, equal value for level i+1

q_i: Q-value at level i

q_{i+1}: Q-value at level i+1

C_P: monitored value of parameter

Secondly, calculation of Dissolved Oxygen is slightly different, in that Percentage of Saturated Oxygen ($DO_{\%sat}$) is compared to the BP values and also used as the C_P value. The calculation of $DO_{\%sat}$ consists of two steps – calculation of Saturated Oxygen DO_{sat}, and calculate the percentage of Dissolved Oxygen to Saturated Oxygen ($DO_{\%sat}$). To calculate DO_{sat}, temperature time of monitoring is involved in the following formula:

$$DO_{sat} = 14.652 - 0.41022T + 0.0079910T^2 - 0.000077774T^3$$

where:

T: Temperature at time of monitoring

After the determination of DO_{sat} value, the percentage of DO to DO_{sat} is calculated as follow:

$$DO_{\%sat} = {}^{DO}/_{DO_{sat}} * 100$$

Depending on the $DO_{\%sat}$ value, an adjusted WQI calculation may be used. If $DO_{\%sat}$ is between 112 – 200 then formula (1) is used whereas formula (2) is used if $DO_{\%sat}$ value is between 20 - 88. Similarly for pH, a pH value between 8.5 – 9 will use formula (1) whereas a pH value between 5.5 – 6 will use formula (2). This is to prevent negative number in the final WQI result.

The threshold levels for concentrations (BP) for all parameters are provided by the authority in Table 5. It can be seen from the chart that BOD_5, COD, Ammonium-Nitrogen, Phosphate-Phosporus, Turbidity, TSS and Coliform are all similar in term of rating curve. In which case, the increase in any of these parameters concentration in water results in a decrease in Q-value index, implying the degradation of water quality. For DO, the best range for water quality is between 88 and 112 BP_i, and for pH it is between 6 and 8.5.

Table 5: BP_i values for nine parameters mentioned in this WQI model

i	q_i	BPi: BOD_5 (mg/l)	COD (mg/l)	N-NH4 (mg/l)	P-PO4 (mg/l)	Turbidity (NTU)	TSS (mg/l)	Coliform (MPN/100ml)
1	100	4	10	0.1	0.1	5	20	2500
2	75	6	15	0.2	0.2	20	30	5000
3	50	15	30	0.5	0.3	30	50	7500
4	25	25	50	1	0.5	70	100	10000
5	1	50	80	5	6	100	>100	>10000

DO										
i	1	2	3	4	5	6	7	8	9	10
BP_i	≤20.00	20	50	75	88	112	125	150	200	≥200
q_i	1	25	50	75	100	100	75	50	25	1

pH						
i	1	2	3	4	5	6
BP_i	≤5.50	5.5	6	8.5	9	≥9
q_i	1	50	100	100	50	1

After the determinations of all Q-values for parameters comes the final WQI calculation. This model does not use weighting factor, and is a combination of arithmetic mean, geometric mean and Solway methods. The model is expressed in the final formula below:

$$WQI = \frac{WQI_{pH}}{100}\left[\frac{1}{5}\sum_{a=1}^{5} WQI_a \times \frac{1}{2}\sum_{b=1}^{2} WQI_b \times WQI_c\right]^{1/3}$$

where:

WQI: Final Water Quality Index

WQI_a: WQI_{SI} values for DO, BOD_5, COD, NH^+_4-N and PO_4^{3-}–P

WQI_b: WQI_{SI} values for TSS and Turbidity

WQI_c: WQI_{SI} value for Total Coliform

WQC_{pH}: WQI_{SI} value for pH

The final WQI result follows general rule of interpretation from Table 2, with each level top-down represents water quality level A1, A2, B1 and B2 respectively in QC08 (see Appendix 1). The Very Bad quality level indicates water quality is not suitable to use for any purpose.

5 WATER SITUATION IN HANOI

This section explains the situation of water in Hanoi including the hydrology of Red River Basin and Hanoi, centralized wastewater treatment plants, decentralized wastewater management potential, pollution facts, occurrence of pesticides in wastewater and wastewater role in agriculture and aquaculture.

5.1 Hanoi hydrology

The Red River originates from Yunnan, China, flows through Hanoi to the Gulf of Tonkin. Before reaching Hanoi, it is joined by Black River from the South and Lo River from the North to become the largest part of the Red River Basin. Fig. 5 presents the entire basin from the starting point in China, to the Vietnam's Gulf of Tonkin.

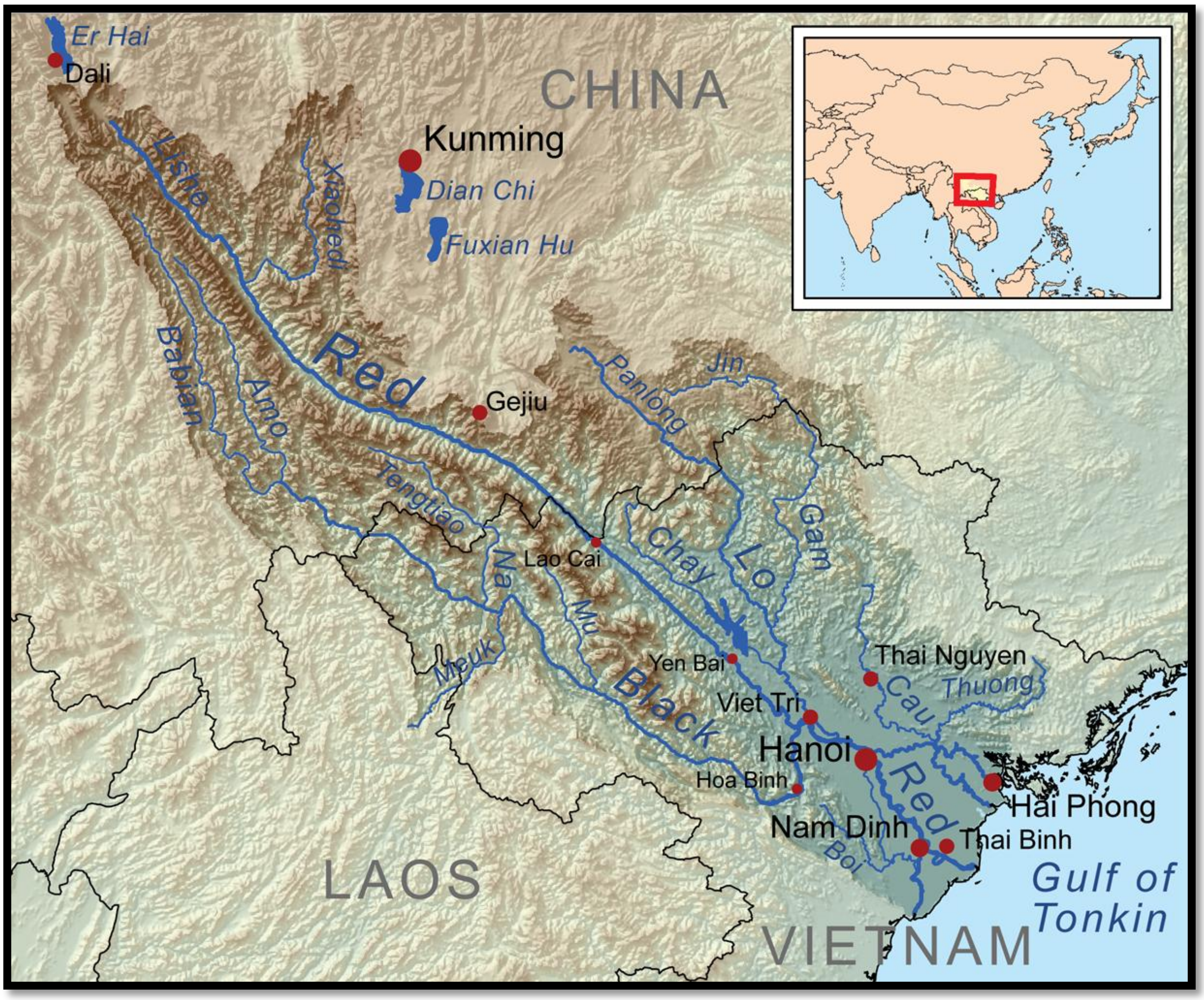

FIGURE 5: Red River basin hydrology (Kmusser, 2010)

Arrive at Hanoi, Red River flows southeast while Day River and Nhue River detach from the main river to flow south. These rivers cover the southwestern urban and peri-urban side of the city. They later join onto Day River and partly reintegrate back into the Red River before discharge to Tonkin Gulf.

Inside the city are the origins of many rivers. The biggest inner city river – the To Lich River used to be a distributary of the Red River, but since the French-colonialists have blocked the distributary in 1989, it is now heavily polluted (Rivers in Hanoi 2009). The current To Lich River flows at a very slow rate from West Lake - which is the biggest city reservoir – and detach to two branches, one of which rejoin with Day River while the other go to Yen So Lake, where Yen So Water Treatment Plant is located. Similarly, Lu River, Set River and Kim Nguu River are all distributaries of Red River or originate from lakes within the city. They all end up at Yen So Lake and partly receive a centralized water treatment before rejoining with the Red River. Another large part of the wastewater going to Yen So Lake – about 300,000 – 350,000 m^3/d, together with a part of To Lich River flow directly to Nhue River without receiving any treatment (Mai et al., 2013).

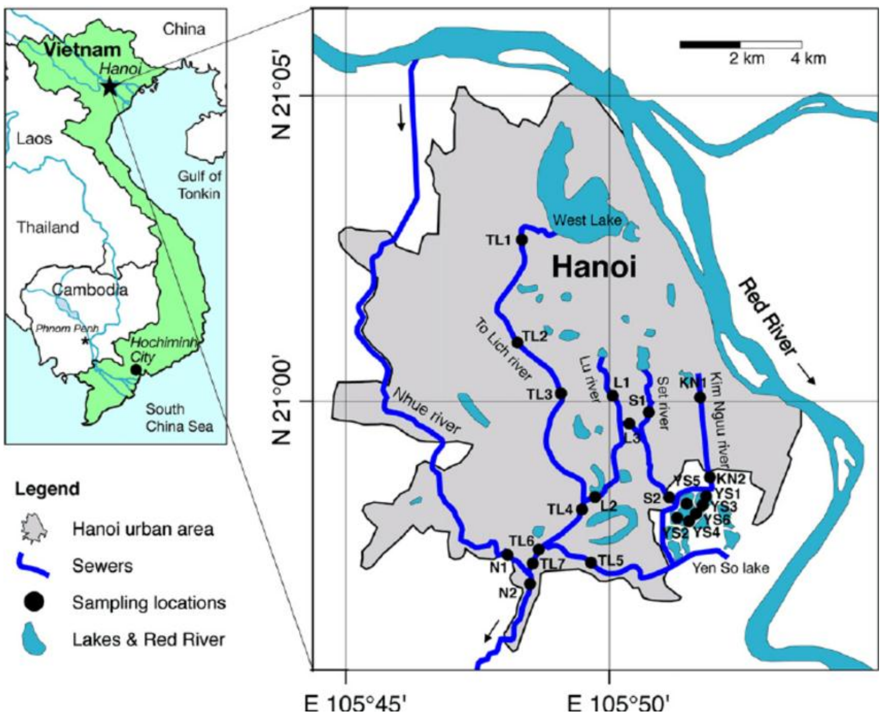

FIGURE 6: Hanoi city sewer system (Hoai et al., 2010)

Fig. 6 shows the sewerage and drainage system of Hanoi, all were originally rivers of the Red River Basin. The high demands for water consumption as well as the lack of proper wastewater treatment have led to frequent discharge of polluted wastewater directly to the rivers (National Environmental Report 2012, 28). Overtime, the accumulation of slug and garbage have stagnated the rivers, decrease their potential to self-cleansing, and result in dark-ish-black contaminated rivers. The authorities of Hanoi have decided to use To Lich River and other rivers within the city as part of the open sewerage and drainage system.

5.2 Wastewater treatment in Hanoi

Built upon the old French-colonialist infrastructure without careful urban planning, the centralized drainage and combined sewage system of Hanoi is underdeveloped. The 70 years old infrastructure is currently under the official provision of the Sewarage and Drainage Company (SADCO), whom is responsible for the wastewater treatment of 60% of the city's area (Viet-Anh 2005, 17). Wastewater from domestic and industrial sources is discharged directly into the open sewerage and drainage system, which are dead rivers. This combined sewage system is also the only drainage route for storm water, which is the reason for frequent flooding and waterlogging in monsoon season.

Fig. 7 (Viet-Anh 2005) describes the urban wastewater collection process in Hanoi. Both individual houses and public structures have connection to the inner Hanoi sewerage system, partly functioned by SADCO. All of these building types release grey wastewater directly to the sewer network.

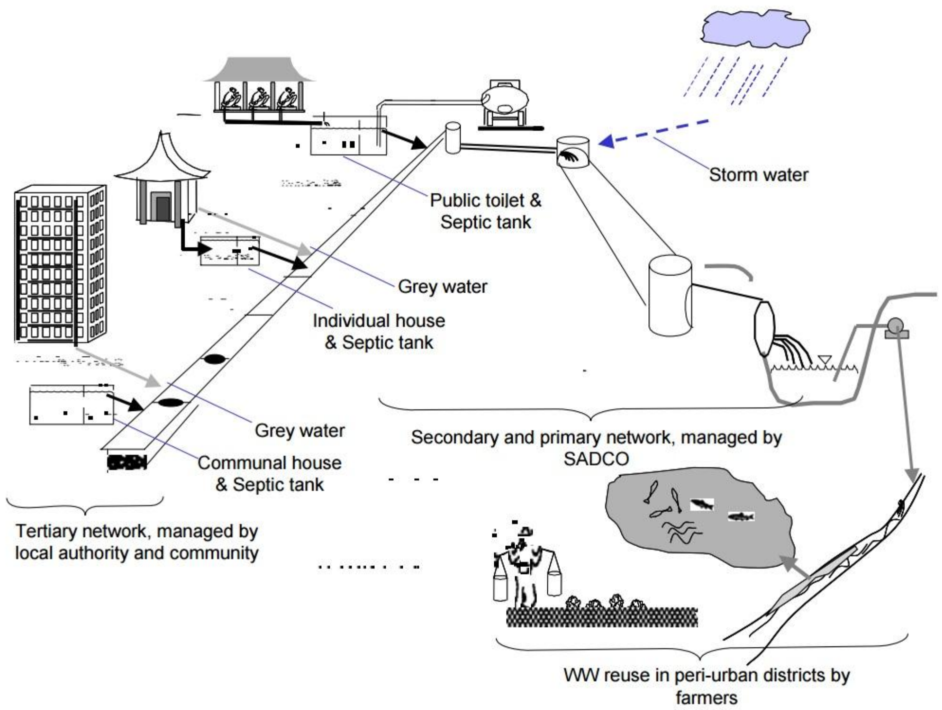

FIGURE 7: Sources and flows of wastewater in Hanoi (Viet-Anh 2005)

For black wastewater however, a majority of buildings have septic tanks installed and these installation can partly treat the water source before discharging to the sewer system. Septic tanks are cleaned occasionally when full, with private companies or the Urban Environment Company (URENCO) in charge of the cleaning job. The part of wastewater coming to the sewerage will be drawn through a network of drainages and settlement ponds where it will receive partly treatment before gathering at wastewater treatment plants. The other wastewater part out of SADCO's management is the responsibility of local authorities and local residences.

Hanoi is divided into two drainage basins, Nhue and To Lich river basins. Most wastewater and rainwater flow to those rivers through a network of sewers, open channels, drains and ditches (Viet-Anh 2005, 17). These channels include the four inner rivers of Hanoi – To Lich River, Lu River, Set River and Kim Nguu River, which source draws the interest for this thesis.

A study estimates that 400,000 – 450,000 cubic metres of domestic wastewater as well as 260,000 cubic metres of industrial wastewater are discharged to the network on a daily basis (Van 2009), in which, less than 10% of urban wastewater is treated before going to the rivers (Senga et al. 2010). The network is also a connection for ponds and lakes. These water stabilization reservoirs contribute significantly to biological wastewater treatment process (Wnukowska 2004, 30).

Along the rivers, pump stations are built to direct all water toward wastewater treatment plants to be treated before discharging back into the Red River to leave the city. Table 6 lists the four major centralized wastewater treatment plants in Hanoi. The locations of these plants, except for North Thang Long wastewater treatment plant due to having located outside of inner Hanoi, are presented in Fig. 3.

Table 6: Centralized wastewater treatment plants in Hanoi (An, 2013)

No	Plants	Start up year	Capacity, m3/d		Sewer type	Treatment process / technology
			Design	Operation		
1	Kim Lien	2005	3,700	3,700	CSS	A20 (AS)
2	Truc Bach	2005	2,500	2,500	CSS	A20 (AS)
3	North Thang Long	2009	42,000	7000	CSS	AO with nitrification
4	Yen So	2012	200,000	120,000	CSS	SBR

The most recently built plan – Yen So plant also has the highest treatment capacity. Following the construction of Yen So plant is the plan to build eight other wastewater treatment plants in large lakes and rivers of Hanoi (Waste treatment plants need funds 2012) up to a total of 39 wastewater treatment plants by 2030. VUFO states that Hanoi will reach total daily capacity of 1.8 million cubic metres by 2030 (Vietnam Hanoi to build… by 2030, 2016).

5.3 Decentralized wastewater management

The centralized nature of Hanoi wastewater treatment is a challenge especially to the farmers living in the peri-urban areas, where access to clean water is limited or even unavailable. Furthermore, centralized wastewater treatment systems are expensive, difficult to build and require complex processes, which are often time-consuming. Viet-Anh (2005, 33) highlights the potential of decentralized wastewater management, especially in peri-urban areas to complement for the inefficient and downgraded centralized system.

The urbanization has caused a large amount of wastewater to be discharged daily, which exerts pressure onto the drainage situation of the city. As a result, several inner rivers of Hanoi have been converted to open sewers to redirect the high volume of wastewater and stormwater run-off toward treatment plants. Many of these rivers were originally traditional irrigation channels. At the same time, the potential of fresh food to supply the large market raises, forcing the peri-urban farmers to use wastewater directly or indirectly in agriculture and aquaculture practices.

In that context, some creative farmers have found new ways to reduce the impacts from contaminated wastewater. One of which is stated in a case study in EPA Guidelines for Water Reuse 2012 (Viet-Anh et al. 2012). The study presents a situation where the farmers living in the peri-urban area of Hanoi creatively design a multiple wastewater reuse design.

Firstly, the wastewater is drawn into a fishpond, where it will be pumped to fasten the natural water treatment process. During this step, fishes, aquatic plants and the aquatic ecosystem will ecologically treat the wastewater. After that, this improved wastewater in term of nutrient quality and reduced pathogens is further pumped through a long tunnel to reach a vegetable field. Then finally, the wastewater will reach the rice paddies, which have traditionally been the main crops of the people living here.

However, wastewater is increasingly carrying toxic substances released from hospital and industrial activities, which can cause hazardous impacts to fishes, plants and human. Therefore, decentralized wastewater management methods as such mentioned in this example may require further research in order to observe the risks of this wastewater in irrigation, as well as to assess the wastewater ecological treatment efficiency. In other similar practices, peri-urban farmers have seen losses in fishes due to toxic wastewater-fed aquaculture ponds, and thus wastewater usage for aquaculture is now reduced to 10-30% (Viet-Anh 2005, 28).

5.4 Pollution facts

With thousand years of development history alongside the Red River Basin, Hanoians and nearby basin residents cannot deny the fact that the river system is a major element to their survivability and prosperity. The quick urbanization and industrialization of Hanoi have contributed largely to the life standards of people, but the downsides are not to be neglected. Heavy surface water pollution due to untreated domestic and industrial wastewater is a major problem that has not been adequately addressed.

As stated in National Environmental Report (2012, 69), the surface water is polluted due to high levels of microbial pathogens, organic matters, heavy metals and toxic chemicals. The report also mentions that polluted surface water is responsible for causing several diseases and disease outbreaks affecting public health, including diarrhea, hepatitis A, cholera, typhoid, anemia, cancer, gastrointestinal and skin diseases.

There are two possible routes of exposure for the water to reach human. Those are digestion and skin contact. Direct contact with pollution water, such as the usage of contaminated river water for daily activities, showering, swimming, washing…, is susceptible to skin diseases. More severely, ingestion of polluted water, through drinking or eating food that is irrigated or washed with the water can potentially cause a variable set of acute and chronic health effects.

Crafting villages in the peri-urban area around Hanoi is a contributor to this degradation of the Red River Basin. Up to date, more than a thousand traditional crafting villages are still doing what they have been doing for several hundreds or even thousands of years – crafting products. As an unwanted bi-product, wastewater from 1350 craft-villages is discharged to the river system without any prior treatment (Anh 2014).

Together with the wastewater sources from crafting villages are larger, from a later-developed social system but equally lacking in management, urban wastewater sources. These are the domestic and industrial sources. Domestic wastewater is not only discharged from residential areas, but also from hospitals, commercial centres and minor-to-medium processing facilities. A study from United Nations University in 2015 presents that residential activities discharge 600,000 m^3/day, hotels and commercial centres discharge 123,000 m^3/day, and hospital discharge 6,000 m^3/day (Planning for … driven by 2030). While industrial activities discharge approximately 80,000 m^3/day (General Planning … 2050), the impact caused to carrier sewers is twice as much as domestic discharge in term of BOD (see Fig. 8 below).

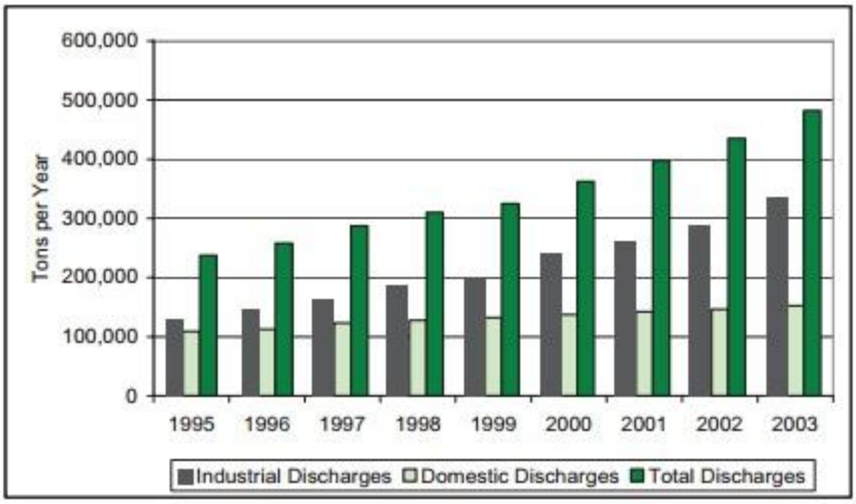

FIGURE 8: Total BOD discharge from 1995 to 2003 (Vietnam EPA Report 2008, 10)

Wastewater from agricultural practices is also a contributing factor to polluted rivers since the water circulation is a common element in rice cultivation. Water run-off that brings artificial and non-artificial nutrients from the soil can also return to the rivers, further adding the chemical fertilizers, herbicides, and all kinds of plant chemical supplements into the waterway. However, there is currently no official local-level solution from the authorities.

Lack of concern for wastewater reuse means lack of research; and without sustainable technologies, Vietnamese farmers and commercial farms can and likely to only rely heavily on chemical means to produce substantial yield to supply the hungry market. The use of chemical fertilizers such as N-P-K, chemical pest control and chemical herbicide are widespread. According to FAO (1985, 48), the application of fertilizer can enhance salinity at the plant's root zone, with various fertilizers recorded for salt index.

To give a glimpse at the problem, Ha et al. (2006) stated that Vietnamese farmers used fertilizers on an average of 233.8 kg/ha/year while the total cultivated soil is 11,569,591 ha in 2004. As a result, over a long time they have deposited estimably large quantity of toxic, anthropogenic substances into the soil. The problem with Hanoi's inner rivers pollution is not anymore an abstract claim, but already and increasingly becoming a clear picture for the people of Hanoi, as in Fig. 9 (Author compiled, 2016).

FIGURE 9: River pollution in Hanoi (Author compiled, 2016)

5.5 Pesticides in wastewater

Pesticides are very toxic artificial chemical compounds used for the purpose of exterminating unwanted pests such as weeds (herbicides), insects (insecticides), fungi (fungicides). The application of pesticides has been widely popular in Vietnam since the 90's. In 1992, there have been the first legislations on the ban of hazardous pesticides such as dichlorodiphenyltrichloroethane (DDT), Hexachlorobenzene (HCB) and many heavy metal based compounds (Gatson 1994, 23). However, according to a recent study, the sediment level of polychlorinated biphenyls (PCBs) and organochlorine pesticides in all four inner rivers of Hanoi as well as Nhue River and Yen So Lake were highest in Vietnam (Hoai et al. 2010). The report also confirmed increasing trend of inputs of banned pesticides up to the monitored date.

The application of pesticide to agricultural crops are not only diminishing the quality of crop and crop yield, but also hazardous to human's health as well as potential to disturb predator-prey sequences which leads to the disturbance of major ecosystems (Ongley 1996). Further adding to this, many pesticides are persistent organic pollutants (POPs), which means that they are resistant to natural degradation processes and can thus accumulate within a medium and cause harmful health effects if the medium is a living organism. DDT and HCB are examples of pesticides expressing this characteristic.

In the environment, pesticides cause ecological impacts primarily due to run-off to waterway. FAO (1996) mentioned two mechanics through which pesticides accumulate in a medium, including bioconcentration and biomagnification. Bioconcentration happens when pesticides run-off to the water and are accumulated into an organism, such as dissolve into the fatty tissues of fish. Then biomagnification is the buildup of the accumulated pesticides in a higher organism in the food chain as it consumes the prior organism. At the top of the food chain (including human), the accumulation of pesticides is the highest. Effects are usually chronic, difficult to observe but can affect the entire food chain.

5.6 Wastewater in agriculture and aquaculture

The casual practice of peri-urban farmers has long been to use river water for crops irrigation and fish ponds. This practice is still common nowadays, despite the fact that many rivers have now been converted to open drains and receive large volumes of wastewater daily. The Red River, which receive treated wastewater is also a major irrigation water source. According to Groves et al. (2002), water from river that has wastewater discharged to is considered as treated wastewater. Therefore the irrigation channels used by farmers from peri-urban of Hanoi are considered partially treated wastewater, the characteristics and components of such water is more closely related to wastewater.

Wastewater contains large quantity of nutrients vital to plant and animal growth such as Carbon, Hydrogen, Nitrogen and Phosphorus. This nutrient rich source can improve yield significantly and thus is recommended to be reused in agriculture and aquaculture. This is a two-for-one approach since it benefits human economically while reduces environmental pollution (Raschid-Sally et al. 2001, 4). The risks, however, are not to be neglected. Several disease outbreaks were reported to be associated with wastewater (see section 3.2.5), persistent toxic chemical can follow wastewater and causes effects to the entire ecosystem (see section 4.5) and groundwater can be polluted if nitrate can leach deep into the ground.

6 RESULTS

The database is collected from a total of 19 sampling locations in four inner Hanoi rivers – To Lich River, Kim Nguu River, Set River and Lu River. These rivers are all origin from the central part of the city, and end up going to the Red River or Nhue River (see Fig. 6). All of these rivers are converted to the city's open drainage sewers, where wastewater from all sources is directly discharged into. All of these sewer channels are connected at Yen So Lake where a part of wastewater will be treated before discharging to Red River. Whereas, a large part of water from these inner rivers and Yen So Lake flow southward to Nhue River does not receive any treatment at all.

Red River and Nhue River are large rivers belong to the Red River Basin. They have traditionally been the water source for agriculture and aquaculture of a large portion of farmers in Vietnam. The assessment of these rivers for its suitability to agriculture thus becomes very interesting and will require a lot of attention in the future. This thesis, however, only assess the quality of wastewater in the four inner rivers of Hanoi, from which source many peri-urban communities are using for irrigation and fish raising. This serves the purpose of giving an overview to the water quality of these rivers, which helps the farmers acknowledge the harmful potential if pollution is presence.

Comparison to both national technical regulations show that there is severe pollution in these four inner rivers of Hanoi in term of organic matters, microbial pathogens, heavy metals, excess nutrients and micropollutants. WQI index using the model mentioned in section 4.3.4 shows the quality of all four rivers at significantly polluted and unsuitable for use of any purposes. The output of this analysis shares similar conclusions with other researches as mentioned in section 7.

6.1.1 Comparison to QC39

The data is secondary data from different studies on general water quality assessment. This leads to the use of a variety of water quality indicators that may not serve the National Technical Regulation on Water Quality for Irrigated Agriculture - QC39 (see Appendix 1), or lack the parameters as measured in this regulation. QC39 is strict in term of heavy metals in comparison to FAO Guidelines (1985) with parameter limits equal or even lower than that provided by FAO (see Appendix 4).

The author's data for parameters as listen in QC39 is largely incomplete. Only 53% of all 15 parameters mentioned are filled in all of sampling sites. Some of the parameters are completely absent including Boron, Chloride, Sulphate and SAR. Of all the other parameters, only pH and DO data is completely filled. The remaining seven parameters – TDS, Leads (Pb), Copper (Cu), Zinc (Zn), Cadmium (Cd), Chromium (Cr), Mercury (Hg) are missing 30-50% of the data.

In check for compliance with QC39, the parameters pH, TDS, Cu and Zn are below the limits set out, showing that these parameters are in acceptable quantity for irrigation water. The pH parameter fluctuates between 7.25 and 7.7 in all cases, satisfying both the limit range 5.5 – 9 as set out in QC39 and A1-type in QC08 (see Appendix 1).

In term of Dissolved Oxygen (Fig. 10), most of the sampling points fail to comply with QC39 regulation, in which DO value is ≥ 2. Only five (5) sampling points – of which three (3) from To Lich River, zero from Kim Nguu River, one (1) from Lu River and one (1) from Set River meet the criteria. The location with lowest DO value (below 0.5) recorded is Van Dien commune. This is an indication to severe lack of oxygen vital for the water ecosystem, leading to pollution, as without oxygen many species vital to the ecological cleansing ability of water will not survive.

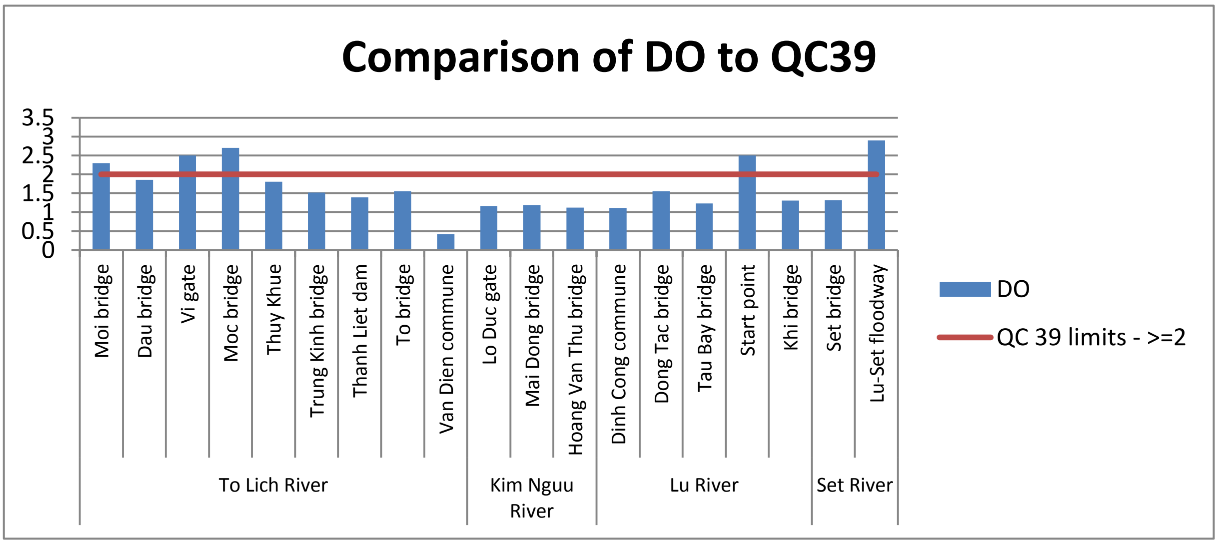

FIGURE 10: Comparison of DO to QC39

Cadmium (Cd) concentration was found exceeding QC39 from 1.7 to 119 times, in six (6) sampling locations in all four rivers (Fig. 11). Four of the samples exceed the limits 99 times or more. The exceedances appear in almost half of sampling locations. Heavy metal pollutions such as Cadmium are more prone to be caused by industrial activities than domestic activities.

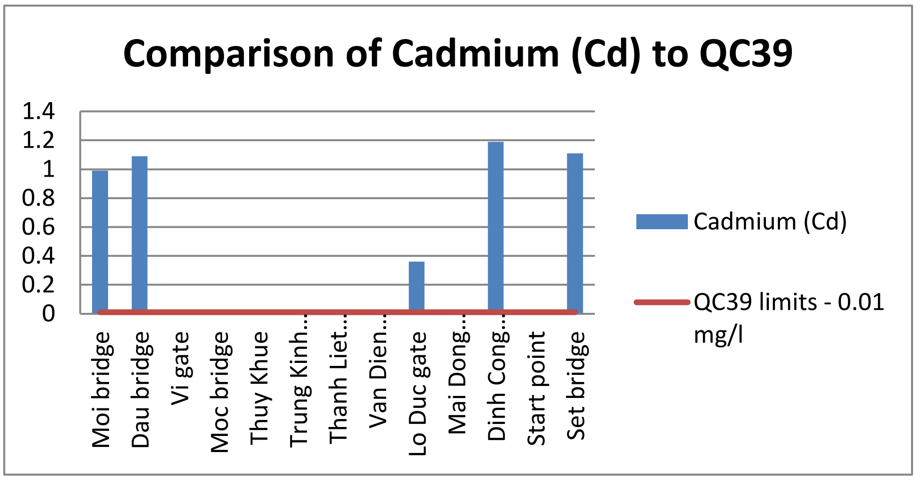

FIGURE 11: Comparison of Cadmium (Cd) to QC39

There were only nine (9) Chromium (Cr) samples, of which only Trung Kinh Bridge – To Lich River exceeds the QC39 limits (see Fig. 12). For Arsenic (As), the samples were taken from sixteen (16) locations, of which three (3) samples slightly exceed the limits of 0.05 mg/l. It can be concluded that there is a source for heavy metals such as Cr and As, however the water can still disperse the metals and thus not many exceedances have been found.

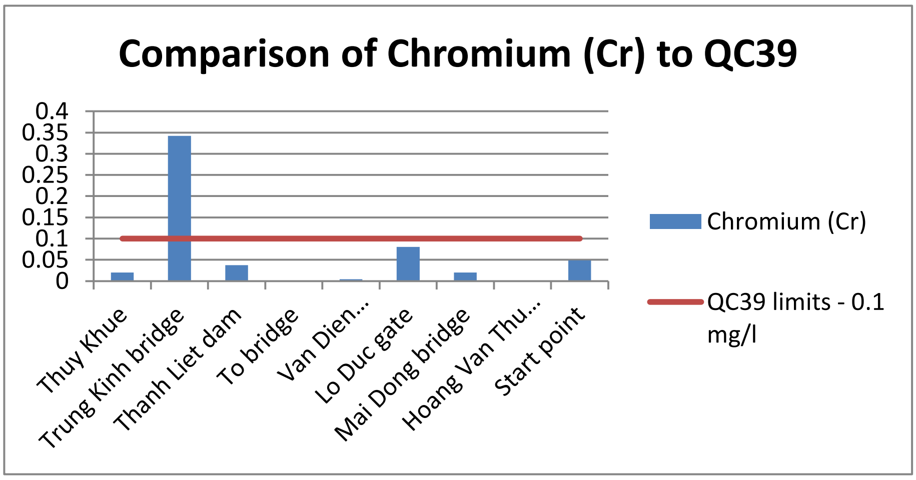

FIGURE 12: Comparison of Chromium (Cr) to QC39

In the case of Mercury (Hg), there were thirteen (13) samples with four (4) cases few times above the limits of 0.001 mg/l. Most of other samples have value below 0.001 and are considered safe to use in term of Hg toxicity. Still, as Mercury is extremely toxic to human and fish, there needs to be findings into the sources of Mercury disposal to have pre-treatment before discharging into the environment. Fishes are more vulnerable to Mercury toxicity than annual crops, and therefore aquaculture may be affected more from this source of irrigation water. Nevertheless, accumulation of Hg on human is extremely hazardous, thus wastewater from these sources are not suitable for agriculture and aquaculture purposes.

Faecal Coliforms were found to break the limits set out by this regulation from 500 – 4000 times in 100% of the samples (see Fig. 13). There were in total ten (10) sampling locations, with half of them have faecal coliform parameter in the range between 100,000 – 300,000 MPN/100ml. The waters from these sources are heavily polluted with microbial pathogens. Therefore, they should not be used for any purpose involving directly or indirectly physical contact or ingestion. Irrigation of crops and wastewater-feeding aquatic ponds should require prior treatment such as the use of reed-bed system.

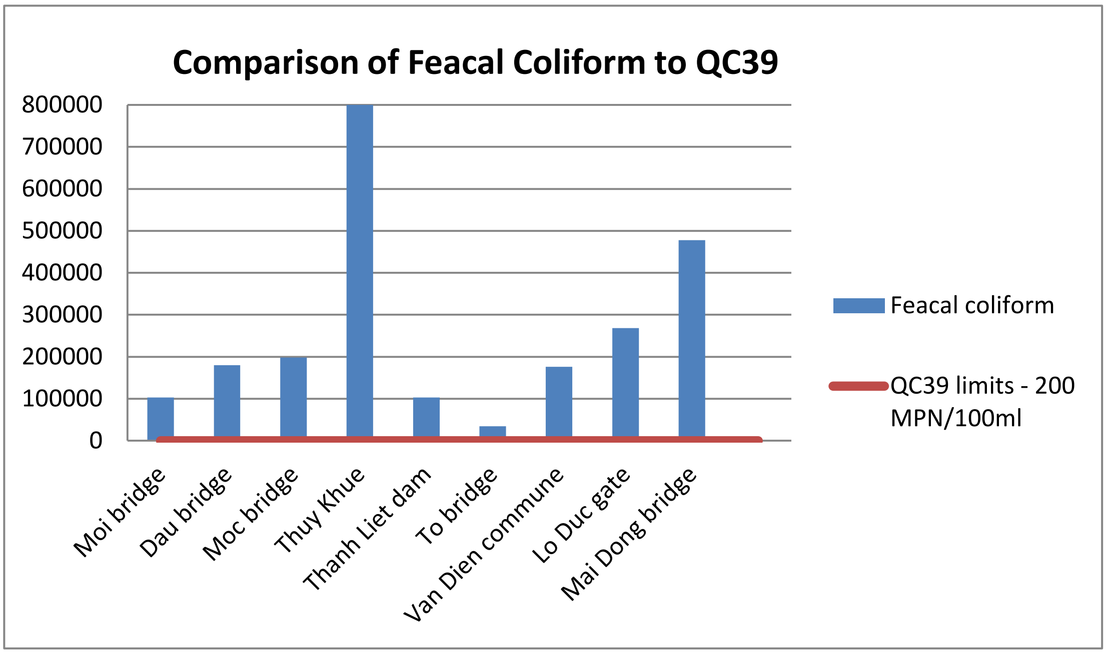

FIGURE 13: Comparison of Faecal Coliform to QC39

Most of the sampling locations have problems with compliance to QC39 in certain ways, except for Lu-Set floodway – Set River and Vi Gate – To Lich River because these sampling location lacks data for many parameters. Thirteen (13) of the locations have problems with two or more exceedances, with Lo Duc Gate – Kim Nguu River and Set Bridge – Set River each has five (5) exceedances out of eleven (11) parameters. Having due to such problems, only six (6) – 32% sampling locations spreading in all four rivers meet or slightly meet QC39 for irrigation water quality. Thus, it can be concluded that this river is unsuitable to be used for agricultural purposes and prior treatment must be provided if it is to be used in irrigation or aquaculture.

6.1.2 Comparison to QC08

QC08 is a more diverse national technical regulation on the overall water quality. It provides limitations for 32 different parameters in four water classification types – A1, A2, B1 and B2 (see Appendix 1). Water type A1 is best quality water, suited for urban water supply, water type A2 is for aquatic ecosystems, B1 is for irrigation and B2 is for water transportation, with lowest limitations on water quality.

In the database collection for this work, 23/32 parameters were recorded. The missing parameters were mainly pesticides of organochloride and organophosphate origins, herbicides and radioactive parameters. Some important missing parameters were Chloride, Nitrite and Phosphate. For 23 parameters that contain data, 77.8% of values were filled for all 19 sampling locations, with missing data in some locations for toxic ions, microbial pathogens, surfactant and oil and grease.

Comparison with QC39 above have shown the compliance with nine parameters including pH, DO, Pb, Cu, Zn, Cd, Cr, As and Hg. Limits for these parameters are similar in QC08 type B1 water quality for irrigation purposes. However, in term of DO, QC08 requires DO to be above 4 – a limitation that all nineteen (19) sampling locations failed to meet.

In all 23 parameters, 13 parameters show exceedances, 10 parameters are completely under compliance with QC08 type B1. The exceeded parameters are DO, TSS, COD, BOD_5, Total Coliform, *E.coli*, Pb, Cd, Ammonium (NH_4), As, Hg, Phenol and Total oil and grease. The compliances are pH, Iron (Fe), Cu, Zn, Nitrate (NO_3), Fluoride (F), Cyanide (CN), Cr^{3+}, Cr^{6+} and surfactant.

Total Suspended Solids (TSS), Chemical Oxygen Demand (COD) and BOD_5 are parameters that affect the biological self-cleansing ability of water. High TSS, COD and BOD_5 can both imply that the wastewater contain high organic matters ready for the consumption of aquatic organisms. TSS additionally affects the turbidity of wastewater, and can potentially block the sunlight that leads to the slowed down biological breakdown process.

Fig. 14 shows TSS, COD and BOD_5 and their limits as set out in QC08. Almost all data from these parameters exceed the limits, with only two exceptions from the parameter TSS. Most locations have TSS value exceeds 1-3 times the limits, COD value exceeds 2-6 times the limits and BOD_5 value exceeds 1,5 – 7 times the limits. These values prove that wastewater is heavily polluted in term of organic pollution. This could be a precious water reuse source for agriculture and aquaculture due to its high nutrient content.

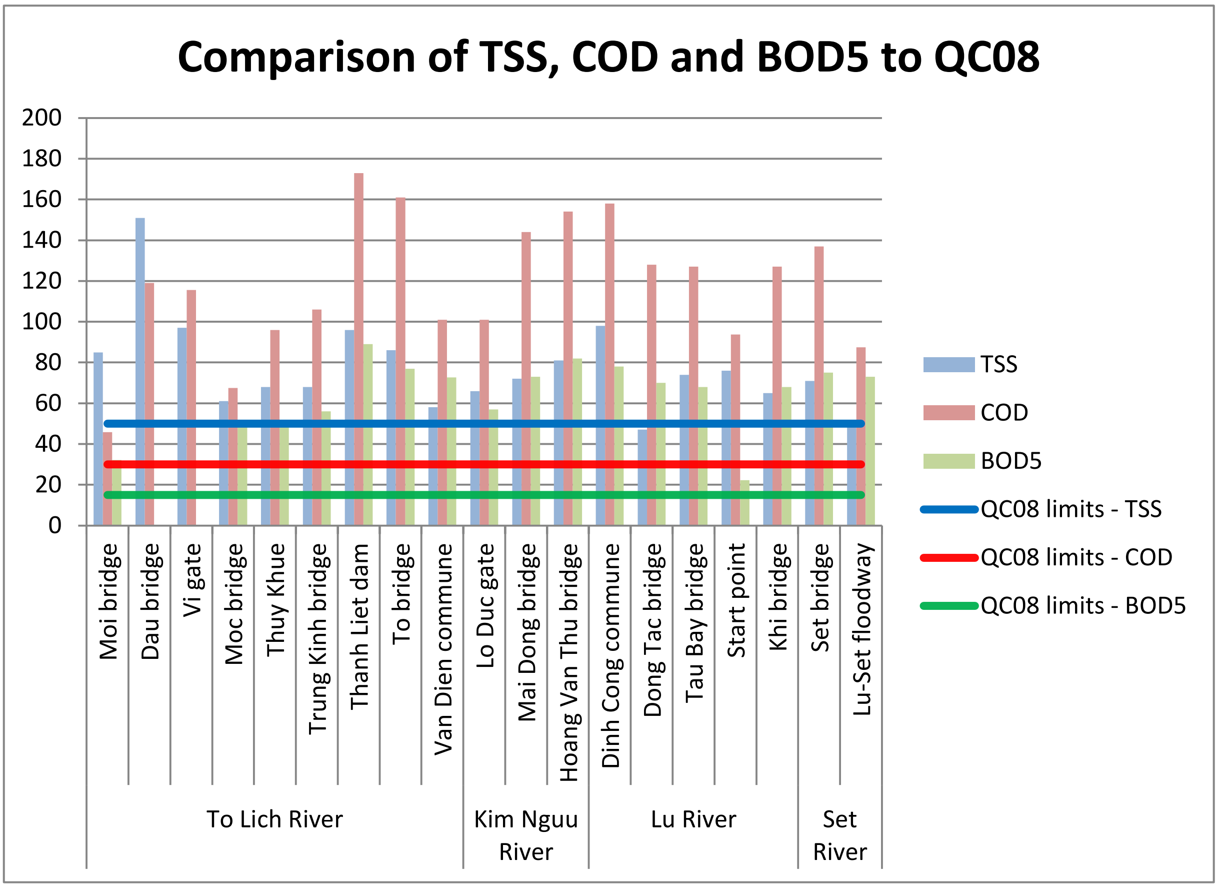

FIGURE 14: Comparison of TSS, COD and BOD_5 to QC08

Data for microbial activity – such as Total Coliform, Faecal Coliform and *E.coli* in wastewater were partly missing. There were quite complete data for Total Coliform but the method of measurement was Colony Forming Unit whereas the limits require Most Probable Number measurement method, therefore this data is not suitable for use. Fig. 15 combines data from all three parameters in proportion to each other (e.g. Total Coliform covers Faecal Coliform, and *E.coli* is a bacteria origin from faecal environment).

It could be seen from the figure that faecal coliform accounts for 80 – 90% of total coliform culture. *E.Coli* are found present in at least 10% of faecal coliform, which is a lot comparing to the 1% as set out in the regulation. Expectably, *E.coli* parameter exceeds the limit at least 290 times, in a total of six (6) monitored sampling locations. These parameters show a heavy pollution in term of microbial activity, and thus water from these sources should not be used without prior treatment in any way that can potentially be a pathway to human, including the reuse of wastewater for agriculture and aquaculture.

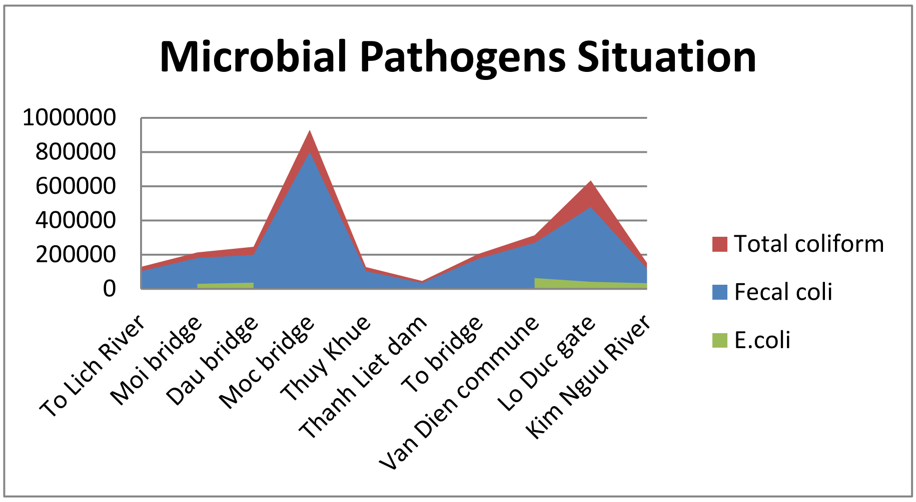

FIGURE 15: Microbial Pathogens Situation

The limitations set out for Fluoride, Cyanide and Surfactant are completely under compliance with all values remain stable and many times lower than the limits. On the other hand, Phenol and Total oil and grease appear to exceed the limits in many sampling locations. Phenol is a toxic substance used in the production of herbicides, detergents and pharmaceutical drugs. The limitation for Phenol parameter is 0.01 mg/l, the exceedances are generally 2 – 3 times larger than the limits. There are five locations with Phenol exceeding QC08, of 16 sampling locations (see Fig. 16). The remaining locations are found little or no quantity of Phenol at all.

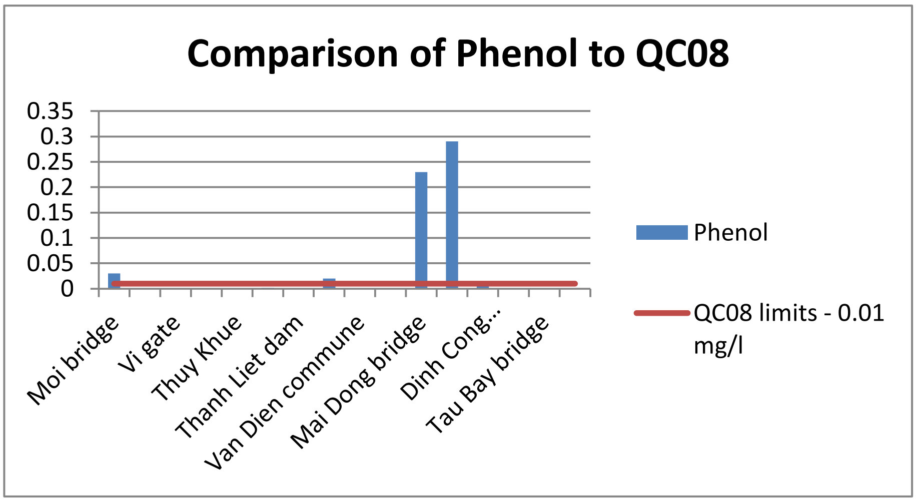

FIGURE 16: Comparison of Phenol to QC08

Comparison of total oil and grease to QC08 (Fig. 17) shows that all sampling locations with data available have total oil and grease quantity many times over the limits of 0.1 mg/l. On average, the excess quantity is 2 times over the limits. The presence of these non-soluble substances can cause major clogging and blockage of sewers. In aquatic environment, oil and grease can reduce aquatic organisms' ability to reproduce and survive. Some aromatic compounds are lethal to aquatic organisms at only 0.3 – 0.6 mg/l (Stenstrom et al. 1982).

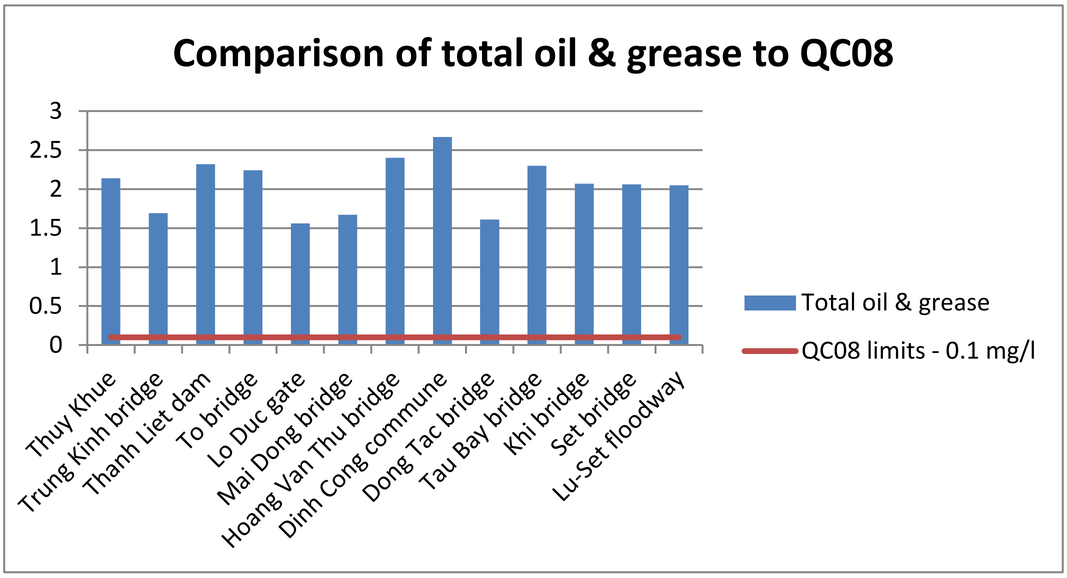

FIGURE 17: Comparison of total oil & grease to QC08

6.1.3 WQI Results

A WQI table for 19 sampling locations of four inner Hanoi rivers is generated and presented in Appendix 6. A small part of data was missing for BOD_5, NH_4^+-N, PO_4^{3+}-P and entire data for Turbidity. From the missing parameters, it is still possible to calculate the final WQI values following the method laid out in section 3.3.4. However, more missing parameters means an adjusted model has to be used, which leads to less accurate results in comparison to the original, completed calculation model.

To calculate DO_{sat} and $DO_{\%sat}$ serving the determination of WQI_{SI} for DO, an average temperature of 25°C have been assumed for all cases. Turbidity could not be assumed since the variation is too large, usually ranging from 50 to 400 NTU in other rivers with similar wastewater flow. In the case of Phosphate – Phosphorus (PO_4-P), only data for total Phosphorus (P) was available, so the average value for this parameter is assumed to be 1:10 of total Phosphorus in water as stated by FAO (Kutty 1987).

The results have found that, of all 19 sampling locations, only one (1) were classified as Bad – or type B2 in QC08, only suitable for water transportation, while the other eighteen (18) were Very Bad – heavily polluted not suitable for use in any purposes. Table 7 presents a clearer picture of all sampling locations. According to this WQI calculation model by Vietnam Environment Administration, all four rivers failed to meet the water quality to use for agriculture and aquaculture. Moreover, these rivers are considered dead and will need immediate actions if they are to be used for any purpose.

Table 7: WQI Results for 19 sampling locations

WQI INDEX SCALE	91-100 Excellent	76-90 Good	51-70 Medium	26-50 Bad	1-25 Very Bad

To Lich River								
Moi bridge	Dau bridge	Vi gate	Moc bridge	Thuy Khue	Trung Kinh bridge	Thanh Liet dam	To bridge	Van Dien commune
9.5	2.9	21.5	8.8	6.7	6.4	3.0	3.2	8.5

Kim Nguu River			Lu River				Set River		
Lo Duc gate	Mai Dong bridge	Hoang Van Thu bridge	Dinh Cong commune	Dong Tac bridge	Tau Bay bridge	Start point	Khi bridge	Set bridge	Lu-Set floodway
3.5	7.3	5.9	5.1	7.3	6.2	35.0	6.5	7.1	22.6

7 DISCUSSION

The process of gathering data has been time-consuming and challenging. A database of four inner Hanoi’s rivers were collected entirely from secondary sources due to the lack of time for monitoring, the lack of availability of laboratories for self-analysis, and the high service charges for laboratory analysis. This leads to high risk of accuracy and data synchronization, due to variables in time, season, sampling instance, location, sampling method, analysing method and human factors.

Nevertheless, this is an unavoidable task, because the official sources of data belong to monitoring centres of the authorities and are not open to the public. The proposal to get data for research is usually either time-consuming with complicated documentation or having to bribe the officer in charge of the database. The author has had problems accessing various governmental websites from a foreign country, while this is not an issue within Vietnam.

The Results section is divided into three smaller parts, including comparison to QC39, QC08 and WQI calculation. All three sections conclude that all four rivers are highly polluted in term of organic matters and microbial pathogens. Comparison to QC39 additionally shows that these wastewater contain exceed amount of some heavy metals (Cd, Cr, Zn, As), including extremely toxic Mercury (Hg). QC08 provides a more complete assessment of water quality with more parameters exceeding its limits such as Phenol, oil and grease.

What QC08 lack in term of irrigation water quality are parameters indicating total salinity and water infiltration rate. While QC39 tackles this issue, the database was not available at all for these parameters. On a more general scale, the WQI model is limited in term of its parameters calculated. From the parameters involved, it can only conclude whether the water is polluted organically and microbial pathogenically.

The results from this thesis share similar conclusion with various other researches. Lan-Huong et al. (2008) concludes heavy metal pollution of Pb, Cu, Zn, Cr, Cd and Ni on To Lich River and Kim Nguu River. Dao et al. (2010) and Hoan et al. (2015) shares the same conclusions for Cd, Cu, Pb, Zn, Mn, Fe and Cr^{6+}. All of these researches conclude heavy organic pollutions in inner rivers of Hanoi. Lan-Huong et al. (2014) did a research on irrigation potential on Nhue River – the receiver of a part of untreated wastewater from the inner Hanoi's rivers, also confirms heavy metal pollution, though organic pollution was not mentioned in the study.

Trinh (2012) from Institute for Environmental Science and Development (VESDEC) summarizes the state of inner Hanoi's rivers as significantly polluted due to excess nutrient, organic matters, surfactant, oil and grease, microbial pathogens, toxic substances (phenol, cyanide), toxic ions (chloride, fluoride, heavy metals) and pesticides. In his report, two specifics WQI models based on arithmetic and geometric means are used to calculate water quality index. Both methods result in water quality from Bad to Very Bad (see Table 2) in all four rivers.

8 PROPOSAL FOR ALTERNATIVE METHOD

A suitable alternative method must satisfy the following criteria: (1) it is efficient in wastewater treatment and (2) it is economically applicable for individual or small group of farmers to install. Efficiency of wastewater treatment results in the treatments of organic matters, surfactant, oil and grease, microbial pathogens, toxic substances and micropollutants such as pesticides. Of all the many wastewater treatment technologies available, the most economical methods are those involving biological oxidation processes instead of chemical treatment methods.

Having identified the main causes for water pollution in inner Hanoi's rivers being organic, microbial pathogenic and heavy metal pollutions, the application of a reed bed system can potentially be effective. This system can be installed as a method for prior treatment of wastewater before reusing for common agricultural and aquacultural practices. The specific design is mentioned in the following sections.

8.1 Constructed wetland and reed bed

Reed bed is a natural occurrence found in waterlogged areas. It mainly consists of species of reeds colonizing an area of wetland. This is a natural habitat for several species of birds, invertebrates and fishes where they seek food and shelter. Such occurrence can act as a natural wastewater treatment due to its potential to transform and absorb excess essential elements and macronutrients found in wastewater.

Mimicking this natural process, a reed bed system (or more generally constructed wetland) is an artificial system created for the purpose of water treatment from different sources including domestic, industrial, hospital and agricultural wastewater discharges. Constructed wetland (CW) in theory can be a bed for any macrophytes growing on soil, sand or gravel, but reeds are more commonly used in practice. It is effective in BOD, solids and nutrient removal in wastewater. However, a CW model can be potentially useful to serve different wastewater characteristics if an effective design of factors such as hydrology, soil, microorganisms and plant species is considered.

A CW model can be designed and built from scratch – artificially, or modified from an existing natural wetland area. Any river system has floodplains alongside its riverbanks. These are natural wetland areas and thus can be modified to improve the treatment ability, as well as to direct a part of the treated wastewater for human's purposes. This is a good practice especially for peri-urban farmers in Hanoi who relies majorly on the river water source for farming and raising fishes.

It can be a sole wastewater treatment model for some cases, but according to WHO (2006, 87) CW is usually in the secondary or tertiary stage. Fig. 17 (Ebie et al. 2013) shows the common pathways for wastewater discharge into the environment. In Hanoi situation, wastewater follows both Collected and Uncollected categories as it is released directly into the inner city's rivers, which leads either to a centralized wastewater treatment plant or to a river untreated. The part treated is discharged into the Red River, while the untreated is discharged into Nhue River.

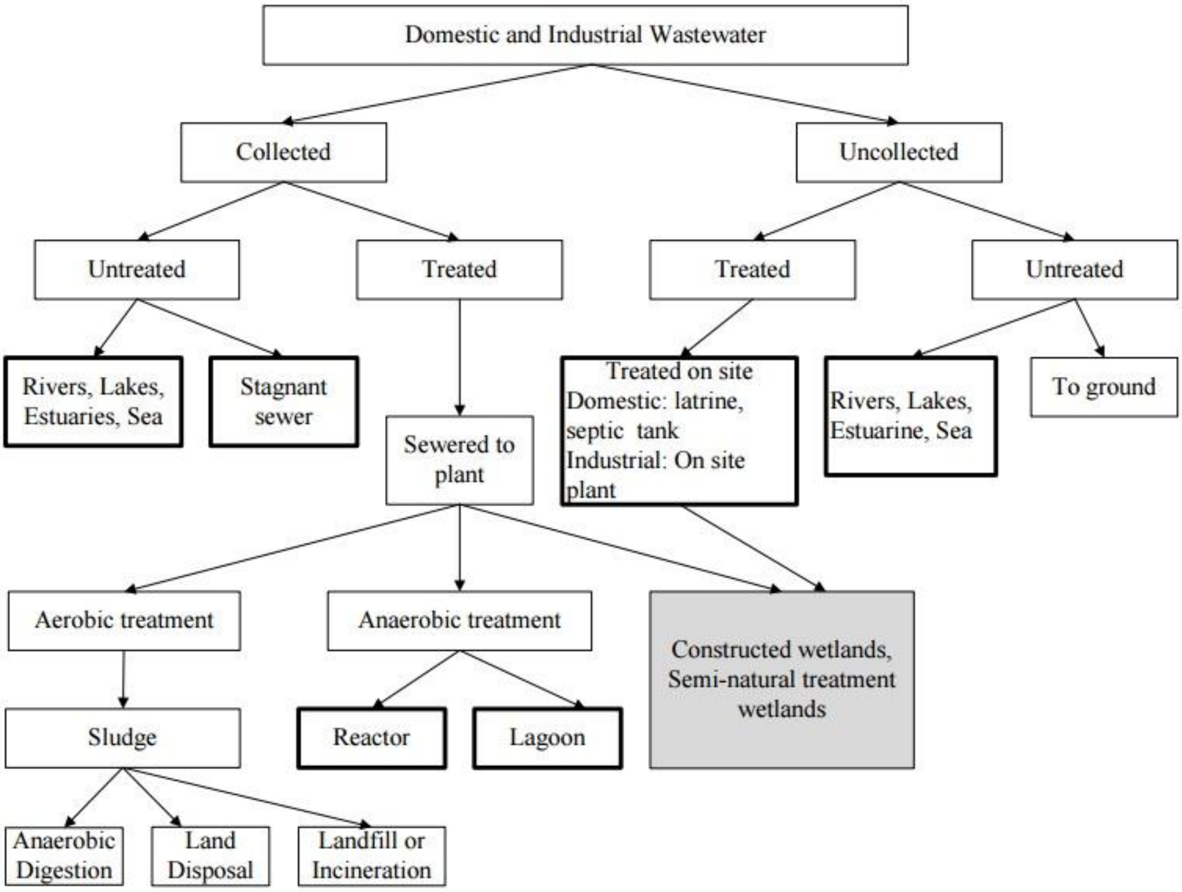

FIGURE 17: Wastewater treatment systems and discharge pathways (IPCC 2013)

Before reaching these large rivers, the water is too polluted and is considered untreated, but when mixed with large rivers, the wastewater is considered treated wastewater even for the part not receiving centralized treatment. In peri-urban areas, the wastewater has mixed well with rainwater and natural river water, so it is considered treated wastewater despite the very low pollutant removal capacity. In which cases, CW can either be primary or secondary or even tertiary treatment method.

A CW system can be classified through three criteria: hydrology, macrophyte growth form and flow path (Ebie et al. 2013). Hydrology is the criteria to assess whether the wastewater is flowing in the surface or in the sub-surface. Macrophyte growth forms are emergent

(*Phrangmites karka*), submerged (some species of pondweeds), free-floating (*Lemna Perpusilla*, *Spirodela Polyrrhiza*, *Wolffia Columbiana*) and floating leaved plants (*Nymphaeaceae*). Flow path is either horizontally or vertically.

Vertical flow CW is effective at removal of organics and total solids with nitrified effluents as a result, while a horizontal flow CW can remove organics, total solids and further causing denitrification to release the mineral to the atmosphere (Ebie et al. 2013). A reed bed system can consist of one or more criteria, such as both horizontal flow and vertical flow in order to boost treatment efficiency of desired parameters. For the purpose of reusing wastewater for agriculture, higher nutrient content is desirable and thus vertical flow beds (VFBs) are more suitable.

8.2 Vertical flow bed (VFB) design

A VFB design model has been chosen from its successful establishment and functionality in Nepal (ENPHO 2008). The VFB have been proved to be very efficient at removing BOD_5, and the Reed Bed Treatment System by Shreshtha (1999) have shown to be able to remove almost completely TSS, BOD_5, COD and NH_4. In a specific case, ENPHO (2008) notices 99.9% removal of total coliforms. The removal of surfactant, oil and grease can be done through labour-work with observable result. There was no information on metal removal efficiency. For micropollutants such as pesticides, biological methods are not efficient while possible treatment technologies are still costly (Leal 2010, 58). Economically, Shreshtha (ENPHO 2008) notes that the construction of a $6m^2$ VFB system costs USD500 with treatment capacity of $0.5m^3/d$. Overall this design is both efficient in treatment capability and economically viable that peri-urban farmers could use to partially reduce hazards associated with using contaminated wastewater for agriculture and aquaculture.

8.2.1 Design

The design of vertical flow bed system is proposed by Shreshtha (1999) as part of a decentralized wastewater treatment system called the Reed Bed Treatment System. The system itself consists of additionally a horizontal flow bed (HFB) but due to the highly nitrified effluent, VFB is the sole design proposed for the case of Hanoi.

At first, the wastewater is directed into a settlement pond for sedimentation and separation of surfactant, oil and grease. During this stage, water is stagnated inside the pond for a period of time, then surfactant, oil and grease are physically skimmed away by the farmers. Afterward the separated water layer is pumped to the vertical flow treatment bed. A visualization of VFB model is presented in Fig. 18.

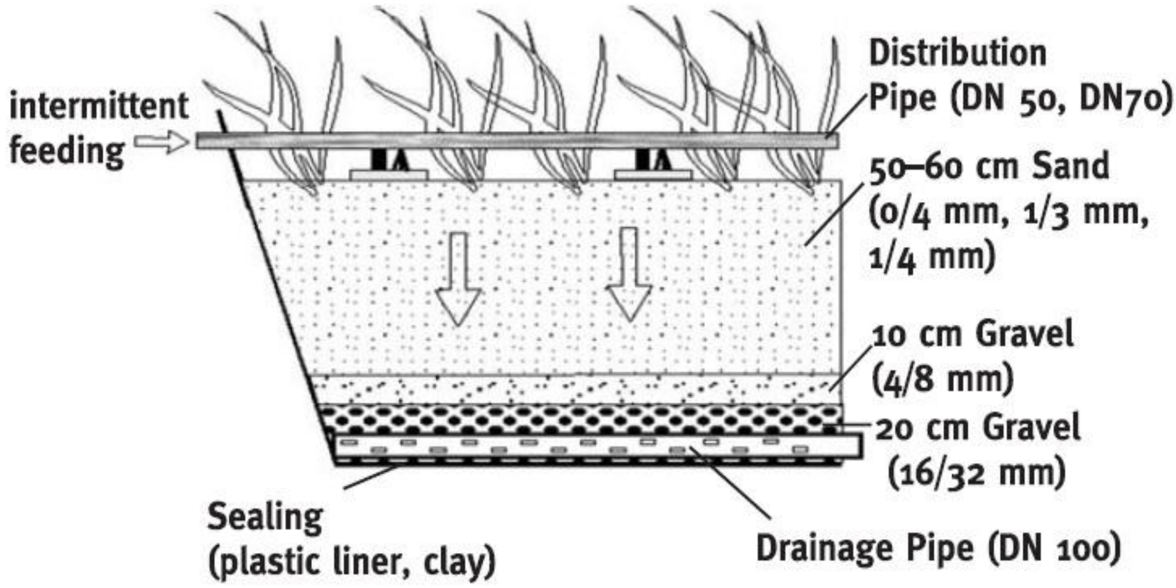

FIGURE 18: Vertical flow constructed wetland bed (Shreshtha 1999)

The construction of this VFB bed consists of several layers inside a 1-meter deep hole below soil level, with the bottommost layer made of plastic liner or high clay soil acts as a sealing layer from water infiltration. A drainage pipe with diameter nominal (DN) 100 is fixed in for the outlet water. Afterward a 20 cm layer of coarse gravels is spread on top for quickest drainage at the bottom of the design. Then a 10 cm layer of finer gravels and 50-60 cm layer of sand are respectively filled into the bed.

Macrophytes such as reeds (i.e. *Phrangmites karka*) are planted at intervals in the sand layer. It is spread evenly so that all wastewater receive similar treatment. An intermittent feeding system of distribution pipes (DN50, DN70) is installed few centimetres above sand layer. This system is for spreading wastewater thoroughly on the surface of the sand layer for percolation through gravitational pressure and adsorption.

8.2.2 Removal of wastewater constituents

Especially designed due to the known efficiency at removing suspended solids and soluble organics, a VFB is further capable of removing a variety of wastewater constituents as laid out in Table 8. Nutrients, metals and pathogens are all removable constituents through VFB.

Table 8: Removal mechanisms for some wastewater constituents (Cooper et al. 1996)

Wastewater constituents	Removal mechanism
Suspended solids	Sedimentation / Filtration
Soluble organics	Aerobic microbial degradation / Anaerobic microbial degradation
Phosphorus	Matrix sorption / Plant uptake
Nitrogen	Ammonification followed by microbial nitrification / Denitrification / Plant uptake / Matrix adsorption / Ammonia volatilisation
Metals	Adsorption and cation exchange / Complexation / Precipitation / Plant uptake / Microbial oxidation/reduction
Pathogens	Sedimentation / Filtration / Natural die-off Predation / UV irradiation Excretion of antibiotics from roots of macrophytes
Surfactant, oil and grease	Separation / Skim removal

Suspended solids

In suspended solids removal, the wastewater distributing to the VFB must be settled in a sedimentation tank for partial removal of sediments. Then filtration occurs when the water is released and percolates through the several layers of fine sand to coarse gravels.

Soluble organics

Soluble organic matters are degraded through aerobic microbial degradation process. As the effluents are drained thoroughly, oxygen from the air can refill the bed and thus the main degradation process is through aerobic degradation. For HFB the degradation process consists of anaerobic, anoxic and aerobic processes similar to the processes in conventional centralized wastewater treatment plants.

Phosphorus and Nitrogen

These macronutrients are similar in that both can be removed via sorption, and contribute a large portion to plant's food. Nitrogen can be removed via further mechanisms. Part of it goes through the ammonification process by nitrogen-fixing bacteria in the soil, then a portion volatiles while the remaining goes through nitrification. At this stage, the effluents of VFB come out as highly nitrified. This effluent is a good source of fertilizer for plants and aquatic animals and thus the process ends here. If the objective is to complete the removal circle of Nitrogen from wastewater then denitrification may occur in a HFB, which will transform Nitrate to atmospheric Nitrogen.

Metals

Some metals are micronutrients for plants and thus they will be removed as part of the plant's uptake. Some are binds into the particles through adsorption, some exchanges cation with other minerals and some undergoes microbial oxidation. In the end of the process, a part of metals is removed from the wastewater.

Pathogens

In wastewater pathogens attach to solids, therefore the removal of solids means the removal of pathogens. Sedimentation and filtration are effective at removing pathogens since they are effective at removing suspended solids. Furthermore, pathogens are naturally killed through sunlight (UV-ray), predation, antibiotic from rhizosphere of macrophytes and from altered living condition.

9 CONCLUSION

The outdated centralized wastewater treatment situation in Hanoi is insufficient to support the large population, resulting in exploitation of natural inner city's rivers as drainage and sewerage channels. This bad practice has caused heavy pollution in these rivers, posing great health risk and environmental pollution for Hanoians.

Oblivious to that context, peri-urban farmers are still using the contaminated water from these primary rivers (To Lich River, Kim Nguu River, Lu River and Set River) as well as secondary rivers that indirectly receiving the wastewater (Nhue River, Red River) as sources for irrigation and fish raising. This thesis shares similar conclusion to various other researches that all four inner Hanoi's rivers are heavily polluted in term of organic matters, microbial pathogens, heavy metal pollutions and other severe consequences. None of the four rivers was qualified for use of any purposes through WQI calculation. Both National Technical Regulations QC08 (2008) and QC39 (2011) have found exceedances in several parameters such as DO, BOD_5, COD, Coliform, Heavy metals and more.

Peri-urban farmers are forced to use the wastewater as a source of irrigation and fish raising, surprisingly because of their need for food, shelter and financial security. Having acknowledged of such bottleneck, the thesis proposes a method for biological treatment of wastewater before reused in agriculture and aquaculture. This treatment method opens up the potential to reuse wastewater more sustainably to constitute for the lack of clean water supply, especially for agriculture and aquaculture practices in Hanoi.

This paper highlights the potential of reed bed system, particularly vertical flow bed (VBF) as a viable, efficient and economic method for peri-urban farmers to partially treat wastewater before reuse in agriculture and aquaculture. The design has been successfully used in Nepal with almost 100% treatment efficiency for BOD_5, COD, NH_4 and in a specific case, pathogens. Treatment possibility of heavy metals is also noted. It is also reasonably cheap to construct – about USD500 for a $6m^2$ VFB system with treatment capacity of $0.5m^3/d$. The area required is small and thus boosting the economic viability of the design as paying for land ownership is usually expensive in Hanoi.

Decentralized wastewater treatment has been seen from this thesis's perspective as a potential alternative for people living outside of SADCO's service (see section 4.2). As the authorities of Hanoi is having ambitious plan on accomplishing four times the current level of daily wastewater discharge of the city by 2030, decentralized wastewater treatment such as VBF could be a part of the solution for peri-urban farmers in the wait until the project is completed.

9.1 Further work

The proposal for using VFB as an alternative method for decentralized wastewater treatment for peri-urban Hanoians could be seen as the base design due to its efficiency in solving many of the pollution problems in wastewater while remaining reasonably cheap. However, there are some limitations to this design as certain pollutants are yet completely treated, including surfactant, oil and grease, heavy metals and micropollutants. These limitations open up research opportunities in the development of the method, or in the proposal for the authorities to enhance the implementation and practices of certain industrial and crafting village activities so as to reduce pollutants that are persistent and toxic in the environment.

Prior- or later treatment stages that further enhance the design could be included in further works. More efficient method in removal of surfactant, oil and grease instead of physically removal by hand-skimming should be considered. Studies on heavy metals removal efficiency of this design, or specifically heavy metal removal through the ability of different plants to accumulate heavy metals within its tissues are very important in the development of biological wastewater treatment technology. Studies with regard to treatment of micropollutants using inexpensive technology could be significantly useful especially for countries with underdeveloped wastewater treatment system such as Vietnam.

The application of reed bed system as a tertiary wastewater treatment process can further boost the efficiency of current wastewater treatment system as the wastewater is discharged to large rivers upon having been treated. This system does not only enhance the treatment capacity, but also is a good environmental practice in term of creating habitat for wildlife, reducing artificial treatment costs while also remain effectively for a long time due to being naturally maintained. If certain barriers in the treatment capacity of some parameters such as heavy metals, micropollutants, oil and grease are improved, then reed bed system can become a multifunctional and sustainable tool for environmental and economic development.

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Appendix 1 - National technical regulation on surface water quality (QCVN 08:2008/BTNMT)

No	Parameter	Unit	Limit value			
			A		B	
			A1	A2	B1	B2
1	pH		6-8,5	6-8,5	5,5-9	5,5-9
2	DO	mg/l	≥ 6	≥ 5	≥ 4	≥ 2
3	TSS	mg/l	20	30	50	100
4	COD	mg/l	10	15	30	50
5	BOD5	mg/l	4	6	15	25
6	NH4+	mg/l	0,1	0,2	0,5	1
7	Cl-	mg/l	250	400	600	-
8	F-	mg/l	1	1,5	1,5	2
9	NO2-	mg/l	0,01	0,02	0,04	0,05
10	NO3-	mg/l	2	5	10	15
11	PO43-	mg/l	0,1	0,2	0,3	0,5
12	CN	mg/l	0,005	0,01	0,02	0,02
13	As	mg/l	0,01	0,02	0,05	0,1
14	Cd	mg/l	0,005	0,005	0,01	0,01
15	Pb	mg/l	0,02	0,02	0,05	0,05
16	Cr3+	mg/l	0,05	0,1	0,5	1,0
17	Cr6+	mg/l	0,01	0,02	0,04	0,05
18	Cu	mg/l	0,1	0,2	0,5	1,0
19	Zn	mg/l	0,5	1,0	1,5	2,0
20	Ni	mg/l	0,1	0,1	0,1	0,1
21	Fe	mg/l	0,5	1,0	1,5	2,0
22	Hg	mg/l	0,001	0,001	0,001	0,002
23	Surfactant	mg/l	0,1	0,2	0,4	0,5
24	Total oils & grease	mg/l	0,01	0,02	0,1	0,3
25	Phenol	mg/l	0,005	0,005	0,01	0,02
26	Organochlorine pesticides					
	Aldrin + Dieldrin	µg/l	0,002	0,004	0,008	0,01
	Endrin	µg/l	0,01	0,012	0,014	0,02
	BHC	µg/l	0,05	0,1	0,13	0,015
	DDT	µg/l	0,001	0,002	0,004	0,005
	Endosunfan (Thiodan)	µg/l	0,005	0,01	0,01	0,02
	Lindan	µg/l	0,3	0,35	0,38	0,4
	Chlordane	µg/l	0,01	0,02	0,02	0,03
	Heptachlor	µg/l	0,01	0,02	0,02	0,05
27	Organophosphate pesticides					
	Paration	µg/l	0,1	0,2	0,4	0,5
	Malation	µg/l	0,1	0,32	0,32	0,4
28	Herbicides					
	2,4D	µg/l	100	200	450	500

	2,4,5T	µg/l	80	100	160	200
	Paraquat	µg/l	900	1200	1800	2000
29	Radioactivity of alpha radiation	Bq/l	0,1	0,1	0,1	0,1
30	Radioactivity of alpha radiation	Bq/l	1,0	1,0	1,0	1,0
31	E. Coli	MPN/100ml	20	50	100	200
32	Coliform	MPN/100ml	2500	5000	7500	10000

A1 – Good for urban water supply; and other purposes in A2, B1, B2

A2 – Qualified for urban water supply only if receive appropriate treatment; suitable for aquatic ecosystem; and other purposes in B1, B2

B1 – Suitable for irrigation and similar water-use purposes; purposes in B2

B2 – Suitable for water transportation and other purposes with low quality water expectation

Appendix 2 - National technical regulation on Water Quality for irrigated agriculture (QCVN 39:2011/BTNMT)

No	Parameter	Unit	Limit value
1	pH		5,5-9
2	DO		≥ 2
3	TDS	mg/l	2000
4	SAR	mg/l	9
5	Cl-	mg/l	350
6	SO42-	mg/l	600
7	Boron (B)	mg/l	3,0
8	Arsenic (As)	mg/l	0,05
9	Cadmium (Cd)	mg/l	0,01
10	Total Chromium (Cr)	mg/l	0,1
11	Mercury (Hg)	mg/l	0,001
12	Copper (cu)	mg/l	0,5
13	Lead (Pb)	mg/l	0,05
14	Zinc (Zn)	mg/l	2
15	Fecal. Coliform	MPN/100ml	200

Appendix 3 - Compiled data from FAO Irrigation Water Quality Guidelines and other sources (San Antonio Testing Laboratory 2013)

IRRIGATION WATER QUALITY GUIDELINES

Guidelines from Water Quality in Irrigation F.A.O. and other sources

PARAMETER:		Unit of Measurement		Problems Unlikely	Increasing Problems	Severe Problems
Electrical Conductivity	(salinity)	mmhos/cm		<0.75	0.75 - 3.0	>3.0
Sodium Absorption Ratio	(SAR)			<3.0	3.0 - 9.0	>9.0
Chloride	(Cl)	ppm		<70	70 - 300	>300
Boron	(B)	ppm		<0.75	0.75 - 2.0	>2.0
Bicarbonate	(HCO_3)	ppm		<120	120 - 180	>180
Sodium	(Na)	ppm		<70	70 - 180	>180
Calcium	(Ca)	ppm		<100	100 - 200	>200
Magnesium	(Mg)	ppm		<30	30 - 60	>60
pH		NORMAL RANGE: 6.5 - 8.4				

PLANT NUTRIENT AVAILABILITY

PARAMETER:		Unit of Measurement	Low	Normal	High	Very High
Calcium	(Ca)	ppm	<20	20 - 60	60 - 80	>80
Magnesium	(Mg)	ppm	<10	10 - 25	25 - 35	>35
Potassium	(K)	ppm	<5	5 - 20	20 - 30	>30
Phosphorus	(P)	ppm	<0.1	0.1 - 0.4	0.5 - 0.8	>0.8
Nitrogen	(N)	ppm	<1	1 - 10	10 - 20	>20
Nitrate	(NO_3)	ppm	<5	5 - 50	50 - 100	>100
Sulfate	(SO_4)	ppm	<30	30 - 90	90 - 180	>180
Sulfur	(S)	ppm	<10	10 - 30	30 - 60	>60

< = less than > = greater than

ppm = parts per million

ppm x 0.23 = pounds/acre Inch

1 acre foot = 325,000 gallons

450 gallons/min. = 1 acre-inch/hour

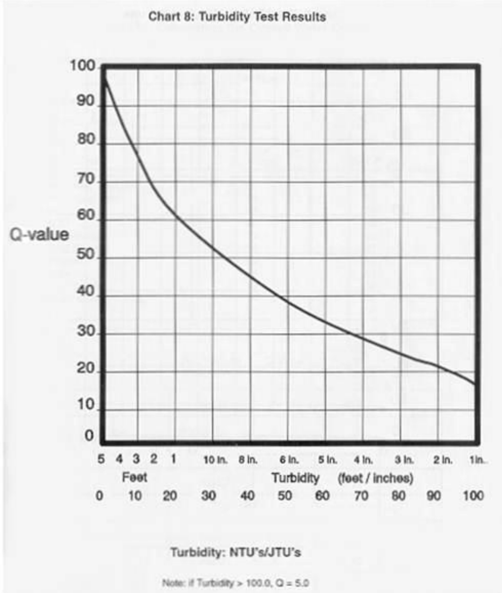
1 gallon of water weighs 8.345 pounds

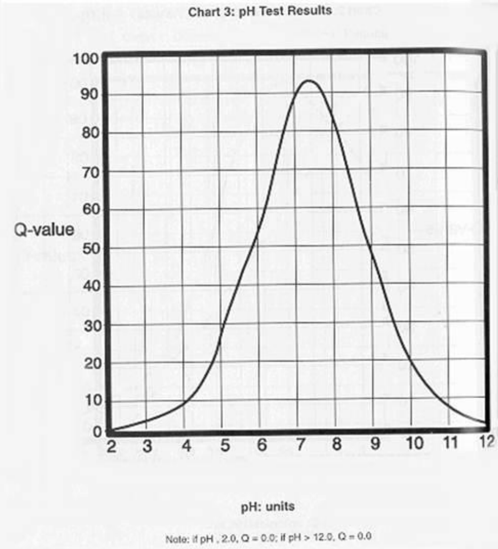
1 cu/ft. of water weighs 62.43 pounds

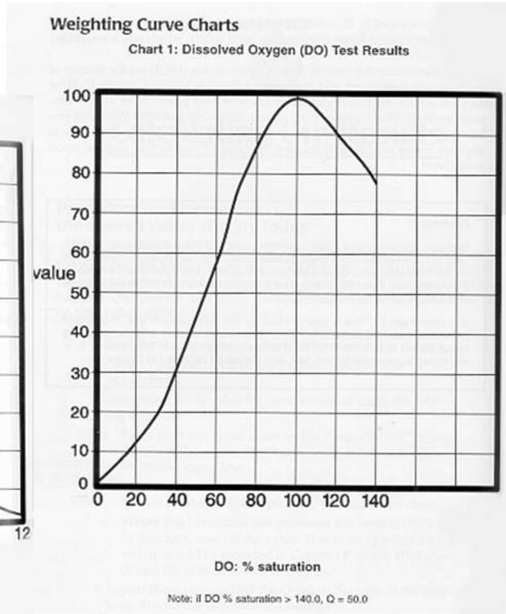
Appendix 4 – Recommended Maximum Concentrations of Trace Elements in Irrigation Water (Ayers et al. 1985)

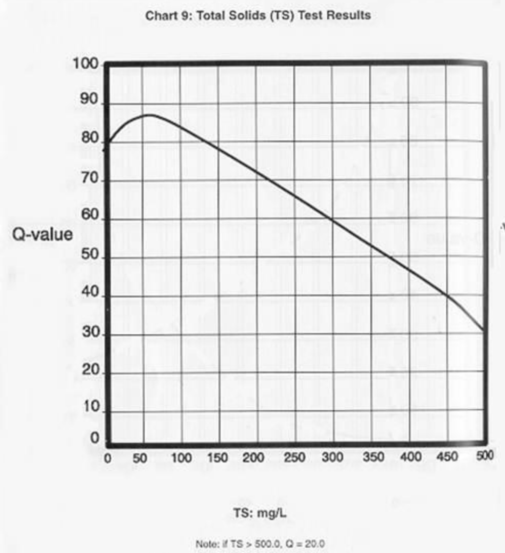
Element	Recommended Maximum Con-centration (mg/l)	Remarks
Al(aluminium)	5	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity.
As (arsenic)	0.1	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Be (beryllium)	0.1	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Cd (cadmium)	0.01	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Co (cobalt)	0.05	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Cr (chromium)	0.1	Not generally recognized as an essential growth element. Con-servative limits recommended due to lack of knowledge on its toxicity to plants.
Cu (copper)	0.2	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
F (fluoride)	1	Inactivated by neutral and alkaline soils.
Fe (iron)	5	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Li (lithium)	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg/l). Acts similarly to boron.
Mn (manganese)	0.2	Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils.
Mo (molybdenum)	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Ni (nickel)	0.2	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Pb (lead)	5	Can inhibit plant cell growth at very high concentrations.
Se (selenium)	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. An essential element to animals but in very low concentrations.
Sn (tin)		
Ti (titanium)	----	Effectively excluded by plants; specific tolerance unknown.
W (tungsten)		
V (vanadium)	0.1	Toxic to many plants at relatively low concentrations.
Zn (zinc)	2	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.

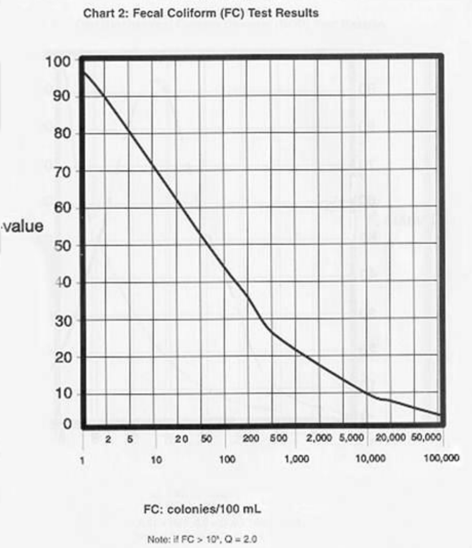
Appendix 5 – Q-value charts for several parameters (Oram 2014)

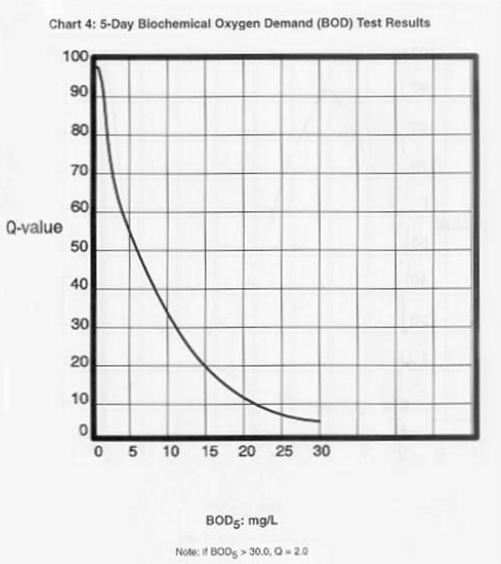


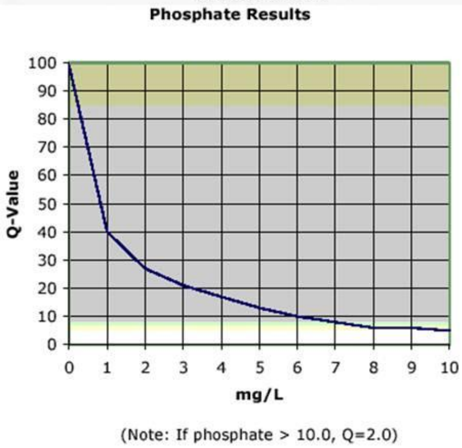


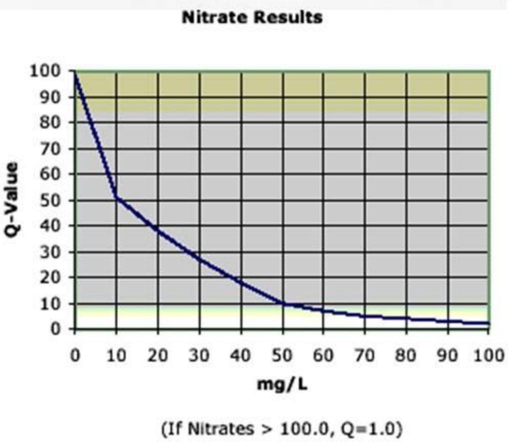


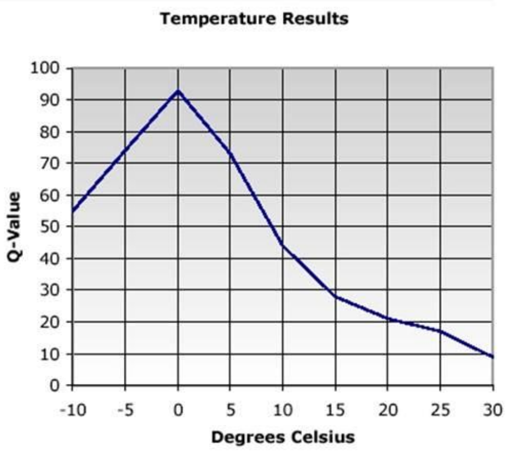












Appendix 6 – WQI Table generated from author's database (Author 2016)

Parameters	Unit	To Lich River									Kim Nguu River			Lu River					Set River	
		Moi bridge	Dau bridge	Vi gate	Moc bridge	Thuy Khue	Trung Kinh bridge	Thanh Liet dam	To bridge	Van Dien com-mune	Lo Duc gate	Mai Dong bridge	Hoang Van Thu bridge	Dinh Cong com-mune	Dong Tac bridge	Tau Bay bridge	Start point	Khi bridge	Set bridge	Lu-Set flood-way
pH	Sub WQI Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
DO		31.8	27.3	33.8	35.9	26.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	33.8	1.0	1.0	37.9
TSS		32.5	1.0	26.5	44.5	41.0	41.0	27.0	32.0	46.0	42.0	39.0	34.5	26.0	53.8	38.0	37.0	42.5	39.5	50.0
COD		30.3	1.0	1.0	11.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BOD5		18.1			1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	31.9	1.0	1.0	1.0
NH4+		11.0			14.2	1.0	1.0	1.0	1.0	18.3	1.0	1.0	1.0	1.0	1.0	1.0	65.8	1.0	1.0	1.0
Coli-form		1.0	1.0		1.0	1.0		1.0	1.0	1.0	1.0	1.0							1.0	
Tur-bidity																				
PO4-P		42.5	41.3							46.3		45.0		40.0					41.3	
WQI		9.5	2.9	21.5	8.8	6.7	6.4	3.0	3.2	8.5	3.5	7.3	5.9	5.1	7.3	6.2	35.0	6.5	7.1	22.6

t	25	**DO sat**	8.2	**WQI INDEX SCALE**	**91-100 Excellent**	**76-90 Good**	**51-70 Medium**	**26-50 Bad**	**1-25 Very Bad**