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Landscape Changes and Loss of Ecosystem Services of Houay Mak Hiao River: a Study in a Rapidly Developing City (Vientiane, Laos)

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Sammanfattning
Arbetet genomfördes i Vientiane, Laos där våtmarker, kanaler och åar är av stor betydelse för stadens vattenkvalitet. I dagens Vientiane pågår stora landskapsförändringar som igenfyllning av våtmarker och kanalisering av rinnande vatten vilket påverkar vattenkvaliteten i staden och har gjort vattnet extremt förorenat. I princip allt dräneringsvatten från staden rinner ut i ån Houay Mak Hiao. Av den anledningen har den här undersökningen fokuserat på åns historiska och nutida tillstånd.

Syftet med det här arbetet är att ta reda på hur Houay Mak Hiaos tillstånd har förändrats över tid och att förklara hur historiska och nutida landskapsförändringar har påverkat ån. Gruppintervjuer genomfördes i sju byar längs med ån för att ta reda på hur åns tillstånd har förändrats över tid. Grupperna bestod av tre till sex personer i varje by och för att få så relevanta svar som möjligt deltog fiskare, bönder, byns äldste och ”head of village” i intervjuerna. För att undersöka dagens vattenkvalitet analyserades vattenkvalitetsprover från nio olika ställen längs med ån.

Resultatet visar att åns tillstånd började bli markant sämre för ungefär tio år sedan och har sedan dess bara blivit sämre och sämre. Vattnet i ån är numera extremt förorenat vilket har påverkat fiskpopulationen och vegetationen på ett mycket negativt sätt. Denna försämring kan till stor del förklaras av de kanaliseringar och våtmarksförminskningar som skett i Vientiane. Graden av förorening minskar närmare åns utflöde i Mekong vilket kan bero på flytväxters förmåga att ta upp föroreningar i kombination med utspädningseffekten i vattnet.

Abstract

This project was conducted in Vientiane, Laos where wetlands, channels and rivers play an important role for the water quality maintenance. Now, large landscape changes like backfilling of wetlands and channelization is affecting the condition of the urban waters which has become extremely polluted. For that reason this survey has focused on the past and present status of Houay Mak Hiao River, who receives basically all drainage water from the city.

The purpose of this project is to find out how the condition of Houay Mak Hiao River has changed over time and to describe how historical and current landscape changes have affected the river. Group interviews were conducted in seven villages along the river to find out about the past and present status. The groups consisted of 3-6 respondents in each village. To get as relevant answers as possible, elders, fishermen, farmers and the head of village in each village were participating in the interviews. Water samples were collected at nine sampling sites to determine the water quality of today.

The results show that the condition of the river started to significantly decrease about ten years ago and has since then become worse and worse. Today, the water is extremely polluted which has affected the fish population and the vegetation along the river in a very negative way. The deterioration can be connected to channelization and wetland area loss in Vientiane. The level of contamination decreases closer to the outflow into Mekong River which can be due to uptake by floating plants and dilution effects.

ບົດຂັດຫຍໍ້

ໂຄງການນີ້ໄດ້ດໍາເນີນການໃນນະຄອນຫລວງວຽງຈັນ, ສປປລາວ ຊຶ່ງເປັນພື້ນທີ່ ທີ່ມີດິນບໍລິເວນນ້ຳ, ຮ່ອງລະບາຍນ້ຳ ແລະ ແມ່ນ້ຳທີ່ມີ ຄວາມສໍາຄັນສໍາລັບການບໍາລຸງຮັກສາຄຸນນະພາບນ້ຳ. ໃນປັດຈຸບັນ, ການປ່ຽນແປງສະພາບຂະຫນາດໃຫຍ່ ເຊັ່ນ: ການຖົມດິນເຂດດິນບໍລິເວນນ້ຳ ແລະຮ່ອງລະບາຍ ຊຶ່ງມີຜົນກະທົບຕໍ່ສະພາບຂອງການລະບາຍນ້ຳໃນເຂດຕົວເມືອງ ຊຶ່ງໄດ້ກາຍເປັນມົນລະພິດໃນທີ່ສຸດໄດ້. ສໍາລັບເຫດຜົນການສໍາຫຼວດນີ້ໄດ້ສຸມໃສ່ການສຶກສາສະຖານະພາບໃນອະດີດ ແລະປະຈຸບັນຂອງຫ້ວຍຫມາກຮຽວ, ຜູ້ທີ່ໄດ້ຮັບຜົນກະທົບຂັ້ນພື້ນຖານຈາກ ການລະບາຍຈາກຕົວເມືອງທັງໝົດ.

ຈຸດປະສົງຂອງໂຄງການນີ້ແມ່ນເພື່ອຊອກຮູ້ສະພາບຂອງຫ້ວຍຫມາກຮຽວ ໄດ້ມີການປ່ຽນແປງໃນແຕ່ລະໄລຍະ ແລະ ຄວາມເປັນມາ ແລະການປ່ຽນແປງພູມສັນຖານໃນ ປະຈຸບັນທີ່ກະທົບຕໍ່ສາຍຫ້ວຍໝາກຮຽວ. ການສໍາພາດກຸ່ມໄດ້ດໍາເນີນໃນເຈັດບ້ານທີ່ອາໃສຕາມແຄມຫ້ວຍໝາກຮຽວ ເພື່ອຊອກຫາຂໍ້ມູນກ່ຽວກັບສະຖານະພາບໃນອະດີດແລະປະຈຸບັນ. ແຕ່ລະ ກຸ່ມ(ບ້ານ)ທີ່ໄດ້ສຳພາດມີຈຳນວນ 3-6 ຄົນ. ເພື່ອໃຫ້ໄດ້ຂໍ້ມູນທີ່ທີ່ ກ່ຽວຂ້ອງ ໃນການສຳພາດຄັ້ງນີ້ຈຶ່ງໄດ້ມີສຳພາດ ຜູ້ເຖົ້າ, ຊາວປະມົງ, ຊາວນາ ແລະ ນາຍບ້ານຂອງແຕ່ລະບ້ານ. ການເກັບຕົວຢ່າງນ້ຳ ແມ່ນເກັບຢູ່ 9 ຈຸດ ເພື່ອ ການກຳນົດຄຸນນະພາບນ້ຳຕົວຢ່າງນ້ຳໃນໄລຍະນີ້.

ຜົນໄດ້ຮັບສະແດງໃຫ້ເຫັນວ່າສະພາບຂອງຄຸນນະພາບນ້ຳ ໄດ້ເລີ່ມຕົ້ນເຊື່ອມ ໂຊມລົງເລື້ອຍໆໃນໄລຍະ 10 ປີທີ່ຜ່ານມາ ແລະ ນັບມື້ນັບເປື້ອນຂື້ນ. ໃນມື້ນີ້, ຄຸນນະພາບນ້ຳມີມົນລະພິດຫຼາຍທີ່ສຸດ

ທີ່ໄດ້ສົ່ງຜົນກະທົບປະຊາກອນປາ ແລະ ພືດຜັກຕາມແຄມນ້ຳຫ້ວຍໝາກຮຽວ ຊຶ່ງມີຜົນກະທົບທາງລົບຫຼາຍ. ການເຊື່ອມໂຊມຂອງຄຸນນະພາບນ້ຳດັ່ງກ່າວນີ້ ມັນພົວພັນເຖິງການພັດທະນາລະບົບຄອງລະ ບາຍນ້ຳ ແລະ ການສູນເສຍພື້ນທີ່ດິນ ບໍລິເວນນ້ຳ ໃນ ນະຄອນຫຼວງວຽງຈັນ. ລະດັບຂອງສານຕົກຄ້າງຫຼຸດລົງໃນເຂດ ປາກນ້ຳຫ້ວຍໝາກຮຽວ ນັ້ນອາດຈະເປັນຍ້ອນວ່າ ມີການດູດຊຶມ ໂດຍພືດນ້ຳ ແລະ ເຮັດໃຫ້ຈາງລົງ.

Nyckelord/Key words

Water quality, channelization, landscape science, wetlands, Vientiane, ecosystem services

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1. Introduction

1.1 Landscape changes

The landscape is constantly changing. Various natural forces such as wind and water, has always affected the landscape appearance, something you do not always notice on a short time scale. However, today´s landscape is mostly not shaped by the forces of nature; the most effective converter of nature in our time is man who has shaped the landscape through technology, economics and politics in complex interactions. Many of the operations that man makes in the landscape are of such extent that all traces of the landscape that has emerged throughout the millennia are of risk to be lost for future generations (Ihse, 2005). Laos is one country that has been facing large-scale landscape changes during the last decades. Many of the changes are associated with population growth and socio-economic factors (Boundeth et. al, 2012).

1.2 Project location

The Lao People's Democratic Republic (Lao PDR), more commonly known as Laos, has an area of 236 800 km^2 and is located in Southeast Asia (figure 1). It has a population of 6.4 million and most of the people live in rural areas where agriculture is the main occupation (Utrikespolitiska institutet, 2012). The country is one of the poorest countries in Southeast Asia and about 27 % of the population lives on no more than 1 USD per day. Even though economic reforms in recent years have led to improvements, Laos still relies on development aid (SIDA, 2009). The country consists of three main geographical zones; fertile river valleys, mountains and plateaus. The tropical climate varies both due to the topographical situation and with the changing seasons (Utrikespolitiska institutet, 2012). Around 94 % of the annual precipitation falls during the rainy season between mid-April and mid-October with the most intensive rainfalls appearing in August. In the capital Vientiane, the average yearly precipitation is approximately 1620 mm. The average annual temperature is 26ºC with the highest mean temperature usually occurring in April and the lowest in December (Lacoursière, 2010).

Figure 1. Laos location in Southeast Asia (PA Tours, 2008).

Laos has throughout history been populated by many ethnical groups and cultures, and the country was incorporated into French

Indochina in 1893. After 60 years as a part of a French colony, Laos declared its independence in 1953. After more than 20 years of civil war and instability, the People's Republic was proclaimed in 1975. It was not until 1988 that the country opened its borders to the outside world and it took until 1994 before tourists could travel freely in the country (Utrikespolitiska institutet, 2012).

"Vientiane Capital", as it is officially known is located along Mekong River and has an estimated population of 801 000 and is rapidly growing (JICA, 2011a). The last decade, the population of Vientiane has increased with 30 % (Nolintha, 2011). The city is situated on low- lying alluvial soils and covers an area of 210 km^2 (Lacoursière et. al., 2010).

1.3 Importance of water treatment by aquatic ecosystems

Wetlands have an essential role in some cities as their physical features provide flood reduction and keep water courses flowing during dry season. These hydrological benefits are often overlooked as cities develop and natural rivers and streams is either being replaced by cement lined channels or destroyed to allow for roads and infrastructure. A common environmental problem in urban areas in development countries is the increasing levels of pollution drained into the urban water bodies. This is often a result of both rapid unplanned urbanization and poor wastewater treatment facilities (Parkinson & Mark, 2005). These problems are very apparent in Vientiane where the urban wetlands, channels and rivers play an important role for the water quality maintenance. For that reason, this survey has focused on the past and present status of Houay Mak Hiao River, who receives basically all drainage water from the city. The water purification functions of the river are of great importance for preventing Vientiane's wastewater to reach directly into Mekong River.

2. Objective

The purpose of this project is to find out how the condition of Houay Mak Hiao River has changed over time. The study will describe how historical and current landscape changes such as wetland area losses, channelization and urban development have affected the ecosystem and ecosystem services of the river.

This study intends to answer the following questions:

- Have different landscape changes affected the water quality, fishery, vegetation and flooding of Houay Mak Hiao River over the past 50 years? If so, in what way?
- When did the changes occur?
- How is the water quality today?
- Is there a difference in the condition of the river with increased distance from Vientiane? If so, why is that?

3. Background

This section will explain important terms and concepts of this study. A basic understanding of landscape changes and ecosystem services along with an explanation of nitrogen and phosphate and their affects to aquatic ecosystems will be provided. Previous research about our subject will also be highlighted and the information from this section will be used as a core for our discussion.

3.1 Definition of wetlands

Wetlands exist in many different forms and with different hydrological conditions which makes them difficult to define. Common to all wetlands is that they are characterized by the presence of water, either permanently or seasonally intermittent (Dobson & Frid, 1998). Even areas that are not flooded qualify as wetlands if the water table is near the soil surface during the growing season. The plants living in wetlands are adapted to grow in constant flooded areas or seasonally flooded areas where the oxygen content of the soil is low (Kadlec & Knight, 1996).

3.2 Wetland and aquatic ecosystem services

The benefits people receive from wetlands are called ecosystem services and are of great importance, especially for the people who live in close contact with them. When wetland functions deteriorate and its prevalence decreases it affects many groups of people, especially the poor in developing countries who are totally dependent on the resources that the wetlands provide (Millennium Ecosystem Assessment, 2005). Wetland ecosystem is different from both deepwater aquatic systems and well-drained terrestrial system due to the unique physiochemical conditions of such ecosystem hydrology (Mitsch & Gosselink, 2007). One of the most important services that wetlands provide is water purification and the ability to detoxify wastes. The water quality is improved by the processes of sedimentation, microbial interactions, uptake by vegetation, filtration and chemical and physical immobilization (Kadlec & Knight, 1996). When excess nitrogen is absorbed by low- oxygen wetland soils, it transforms into harmless gas that enters the atmosphere (Machtinger, 2007). Since the passage of water through wetlands is relatively slow the ecosystem provides time to improve water quality and treat pollutions. When the water reach the outflow of a wetland, substances such as metals and organic compounds has been absorbed by the sediment (Millennium Ecosystem Assessment, 2005). Both water quality and groundwater recharge are services provided by wetlands but the benefits are not always easily linked to the physical location. Sometimes the benefits can be observed far away from the wetland itself (Mekong River Commission, 2009). For humans, the function of water purification is very important as clean water is necessary for fishing, drinking and other activities (Michaud, 2001). Wetlands located in cities often receive large quantities of runoff water containing organic matter, nutrients and various kinds of pollution. In urban areas, pollutants are accumulated over impervious surfaces such as buildings, streets and industries and are washed into water bodies during precipitation and storm events. These hard impervious surfaces critically changes the local hydrological cycles, as it repel the runoff water and prevent it from infiltrate soil, which leads to a more rapid peak stream discharge into wetlands and water bodies. Unlike impervious surfaces, pervious soil-dominated surfaces infiltrate the water and absorb nutrients (Barnes et. al., 2002; Michaud, 2001). Runoff water that contains a high level of nutrients, in particular nitrogen and phosphorous, can have a negative impact on wetlands and watersheds. High level of nutrients can cause eutrophication and ”algae bloom”. There are more significant problems than the bad smell associated with algae bloom; during the decomposition process of algaes a lot of oxygen is being consumed which can result in death of aquatic life.

Besides the water purification function, wetlands deliver several important hydrological services, for instance flood protection, groundwater recharge and river flow regulation (Millennium Ecosystem Assessment, 2005). Wetlands have a great capacity to slow down the water's velocity and lower flood peaks. This is especially notable in areas with extremely rainy seasons (Michaud, 2001). During a storm, wetlands temporary holds the water and then discharge it slowly over a longer period of time (Mitsch & Gosselink, 2007). Figure 2 shows that when wetlands are replaced by impervious surfaces associated with urbanization, the water accumulates earlier and in higher concentrations (higher peak in the graph) than the situation before urbanization (lower peak in the graph).

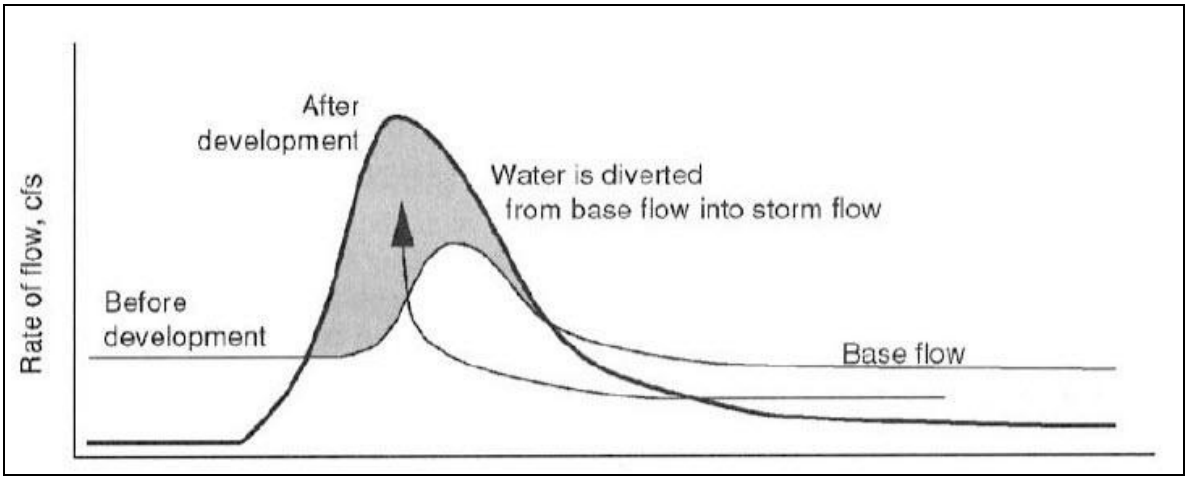

Figure 2. The extension of flow peaks following development with impervious surface (Lacoursière, 2011).

Another crucial benefit that people receive from aquatic ecosystems is food supply. In a majority of the world's developing countries, aquaculture and fisheries are the main sources of protein. The fish catch in these countries is mostly used for home consumption. Long-term food security is often dependent of healthy ecosystems that provides with clean water and other ecosystem services. Many poor people rely on food that is provided directly from ecosystems in their natural state (e.g. capture fisheries etc.) in their close vicinity. Anthropogenic ecosystem such as croplands and aquacultures are also important food sources and are like natural ecosystems dependent on clean water to maintain their functions. When the ecosystems are under stress by for example pollution, landscape fragmentation, channelization and population growth it fails to provide people with food and nutrition which change the livelihood of the poor people as they are forced to look for alternative sources of food. Other aquatic ecosystem services of importance are climate regulation, wood and fiber, primary production, educational and recreational services. These benefits are sometimes divided into four categories: regulatory, provisioning, supporting and cultural services (Boelee et. al., 2011).

3.3 Channelization

Channelization can be defined as stream alterations such as deepening, widening, straightening, clearing and/or dredging. There are several reasons for stream alterations, for instance controlling flooding and erosion, irrigation and drainage of wetlands for urban sprawl. Stream alterations usually lead to higher velocity of the water in the channel (Keller, 2002). In addition to deepening and clearing of the stream, the removal of channel obstructions will further increase the current velocity. This has a lot of negative impacts on stream ecology. Erosion on the stream bed will reduce the drifting benthic invertebrates which is an important food resource for many fishes. The spawning success of fishes is also depending on adequate current velocity (Hahn, 1982). One major negative effect of increased current velocity is the accelerated rate of delivery of pollutants throughout the stream. As the higher stream flow flush the streambed and release sediment pollutants, the quantity of pollutants can increase at downstream areas (United States Environmental Protection Agency, 2012). Unlike meandering and natural vegetated streams, channelized streams lack the ability to filter and absorb nutrients which results in high amounts of nutrients and other pollutants in the water (Anderson, 1992). Another effect is increased turbidity and sedimentation which can be harmful for the biological activities in the water. The turbidity is most notable during and immediately after the channelization but can have long-term effects, depending on the current velocity and erodability of the soils along the stream. Increased turbidity reduces the primary productivity and harms the benthic invertebrates (Hahn, 1982). This will have negative impact higher up in the food chain.

3.4 Destruction of riparian zones

Areas in direct proximity to streams and rivers are called riparian zones, and the distinctive vegetation in these areas is known as riparian vegetation (Koscher & Harris, 2007). Unlike terrestrial ecosystems, riparian zones are characterized by high water table and are periodically flooded (Mitch & Gosselink, 2007). The interaction of riparian hydrology, soils and biotic communities maintain several essential ecological, biological and physical functions (Klapproth & Johnson, 2000). Channelization is a major threat to riparian zones and has long term effects on these vegetated areas. When the water no longer infiltrates the riverbank as far as it used to, the riparian zone is decreasing. The diminishing of vegetated areas along the stream results in habitat loss for a wide range of animals. The narrowing of such ecosystems for instance affects fishes and insects, as they become more vulnerable to human disturbance and other stress factors. Riparian vegetation is also important for the water temperature as it provides shade to the stream (Leopold, 1997). Plants, fish and other aquatic organisms are dependent on adequate water temperature and are often sensitive even to small changes (Gordon et. al., 1992). Riparian zones also prevent nutrients, sediments and other pollutions to enter the stream by the great infiltration capacity provided by the riparian vegetation. A reduce of the vegetated banks usually leads to decreased water quality of the stream. When a stream is channelized and its vegetation is removed more nutrients and pollutants can enter the stream through groundwater or subsurface flow (Klapproth & Johnson, 2000). Yet another problem with reduced vegetation along streams is that the pollutants can reach further downstream in a higher rate of delivery.

3.5 Nitrogen

An elevated availability of inorganic nitrogen in the environment generally increase the overall biomass production, in particular the primary producers. However, too excessive levels of inorganic nitrogen will saturate the ecosystems and thereby harm the biological life in several ways, especially the least tolerant organisms (Camargo & Alonso, 2006). In aquatic ecosystems, nitrogen appears in different dissolved inorganic forms, of which ammonium (NH_4-N), nitrate (NO_3-N) and nitrite (NO_2-N) are the most common and important. Nitrogen may also be present in its organic form, for instance in organic matters or as amino acids in humus (Wetzel, 2001). In biological conditions, ammonium, nitrite and nitrate can transform between the three stages in the ammonia-to-nitrate oxidation. The process is depending on pH and temperature. The three nitrogen fractions can be present naturally in water in several different ways, for example by precipitation, surface and groundwater runoff and biological degradation of organic matter. These reactions of nitrogen are all different steps of the nitrogen cycle. Now, anthropogenic disturbance has altered the global nitrogen cycle, which has resulted in increased movement and accessibility of nitrogen over large parts of the earth. The nonpoint sources of nitrogen caused by human activity, for example urban storm water and leachate from failed septic systems, are of particular significance as they are often large and difficult to control. Additionally, human contribution of nitrogen compounds to aquatic ecosystems can result in inorganic nitrogen pollution (Camargo & Alonso, 2006).

3.5.1 Nitrate

Nitrate is in contrast to nitrite and ammonium, a more chemically stable form of nitrogen and is common in oxygen-rich streams. Nitrate in natural water can originate from bacterial oxidation as well as uptake of nitrogen by plants. However, most of the nitrate comes from anthropogenic sources, such as waste water discharges. Enhanced nutrient runoff can lead to higher levels of nitrate in rivers, which in turn may decrease the utility of the public water resource. Though nitrate itself is not the most toxic form of nitrogen it can transform to nitrite which has more harmful effects to aquatic ecosystems (Environmental Protection Agency, 2001).

3.5.2 Nitrite

Since nitrite tends to easily transform into other forms of nitrogen, it usually occur in very low levels. Even though the concentration of nitrite in wastewater is often relatively low it indicates decreased water quality and closeness to a pollution source (Environmental Protection Agency, 2001). Increased amounts of nitrite can have a negative impact on aquatic organisms and reduced fish population is a common consequence (Lewis & Morris, 1986). Another possible impact of both nitrite and nitrate in water bodies is eutrophication which can decrease the level of dissolved oxygen in the water (Ismail, 2011).

3.5.3 Ammonium

In many natural as well as human influenced ecosystems, ammonium is the main nitrogen source and is available to some extent in most ecosystems. Runoff from fields, sewage discharge and airborne deposition are all common anthropogenic sources of ammonium to aquatic ecosystems.

Although many plants are adapted to high amounts of ammonium, excessive levels can have toxic effects for basically all plants (Britto & Kronzucker, 2002). As pH and temperature rises the toxicity of ammonium increases and becomes very harmful to aquatic organisms (Wurts, 2003). Ammonium ions are eutrophic and may indirectly lead to oxygen depletion in water when biomass decomposes (Naturvårdsverket, 2008).

3.6 Phosphate

In water, phosphates can occur in different forms and all of them include phosphorus. Phosphorus can enter water bodies through both natural sources and human activities. It is extensively used in agricultural fertilizers and as an important component of detergents, especially for domestic use. Important anthropogenic contributions of phosphorus to water bodies are runoff and sewage discharges (Environmental Protection Agency, 2001). Normally phosphates are not toxic to humans and animals. In fact, algae's and aquatic plants is dependent of phosphates for their growth and reproduction but excess levels of phosphates may result in eutrophication and low oxygen levels in water (Ismail, 2011).

3.7 Development in Vientiane

In 2004, Vientiane contained about 1500 km^2 of seasonal and permanent water bodies, floodplains and wetlands (IUCN, 2004). Ever since, the wetland area has significantly been reduced, mostly because of backfilling to make space for the rapid urban development. Much of the city development is unplanned and unstructured growth occurs along new roads in the peri-urban area (Lacoursière personal communication, 2013). The people of Vientiane were previously living in close contact with the city's intricate network of vegetated earth-channels and wetlands. A large amount of aquatic organisms such as plants and fishes were used as food for the local citizens and their animals. At that point most of the carbon and nutrients stayed in these urban waters and wetlands. At the beginning of the 21^{th} century a lot of changes took place in the urban structure, more specifically the construction of the drainage channels, in order to reduce flooding. The earlier earth-channels were successively replaced by straighter and deeper cement lined channels to drain the water quickly out of the urban aquatic areas. In addition to the channelization, infrastructure like roads with associated stormwater management was built. As the solution to the ongoing flooding crisis was so urgent, the sanitation problem was missed out for the time being. Budgetary restrictions at that time left the sanitation component of the problem to a later phase (Lacoursière et. al., 2003).

The drainage in Vientiane is further complicated by the low soil permeability and high groundwater (Keosithamma, 2004). The two main drainage channels in Vientiane are called Hong Ke and Hong Xeng and has a total catchment area of 9.5 km^2 respectively 56.6 km^2 (JICA, 2011b). Hong Ke drains the core of the city and ends up in That Luang Marsh. To the larger Hong Xeng channel, two smaller channels, Nam Pasak and Nam Pasak II are connected. The former collects water from the urban area and the latter mainly from agricultural areas. Hong Xeng empties directly into Houay Mak Hiao River (Lacoursière et. al., 2010).

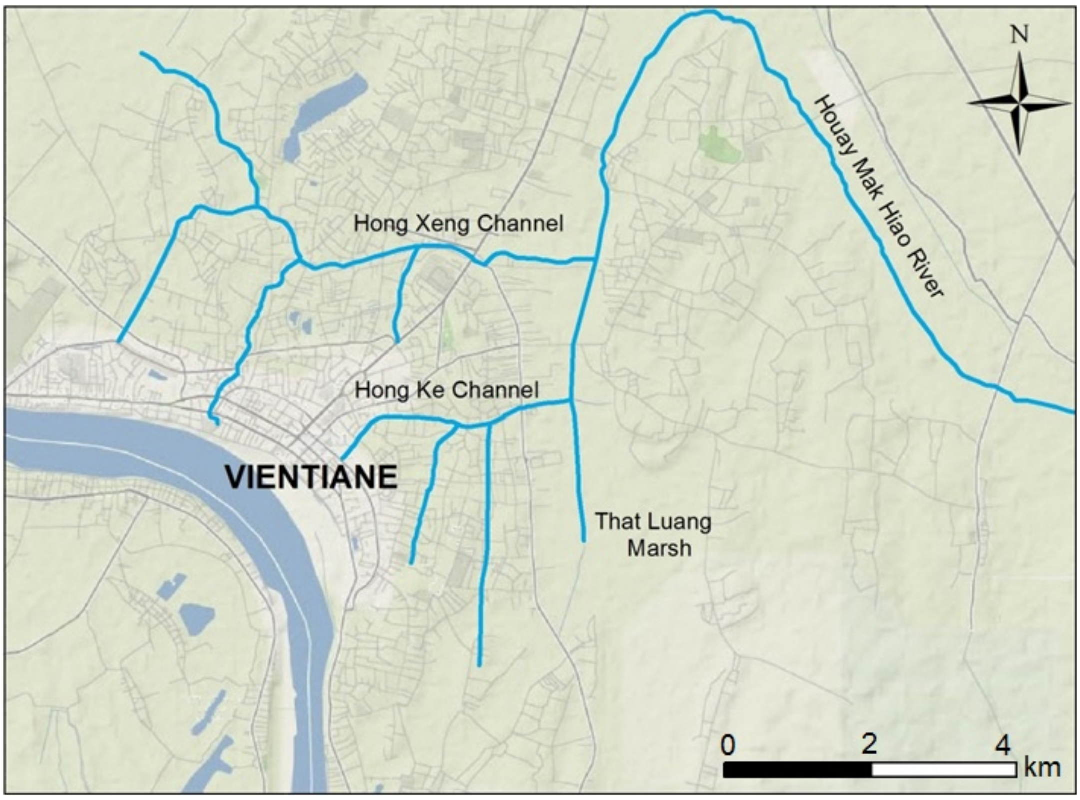

Figure 3. Vientiane City with its main drainage channels connected to Houay Mak Hiao River.

In recent years, projects such as the 2001-2002 Urban Environment in Vientiane Lao PDR from the Danish International Development Assistance (DANIDA) and the 2006-2011 Study on Improvement of Water Environment in Vientiane City from the Japanese International Cooperation Agency (JICA), provided some drive to focus and promote the “green and blue” dimensions of urban development (DANIDA, 2000; JICA, 2011b). Although not listed here, numerous other “development assistance” and investment projects have also significantly contributed to the changes in urban landscape observed in Vientiane during that period. Today, Vientiane is experiencing hyper-rapid development with over a dozen large foreign investment projects (mainly from China, Vietnam and Korea), exploiting with buildings, housings, hotels and commercial complexes in all sections of the city; most of them having been initiated less than 3 years ago (Lacoursière and Vought, personal communication, 2013).

3.8 Water treatment in Vientiane

To this day, Vientiane does not have a central wastewater treatment system and relies on aging septic tanks and soak pits to treat its sewage (JICA, 2011). A septic tank is a sanitation system that treats local wastewater in order to decrease the amount of solid load. It also reduces the peak discharge of household wastewater. The problem is that the septic tanks are not always cleaned the way they should be. Soak pits provides a way for the wastewater to infiltrate the surrounding soils. Rapid economic growth, improved living standards as well as population increase and large scale infrastructure construction has resulted in increased amounts of discharged wastewater. Untreated wastewater from many households discharges into drainage channels along the roads which leads the water to urban wetlands (Lacoursière et al. 2010). The wastewater is then drained by rectified channels, via That Luang Marsh, and ends up in the Houay Mak Hiao River, which eventually empties into the Mekong River (Whelan et. al, 2007). The Mekong River then floats through Cambodia and Vietnam into the South China Sea.

3.9 That Luang Marsh

That Luang Marsh, with an estimated area of 1.42 km^2, is the largest remaining wetland in Vientiane (figure 5). It is situated at the eastern edge of the city (Guerra Garlito, 2012). Water from drainage channels throughout Vientiane is collected by the Hong Ke stream which drains into That Luang Marsh (Gerrard, 2004). Therefore almost all drainage water from Vientiane passes through That Luang Marsh. Prior to the early 1980's That Luang Marsh still had characteristics of a natural wetland and was only partly used for rice cultivation. Before 1986, when a drainage channel was built through the wetland, the water was drained southwards directly to Mekong River. Since then the channel made the water in the wetland drain north into Houay Mak Hiao River (Samuelsson & Österling, 2000).

3.10 Houay Mak Hiao River

Houay Mak Hiao River drains an area of 412.5 km^2, including the urban area of Vientiane city (JICA, 2011). The water passes That Luang Marsh and flows into the river which starts at Hoa Khoa Bridge. The semi-natural river flows eastwards and eventually empties into the Mekong River, approximately 55 km downstream the wetland. The river that is partially realigned and partially meandering flows mostly through a low populated rural area with lesser and lesser built up areas closer to the outflow into Mekong. The first part of Houay Mak Hiao River, mainly realigned, flows through a landscape characterized by the proximity to the city. The immediate surroundings of the low populated part consist of rice fields, paddy fields and waste ground combined with low wooded forest. In order to regulate the water level in the river, a dam was built in 1977 close to the outflow into Mekong River (Lacoursière, personal communication, 2013).

3.11 Previous research of Houay Mak Hiao River

In late March 2006, a research was carried out to determine the extent of the urban pollution impact along the Houay Mak Hiao wetland/river complex using the presence of detergent and free-ammonia as indicators (Whelan et. al., 2007). The survey also included parameters as nitrite (NO_2-N), nitrate (NO_3-N), ammonium (NH_4-N), chemical oxygen demand (COD) and phosphates (PO_4-P), as shown in figure 4. Water samples were conducted at six stations along the river from Hoa Khoa Bridge to Na Kuai Bridge. It was identified that the urban detergent pollution reached 12.5 km in the river, i.e., 23 % of the distance to the outflow in the Mekong River. Whelan et. al. concluded that the filtration capacity of the shallow, wide and vegetated river channel (allowing for a large interaction between water and land) was responsible for the recovery.

A similar study was conducted by JICA (2011b) to determine the water quality in Houay Mak Hiao River and its main tributaries. It showed, with some exceptions, that both NO_3-N and PO_4-P was less than 1.0 mg/l as a whole. Using NH_3-N as an indicator, the study showed that the concentrations dropped along the mainstream of the river. The same trend was seen in NO_3-N concentrations. They stated that this was mainly due to dilution effects.

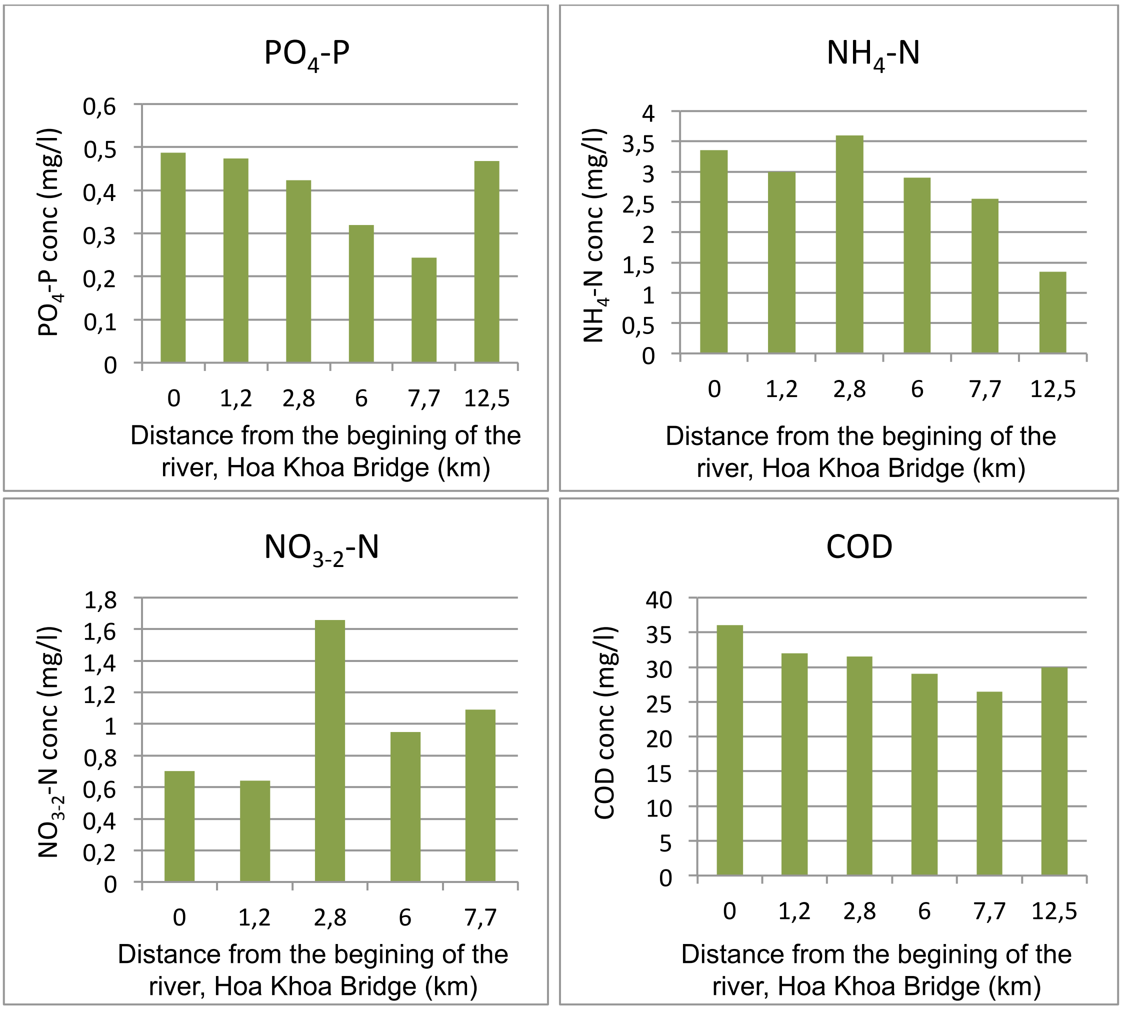

Figure 4. Changes in the concentration of PO_4-P, NH_4-N, $NO_{3\text{-}2}$-N and COD in Houay Mak Hiao River in March 2006. The stations is located along the first 12.5 km of the river, where the first station (0) is closest to the city core and the following stations is located further downstream (remade from Whelan et. al., 2007).

3.12 Loss of wetland areas in Vientiane

Three previous inventories of the 12 main wetlands in Vientiane city has been carried out in the years 1999, 2005 and 2012 in order to estimate the status and area loss of the capitals wetlands. According to Samuelsson & Österling (2000) the natural resources of the wetlands had already decreased and the water quality had been affected by high levels of discharged pollutants at the time of their study. They also pointed out the increasing risks of wetlands being backfilled. In the follow-up survey by Müller, Nilsson and Troedsson (2006) it was stated that construction of roads and buildings were resulting in major losses of wetland area. Müller et. al. (2006) also mentioned that it is often individual actions rather than controlled urbanization that is the underlying cause of land expansion. As shown in table 1 some of the wetlands were suffering substantial area losses between 1999 and 2006. Guerra Garlito (2012) attests that the reduction of wetlands is a result of residential and industrial urbanization. Loss of wetlands will lead to increased amounts of sewage, discharging directly into the rivers and affect the ecosystems. As shown in table 2 the wetlands area loss from 2006 to 2012 was even more extensive than between 1999-2006 (Guerra Garlito, 2012).

Table 1. Estimated degree of wetland area loss from 1999 to 2006 of the 12 main wetlands in Vientiane (Müller et. al., 2006).

Name of wetland	Slight (0-10%)	Medium (10-25%)	Great (>25%)
Bouang Kha Ngong	X		
Nong Bo & Nong Ping	X		
Nong Bone			X
Nong Chanh			X
Nong Douand			X
Nong Kok Pho			X
Nong Loup Ngeauk			X
Nong Pak Dong			X
Nong Pa Lap	X		
Nong Tha	X		
That Luang	X		
Thong Sangngang		X	

Table 2. Estimated degree of wetland area loss from 2006 to 2012 of the 12 main wetlands in Vientiane (Guerra Garlito, 2012).

Name of wetland	Slight (0-10%)	Medium (10-25%)	Great (>25%)
Bouang Kha Ngong		X	
Nong Bo & Nong Ping	X		
Nong Bone			X
Nong Chanh			X
Nong Douand			X
Nong Kok Pho			X
Nong Loup Ngeauk			X
Nong Pak Dong			X
Nong Pa Lap			X
Nong Tha			X
That Luang		X	
Thong Sangngang			X

Müller et. al. (2006) estimated that approximately 30% of the overall area has decreased between the years 1999-2005. By the year 2012, nine of the twelve wetlands were highly impacted and the total area loss since 2006 was estimated to more than 60 %.

4. Material & Methods

4.1 Interviews

To collect information about the survey area, group interviews were conducted in seven villages along Houay Mak Hiao River. The villages were selected mainly by their proximity to the river and to cover as much of the river as possible, an even spread of the villages was pursued. The groups consisted of 3-6 respondents in each village. To get as relevant answers as possible, elders, fishermen, farmers and the head of village in each village were participating in the interviews. Their knowledge and memories about historical conditions and changes along the river and its surroundings was considered important. In addition to the historical perspective, questions were asked about the current status of the river (appendix 1). Mrs Khampheng Homsombath at the Living Aquatic Recourses Research Centre, acted as an interpreter during all interviews. When collecting information through group interviews using an interpreter, there is a risk that some information does not reach the interviewer which can complicate the interaction. Consideration must also be given to that certain historical information, especially numerical data, can be difficult to remember for the respondents. For example, years were probably rounded to even numbers at some times. Nevertheless, the information is contented to get an understanding of the changes. To get historical information of Houay Mak Hiao River, group interviews was considered the most efficient method as there is a lack of easily accessible older descriptions and literature of the studied area. In group interviews, unexpected topics can emerge which can lead to interesting new answers and reactions of the whole group. These stimulating interactions are not possible in an individual interview (Hylander, 2001).

Table 3. Description of the villages where the interviews were conducted.

Number	Name of Village	Distance downstream from the beginning of the river (Hoa Khoa Bridge)	Date	Number of respondents
1	Ban Hongsouphab	3.5 km	8/4 2013	4
2	Ban Xamkhe	7.6 km	8/4 2013	5
3	Ban Doung	12 km	8/4 2013	5
4	Ban Nahai	16 km	8/4 2013	6
5	Ban Nano	21.8 km	9/4 2013	6
6	Ban Sang Hoabo	28 km	9/4 2013	3
7	Ban Mak Hiao	53 km	9/4 2013	6

The questionnaire for the interviews was concerning the condition and ecosystem services of Houay Mak Hiao River in a historical perspective and in chronological order (table 4).

Table 4. Main topics of the questionnaire.

Topics	Comments
Water quality	Uses of water, cleanness.
Flooding	Frequency, effects
Land use	Vegetation, agriculture
Fish	Species, quantity

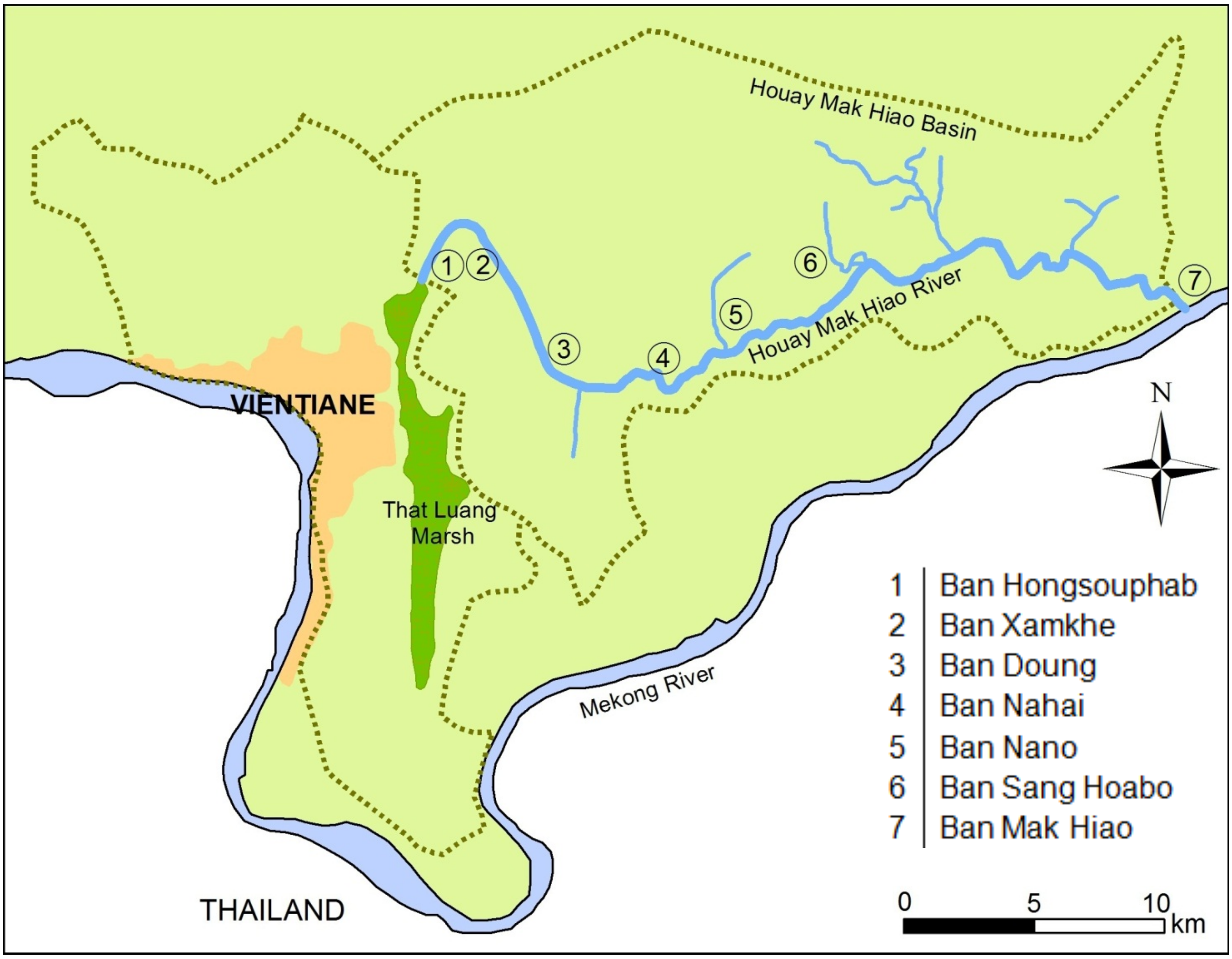

Figure 5. Number 1-7 shows the location of the villages where the interviews were conducted.

4.2 Water chemistry

Water samples were collected 29th of April, 2013 at nine sampling sites along Houay Mak Hiao River and its tributaries. Their location can be seen in figure 6 and appendix 2. The previous week was mostly sunny but there were also two heavy rainfalls. The temperatures that week were just above 30 degrees Celsius. The water samples were analyzed at the Environment Quality Monitoring Center, Natural Resources and Environment Institute, Vientiane.

Table 5. Methods used to analyze the water chemistry.

Parameters	Analytical methods
Ammonium	Phenated Method
Nitrite	Cadmium Reduction Method
Nitrate	Cadmium Reduction Method
Phosphate	Ascorbic Method
COD	Closed Reflux, Titrimetric Method
pH	Electrometric Method

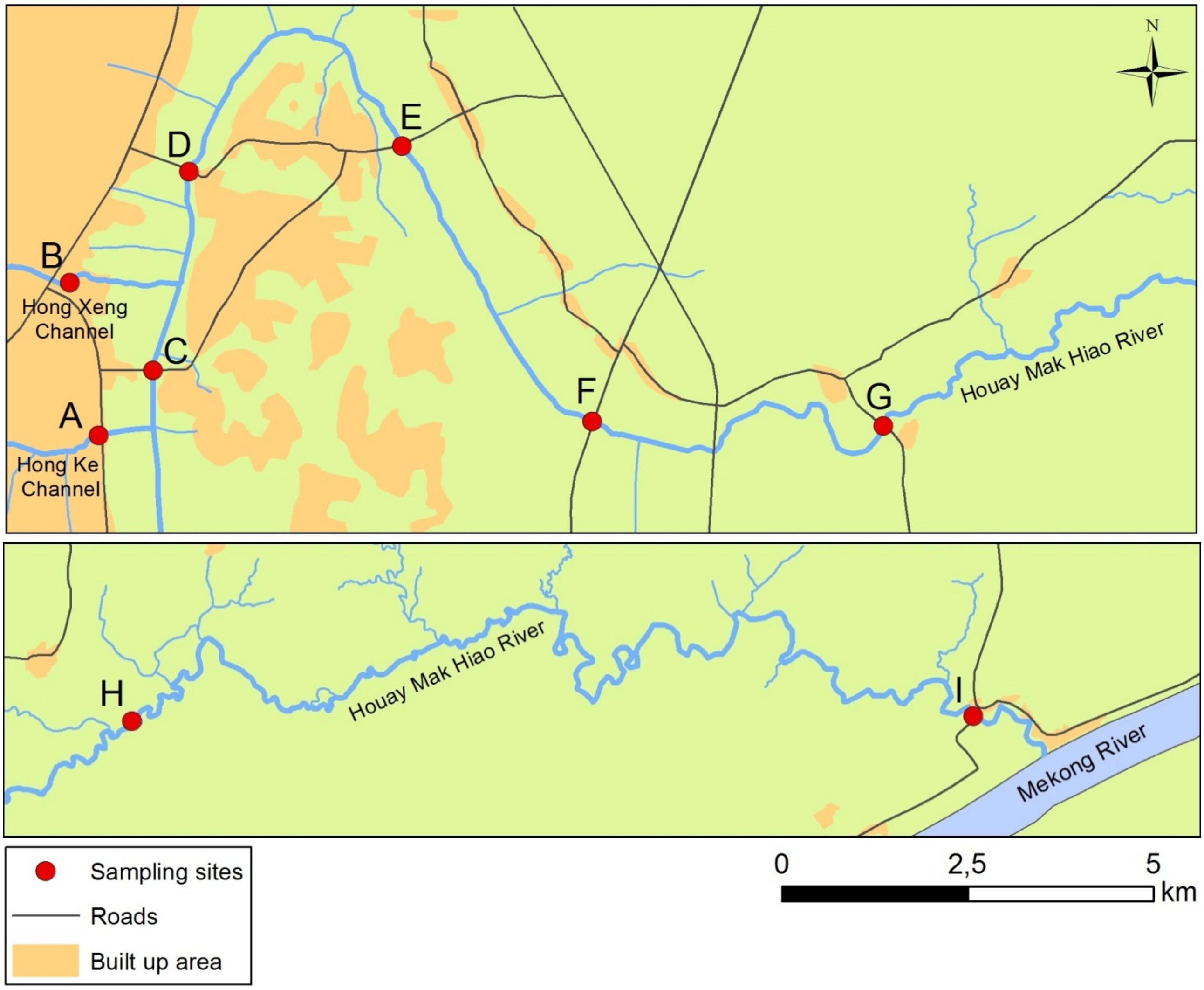

Figure 6. The points A- I shows the location of the water sampling sites. The upper map shows Vientiane, its channels and the western part of Houay Mak Hiao River. The lower map shows the eastern part and the outflow to Mekong River. The maps are in same scale.

5. Results

5.1. Changes of Houay Mak Hiao River

The information provided in this section is mainly based on interviews and the oldest data consist of memories from the 1960s. Information from each village represents the section of the river that flows in close connection to respective village.

5.1.1 Ban Houngsouphab

Inhabitants: 2919.
Distance downstream from the beginning of the river: 3.5 km.
Respondents: Head of village, elder and two fishermen.

Not so long ago, the water quality was good and the vegetation along the river consisted mostly of shrub and plants like *Melastoma sp., Nymphaea lotus, Eichornia crassipes, Marsilliea crenata, Echinochloa sp., Apocopis paleacea Hochr.* and *Xanthophyllum sp*. Before the channelization in 1975-1976 the river was natural flowing and meandering through the landscape. The channelization, dredged by hand with labor from all of Vientiane, made it 3 meters wider, 1 meter deeper and significantly straighter. However, the water quality remained good until about 10 years ago when it started to decrease. The past 10 years, the fish population has declined gradually and today the fish tastes bad, the meat have a hard consistency and fewer and fewer people eat it. The changes in fish catch over the years are shown in table 6.

In January 2013 some parts of the river were channelized once more and the water flows much faster than before. The faster velocity of the water has led to lower water table (30-40 cm during dry season) which in turn has resulted in droughts and insufficient amounts of water for rice production. Today the water quality in this part of Houay Mak Hiao River is like wastewater and has a bad smell. Many of those who come in contact with the water get skin diseases. The poor water quality also has negative effects on the rice harvest in the village.

Table 6. Changes of fish catch per fisherman. The numbers are estimated by the villagers.

Time period	Quantity (kg/day)
30 years ago	5-10
5 years ago	2-3
Today	1

5.1.2 Ban Xamkhe

Inhabitants: 1483.
Distance downstream from the beginning of the river: 7.6 km.
Respondents: Head of village, elder and three farmers/fishermen.

In the past, the water quality was good and clean enough to be used in households and for shower. The natural vegetation consisted mainly of *Nymphaea lotus, Eichornia crassipes* and *Ipomea aquatica* - a common vegetable in the food. At that time, the algae's were green but now they are replaced by brown and white colored algae's. In 1975-1976, the narrow parts of the river were channelized and straightened. Problems connected to dirty water started to occur about 10 years ago. Since then, water from the river is not used for cooking and other household activities. The last decade, fish population of Houay Mak Hiao River has successively decreased and now is only a fraction of the previous stock left.

As an outcome of the channelization in January 2013, the river became deeper with a higher water flow. Since then, not many villagers in Ban Xamkhe go fishing anymore due to further decreased fish population. In recent years, bad smell from the water has been more significant and the riverbank vegetation has been facing more droughts.

Table 7. Changes of fish catch per fisherman. The numbers are estimated by the villagers.

Time period	Quantity (kg/day)
30 years ago	2-5
5 years ago	1-4
Today	1-2

Figure 7. Downstream Ban Sok Bridge, close to Ban Xamkhe. The picture to the left is taken in March 2006. and shows how the river could infiltrate the riverbank vegetation in a natural way. The picture to the right, taken in April 2013, shows how the channelization has altered the flow and vegetation. Photo: Jean O. Lacoursière (left) and Janne Kolehmainen (right).

5.1.3 Ban Doung

Inhabitants: 1277.
Distance downstream from the beginning of the river: 12 km.
Respondents: Head of village, Deputy Head of village, elder and two farmers/fishermen.

Before, the water in Houay Mak Hiao River was clean and it was used for household and drinking. The riparian vegetation was widely spread and the most common species were *Apocopis paleacea Hochr.* and *Cyperus sp*. The channelization in 1975-1976 altered the river's natural flow as it was realigned. It also significantly reduced the vegetation along the riverbank. In the last decade the water quality has become worse.

The last three years, the water quality has reached a critical level and it is now dirty, has a blacker color, and smells bad. Even the fish smells bad and some say they won't eat it without beer. Now almost no one goes fishing anymore because of the high risk of getting diseases by water. Droughts have been more common in recent years and the water table is much lower in the dry season than it used to be. As shown in figure 8, the channelization in January 2013 destroyed much of the riparian vegetation and now the water flows too fast to irrigate the rice fields along the river.

Table 8. Changes of fish catch per fisherman. The numbers are estimated by the villagers.

Time period	Quantity (kg/day)
30 years ago	10
5 years ago	2-3
Today	0,5- 1

Figure 8. Downstream Na Kuai Bridge, close to Ban Doung. The left picture, taken in March 2006, shows the river before the channelization in 2013. The right picture, taken in April 2013, shows how the vegetation has been destroyed and the riverbanks have become steeper as a result of the channelization Photo: Jean O. Lacoursère (left) and Janne Kolehmainen (right).

5.1.4 Ban Nahai

Inhabitants: 665.
Distance downstream from the beginning of the river: 16 km.
Respondents: Head of village, elder, farmer and three farmers/fishermen.

Some time ago, the water quality and fishing was good. Until 30-40 years ago there was so much fish in the river that one could catch them with bare hands. The aquatic vegetation like *Nymphaea lotus* and trees rooted in the water provided them with habitat. For 14-15 years ago the invasive species Golden Apple Snail *Pomacea canaliculata* ate most of the vegetation and ruined the harvest. The water quality in Houay Mak Hiao River started to decrease 10-15 years ago and in the following years significant reduction of the fish population was noticed.

In 2012, some parts of the river was widened and straightened and thereby lost its natural meandering flow. Due to the channelization the water flows many times faster now than before, as plants no longer slows down the velocity. The previously muddy riverbanks are since then dry because of low water table. Today's water is in really poor condition and smells bad. Not many people in Ban Nahai go fishing anymore as the fish population has decreased as well as the quality of the meat.

Table 9. Changes of fish catch in the village. The numbers are estimated by the villagers.

Time period	Quantity (kg/day)
30 years ago	1000*
5 years ago	500*
Today	0,5

*A special fishing method was used where a team of 5 people trapped and caught all fish in a narrow area. The number represents the high season quantity.

Figure 9. The floating plant water hyacinth *Eichornia crassipes* between Ban Doung and Ban Nahai. Floating plants like this could be seen at some parts of the river. Photo: Janne Kolehmainen, April 2013.

5.1.5 Ban Nano

Inhabitants: 1470.
Distance downstream from the beginning of the river: 21.8 km.
Respondents: Head of village, elder and four farmers/fishermen.

Not so long ago, the water quality in the river was good and was used for drinking, household, shower and swimming. Grasslands, woods and eatable plants covered the riverbank and commonly encountered plants were *Trapa bicornis, Melastoma sp., Xanthophyllum sp*. and *Eichornia crassipes* – commonly used as food for livestock. At that time the fishing was good (see table 10). 6-10 years ago the water quality started to decrease and has since then gotten worse and worse. In the last decades the grasslands has been replaced by rice fields on both sides of the river. As a combination of dirty water and droughts, more than 90% of the rice fields of Ban Nano has been destroyed and is since 5 years ago no longer in use. The remaining woods have also died of droughts in the past few years.

During the channelization in January 2013, some parts of the river were drained and the natural flow was altered. Since the change, the water quality has further deteriorated which has caused fish diseases and in some cases fish death. Both the smell and the taste of the fish are bad and not many people go fishing after the channelization. Decreases in fish catch and rice production has made the villagers look for alternative jobs and the children are often sent to Vientiane to find jobs. Many villagers now rely on handicraft, like bamboo fishing gear and rice cooking equipment, instead of agriculture and fishing.

Table 10. Changes of fish catch per fisherman. The numbers are estimated by the villagers.

Time period	Quantity (kg/day)
30 years ago	20-30
5 years ago	3-5
Today	0,5

5.1.6 Ban Sang Hoabo

Inhabitants: 865.
Distance downstream from the beginning of the river: 28 km.
Respondents: Head of village, elder and one farmer/fisherman.

In the past, the water from Houay Mak Hiao River was used for drinking, household, shower and swimming. The vegetation along the river mostly consisted of grasslands, bamboo and rice fields. Plants such as *Eichornia crassipes, Melastoma sp.* and *Xanthopyllum sp*. could be found. Around 10 years ago, the water quality started to decrease and some people got skin diseases after contact with the water. At that time it also became more common with droughts along the riverbank which affected the vegetation and vegetables. The irrigation system of Ban Sang Hoabo began to deteriorate as a consequence of the droughts and low water quality. This, of course, impacted the rice production negatively. Sometimes during heavy rainfalls, polluted water from upstream flooded the rice fields which also reduced the harvest, approximately by 20 %. The last decade, the fish population has successively decreased.

The channelization in 2013 made the water flows much faster and since then it has become even dirtier. The fish has obtained a bad taste and almost no one goes fishing anymore. Despite the changes and bad conditions of Houay Mak Hiao River, the livelihood of the villagers has not been affected that much because they also own and cultivates rice fields further from the river.

Table 11. Changes of fish catch per fisherman. The numbers are estimated by the villagers.

Time period	Quantity (kg/day)
30 years ago	20-30
5 years ago	3-5
Today	0,5

5.1.7 Ban Mak Hiao

Inhabitants: 1405.
Distance downstream from the beginning of the river: 53 km.
Respondents: Deputy Head of village, elder and four farmers/fishermen.

When the water quality was still good the water was used for drinking, household, shower and swimming. At that time there were almost no rice fields in that area, instead the surroundings of the river were characterized by trees, shrub, bamboo and wetlands. *Melastoma sp., Anthocephalus sp.* and *Ficus hispida* were widespread. A dam built in 1977, made it possible to use an irrigation system so there was water available for a second harvest. After that, the natural vegetation was successively diminishing and replaced by different crops, such as bananas, water melon, mango, long bean and corn. About 10 years ago the water quality of Houay Mak Hiao River started to decrease and skin diseases (that got the skin to itch) appeared for the first time.

In June 2012, the natural flow of the river was altered. The river was made deeper which destroyed much of the riparian zones and a lot of fish habitats (figure 10). The eatable plants of the river are no longer used for cooking in the same extent as before due to the polluted water.

Table 12. Changes of fish catch in the village. The numbers are estimated by the villagers.

Time period	Quantity (kg/day)
30 years ago	2000*
5 years ago	4-5
Today	1-2

*A special fishing method was used where a team of 5 people trapped and caught all fish in a narrow area. The number represents the high season quantity.

Figure 10. Houay Mak Hiao River near to the village of Ban Mak Hiao. The picture shows how riverbed soil has been dumped on the riparian zone and destroyed much of the vegetation. Photo: Janne Kolehmainen, March 2013.

5.2 Loss of fish species

In the last decade, fish populations of some species have significantly been reduced and several species has disappeared entirely (table 13). This does not exclude that some of the listed species may sometimes appear in the parts of the river closest to the outflow in Mekong. For all existing fish species in Houay Mak Hiao River, see appendix 3. The information in this section is based on the interviews.

Table 13. Fish species that has disappeared in Hoauy Mak Hiao River in recent years according to the respondents.

Lao name	Scientific name
Pa Kat	*Betta sphendens*
Pa Mat	*Trichopsis vittata*
Pa Khao	*Wallago attu*
Pa Yon	*Pangasius micronemus*
Pa Do	*Channa micropeltes*
Pa Phia	*Morulius chrysophekadion*
Pa Nang	*?*
Pa Souay	*Pangasianodon hypophthalmus*

5.3 Floodings

During the rainy season, the water level in Houay Mak Hiao River is high and the river bank is regularly inundated by water. According to the respondents, there has been several floodings with major consequences throughout the years as listed in table 14. Though not listed in the table, there has been many minor floodings which have not caused the same extensive damages and therefore not described by the villagers. Floodings has affected the villages along the river in different ways. Ban Doung is one of the villages that have suffered the most damage. The information in this section is based on the interviews.

Table 14. Major flooding's and their consequences to the villages 1-7 (see figure 5).

Year	Consequences	Village
1966	Significantly reduced vegetation	1, 3
	Increased fish catch during the flooding	3, 4, 5, 7
	Decreased fish catch after the flooding	1, 3
	Decreased rice production	3, 4, 5, 6
1969	Decreased fish catch after the flooding	7
	Decreased rice production	2
1971	Significantly reduced vegetation	1, 3, 4
	Decreased fish catch after the flooding	1, 3
	Decreased rice production	2, 3, 4, 5
2006	Decreased rice/crop production	6, 7
2008	Decreased rice production	2, 3

5.4 Water quality of today

The information in this section is based on water sample analysis.

As shown in figure 11 the amount of phosphate in the water is gradually decreasing with increased distance from the city. The highest value measured was 1.2 mg/l and the lowest, closest to the outflow in Mekong, 0.1 mg/l.

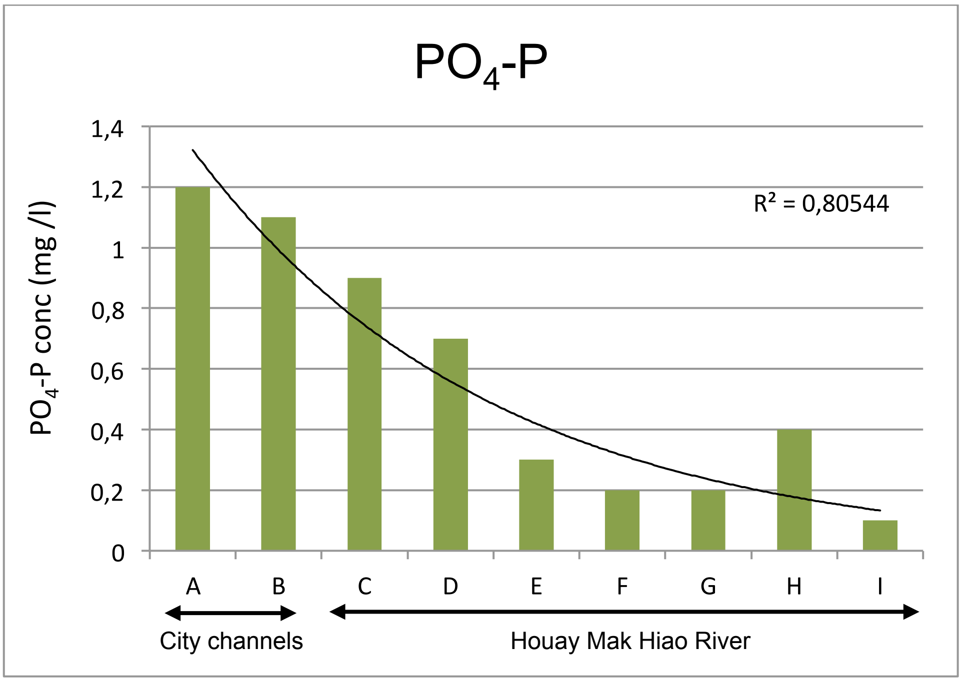

Figure 11. Changes in the concentration of PO_4-P. Sampling sites A-B is located in the city channels Hong Ke and Hong Xeng and are tributaries to Houay Mak Hiao River. Sampling site C-I is located in the mainstream. The trendline shows how the values generally fall with increased distance from Vientiane.

The ammonium level in the water tends to decrease with increased distance from Vientiane, with exceptions from sampling sites F and G which reach levels of 18.2 mg/l respectively 12.9 mg/l (figure 12).

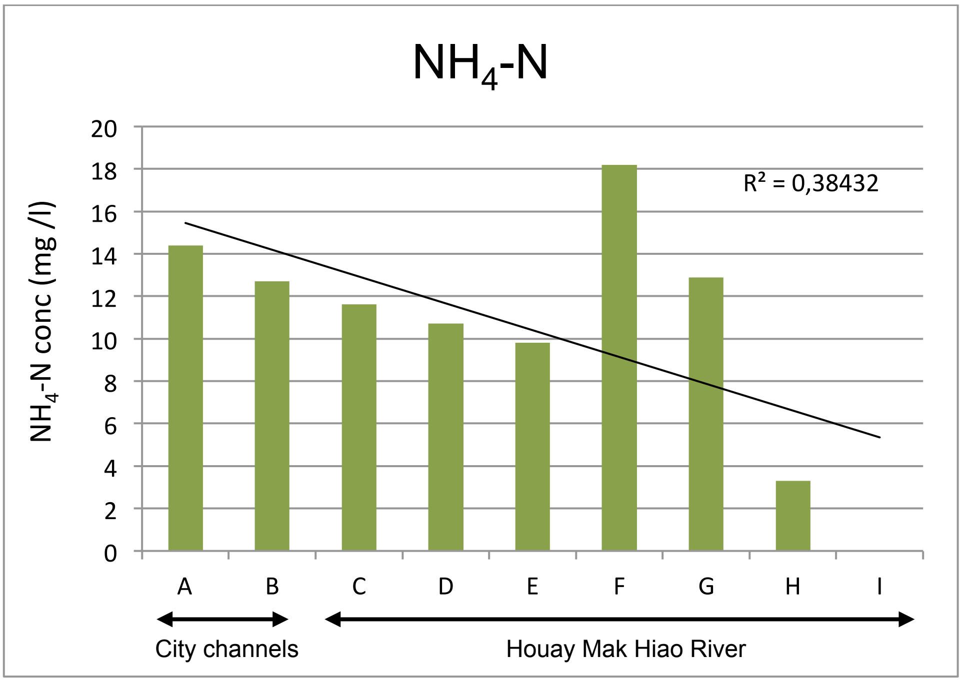

Figure 12. Changes in the concentration of NH_4-N. Sampling sites A-B is located in the city channels Hong Ke and Hong Xeng and are tributaries to Houay Mak Hiao River. Sampling site C-I is located in the mainstream. The trendline shows how the values generally fall with increased distance from Vientiane.

As shown in figure 13, the highest $NO_{3\text{-}2}$-N levels were found at sampling site G, about 12.3 km from the beginning of the river. The analyzed samples from the sampling sites located closest to the city showed values below detection level (<0.01 mg/L).

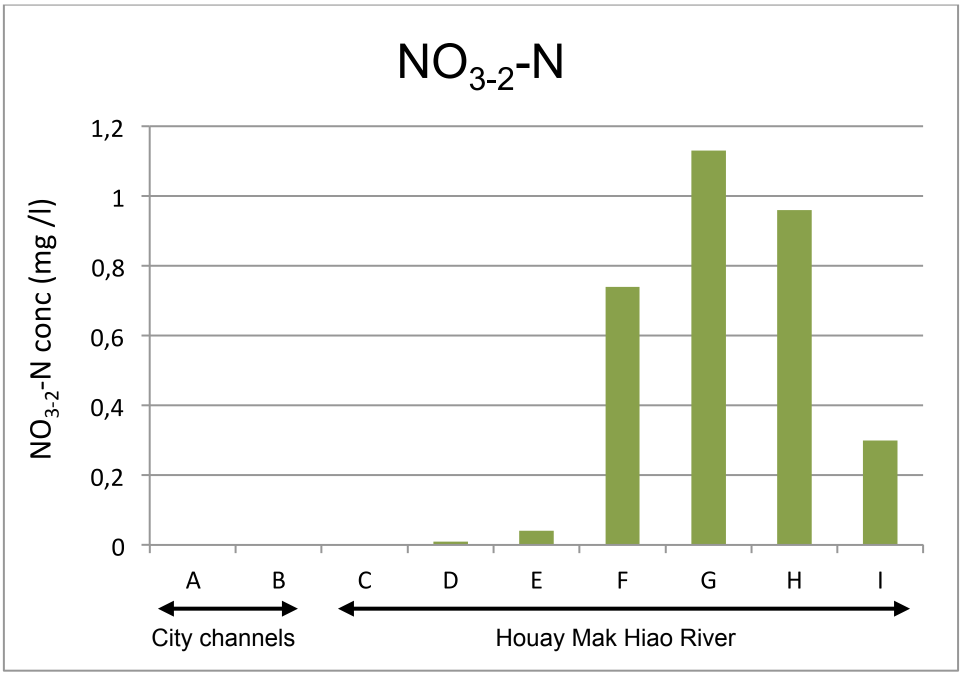

Figure 13. Changes in the concentration of $NO_{3\text{-}2}$-N. Sampling sites A-B is located in the city channels Hong Ke and Hong Xeng and are tributaries to Houay Mak Hiao River. Sampling site C-I is located in the mainstream.

Figure 14 shows that COD are extremely high close to the city and decreases below detection level (<0.40 mg/l) at downstream sampling sites. Due to measurement errors no value could be given to sampling site A.

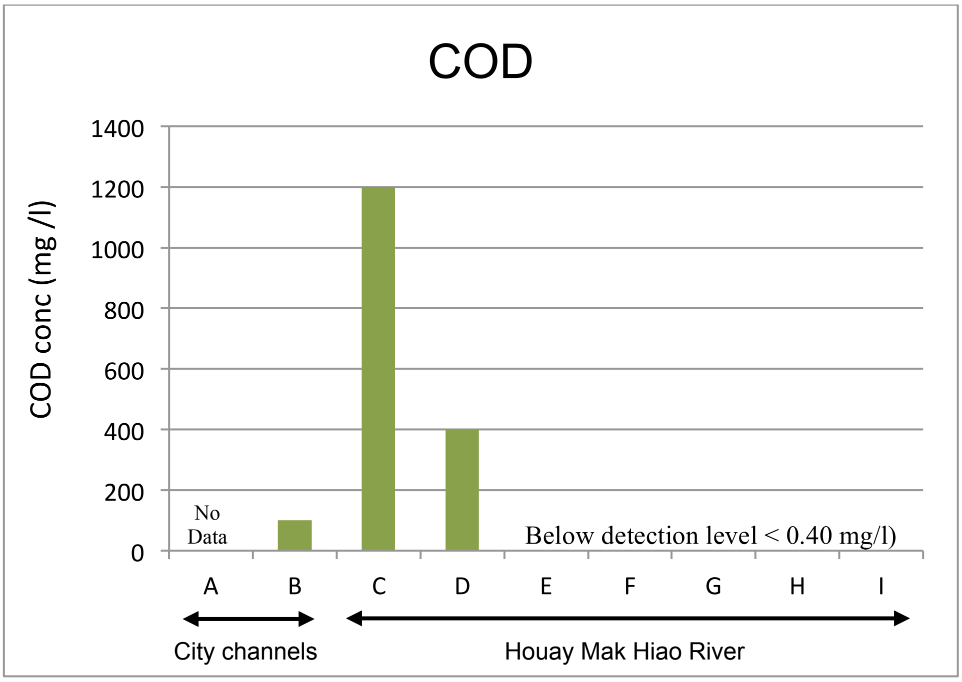

Figure 14. Changes in the concentration of COD. Sampling sites A-B is located in the city channels Hong Ke and Hong Xeng and are tributaries to Houay Mak Hiao River. Sampling site C-I is located in the mainstream.

The pH-value varies along the river but the trend shows increased values with increased distance from the city. The lowest value 7.02 was measured at sampling site E and the highest at sampling site I, 7.90.

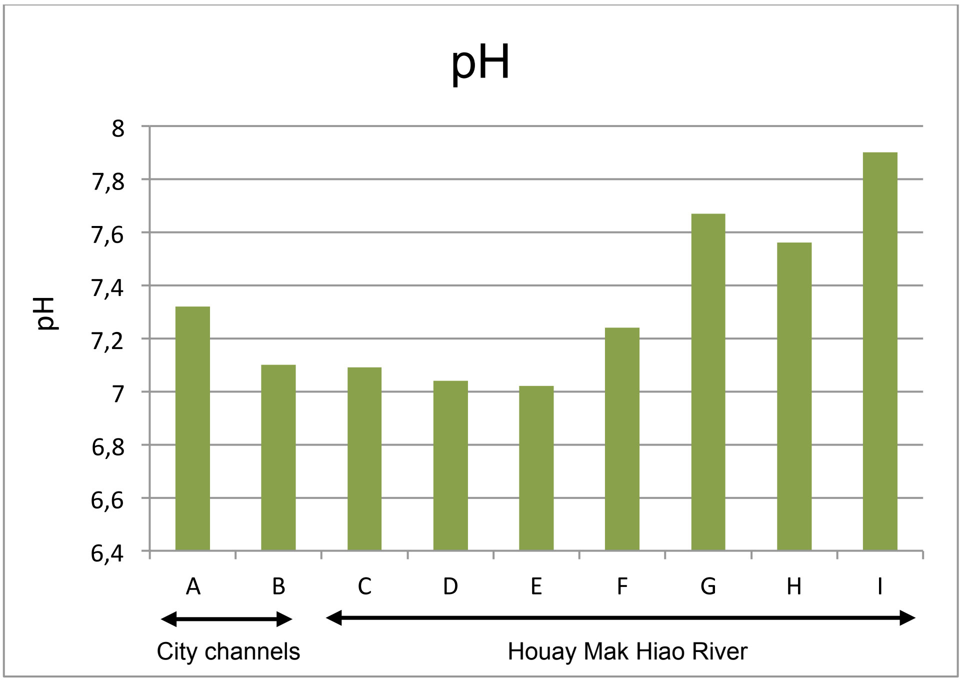

Figure 15. Changes in the pH-value. Sampling sites A-B is located in the city channels Hong Ke and Hong Xeng and are tributaries to Houay Mak Hiao River. Sampling site C-I is located in the mainstream.

6. Discussion

6.1 About the methods

As water chemistry is changing during the different seasons of the year, the date of the sampling has impact on the results. As our samples were collected in April, the results primarily reflect the water chemistry of the dry season.

6.2 Results from interviews

6.2.1 Changes of water quality

During the last 50 years there have been a few big landscape changes in the urban area as well as in and around Houay Mak Hiao River. Most of them have occurred in the last two decades. The effect of these changes has been of varied extent and some of them have had devastating consequences.

The channelization in 1975-1976 had little impact on the river's condition. According to Samuelsson and Österling (2000) the wetlands of Vientiane still provided great water purification services around that time. This great wetland functions probably lowered the negatively effects of that channelization. The results show that the water quality of Houay Mak Hiao River remained good until about 10 years ago. However, it would be more reasonable that the water in the river was polluted closer to Vientiane first, before the pollutions had time to reach further downstream. The deterioration of the water quality around 10 years ago is probably a consequence of the changes in the drainage system in the city, which was happening at about the same time (figure 16).

Figure 16. The left picture, taken in August 2000, shows Hong Xeng as a vegetated earth-channel before the urban channelization about ten years ago. The picture to the right, taken in April 2013, shows the steep cement-lined channel after the channelization. Photo: Jean O. Lacoursière (left) and Janne Kolehmainen (right).

The new concrete channels did not have the great capacity to obtain the pollutants as the previous earth-channels and therefore reach Houay Mak Hiao River in a higher velocity. As shown in table 1, the wetlands of Vientiane's core were suffering great area losses at the same time which should have had further impact on the decreased water quality. Instead of passing through the city wetlands, the wastewater drained directly into the channels and on to the river. The great water purification function of wetlands and naturally vegetated channels had thereby been heavily reduced. In a study in Taiwan by Juang and Chen (2007) they examined how effective a constructed wetland could treat a polluted river. They showed that in 3.4 days the wetland could remove an average of 47.1 % of the total NH_4-N before the water reached the river. They found similar results of other indicators. A similar study, also from Taiwan, by Jing et. al. (2001) shows that wetlands can remove up to 51 % of COD per month. They concluded that the monthly average removal rate varies with the season and that aquatic vegetation had great impact on the water treatment. The mentioned studies from Taiwan indicate that the limited wetlands functions in Vientiane are one important reason for the decreased water quality in Houay Mak Hiao River the last decade. City expansion and fast population growth is most likely other explanations for the deterioration.

The result indicates that the water quality has successively gotten worse over the last decade. It is likely that this also can be associated with the ongoing wetland area losses.

The channelization in 2012-2013 has had great negative impact on the condition and water quality of Houay Mak Hiao River. The decreased water quality that has appeared right after the change is most likely a result of the increased delivery rate of pollutants from Vientiane. As it can be seen in figure 7-10, the deepening and clearing of obstructions has made way for a higher stream flow in the river. A study by Kuenzler et. al. (1984) in USA confirms that pollutions in channelized streams flow significantly faster than in natural flowing streams. As shown in figures 8-10, the channelization has caused large destructions of the riparian zones along the stream. The great filtration capacity has thereby been reduced. In a study of stream channels in New Zeeland by Cooper (1990) it was stated that the riparian zones could remove 56-100 % of the nitrate. It was concluded that plant uptake was responsible for most of the nitrate uptake. Riparian zones also remove other forms of nitrogen as well as phosphorus, although in a smaller extent (Parsons et. al., 1994). This may be one reason that the water quality has significantly been deteriorated since the channelization.

According to the results from the interviews it is difficult to see any significant differences in water quality in the different parts of the river. However, it is likely that the water is worse closer to the city as the result of water samples indicates (figure 11, 12 and 14). The exact degree of contamination might be difficult to describe for the respondents but it is obvious that the water quality is so bad that it can barely be used as a resource in any part of the river anymore.

6.2.2 Fish

As can be seen in table 6-12 the changes of fish catch in Houay Mak Hiao River has been drastically reduced the last years. It is most likely that the decreased numbers in fish catch reflects a decreased fish population. Although fewer people goes fishing these days, it can not be excluded that overfishing may have affected the population earlier. However, it is more likely that less fish is a result of the constantly declining water quality in the last years. Before, when the water quality was good the population was very strong, as the high fish catch number indicates (table 6-12). The bad taste and smell of the fish confirms that the poor water quality has affected the population negatively. As can be seen in figure 12 the ammonium levels are very high at most of the sampling sites. According to Wurts (2003), high amounts of ammonium in combination with high pH and high temperature can be very harmful to fish populations. The removal of the obstructions and vegetation in the river has led to habitat loss for the fish which in turn probably also has reduced the population. According to Hahn (1982), the increased velocity after channelization will affect the spawning success negatively and as the channelization of Houay Mak Hiao River has been so extensive, the increased current velocity will most likely affect the fish population even further. No significant differences in fish catch along the river could be found, which indicates that the entire river is affected. As shown in table 13, 8 species of fish can no longer be found in the river, which means that almost 20 % of the noticed fish species has disappeared. It is likely that the loss of species can be due to a combination of decreased water quality, habitat loss, increased current velocity and perhaps also overfishing. As the quantity of the fish catch was much larger before, a significant part of the villager's protein intake previously came from fish from the river. Now, the villagers have to buy their fish elsewhere which will affect the villager's with already limited economy. As this provisioning ecosystem service from the river no longer can be used, the villagers can no longer sell their fish catch which drives them to look for alternative jobs. For example, the young people of Ban Nano are more often sent to Vientiane to find jobs so they can help to provide the family.

6.2.3 Vegetation

The results show that the reduction and changes in the vegetation along the river is a consequence of droughts, new cultivation of land and lately also the channelization in 2012-2013. Bad water quality is probably another reason for the change in the biodiversity. Britto and Kronzucker (2002) states that excessive amount of ammonium is harmful for the rice production. The high amounts of ammonium shown in figure 12 might thereby be one of the reason why some rice fields along Houay Mak Hiao River has been damaged. As shown in figure 9, the channelization has had more harmful effects on the riparian vegetation than the floating vegetation. It can take years before the riparian vegetation fully recolonizes the riverbank and once again provides with water purification and habitat for aquatic organisms. The wild harvested eatable plants of the river such as *Ipomea aquatica* are less used for cooking due to ther high content of pollution. This makes the villagers more dependent of their cultivated crops. However, sometimes the crops are also harmed by the polluted water and then the villagers have to look for vegetables and rice elsewhere. This of course, puts burden to their economy, especially the poorest people.

6.2.4 Floodings

As shown in table 14, the villages along the river have been affected by the floodings in different ways. This can partly be explained by the fact that the villages are located in different distances from the river. As shown in figure 2, the extension of flow peaks following city development with lots of new impervious surfaces is higher than before urbanization. As many wetlands in Vientiane have been replaced by impervious surfaces in the last decades, this should result in more extensive and intense floodings in and around the city. The result shows that there were two floodings in the river in 2006 and 2008 which affected the rice fields. Before that there had not been any major floodings in over three decades. The floodings in 2006 and 2008 might thus be a result of the changes in the city. It is possible that the channelization in 2012-2013 will result in fewer flooding as the water will be transported to Mekong River in a higher velocity.

6.3 Results from water samples

The high amount of phosphate in the water indicates that the water is very polluted by wastewater (Bydén et. al., 2003). In the study by Whelan et. al. (2007) in March 2006, they showed that the first 12.5 km of the river was already polluted. Our results show that in this part of the river the phosphate levels have, with exception from sampling site F, increased since then. In November 2009, JICA (2011) measured the phosphate level at six sampling sites along the river and their results also generally show lower values than our results. As the phosphate levels did not change much between 2006 and 2009, the increased levels in 2013 might be due to the recent channelization which has led to a higher rate of delivery of pollutants and less uptake by plants. Other explanations could be wetland area loss as well as population growth which leads to higher discharge of wastewater. As shown in figure 11, the values drops further away from the city which can be explained by uptake by floating plants like the water hyacinth *Eichornia crassipes* (figure 9) and maybe also by dilution effects. Reddy and Tucker (1983) declares that the water hyacinth, which still is fairly common in some parts of Houay Mak Hiao River, has a great nutrient uptake capacity. Since lots of the riparian zone in the river has been damaged, it can thereby be assumed that the water hyacinth has the most important role as water purifier in the river.

The data from figure 12 shows that the ammonium levels are extremely high. According to Bydén et. al. (2003) can values that exceed 0.5 mg NH_4-N/l indicate proximity to wastewater discharge. Several of the measured samples showed values well over 10 mg/l NH_4-N which confirms the bad condition of the river. Some of the values are more than three times higher than in the study by Whelan et. al. (2007). This increase has probably similar reason as for the increased phosphate; increased current velocity and lesser uptake by riparian plants as a consequence of the channelization. The overall trend for ammonium in Houay Mak Hiao River is that the level falls with increased distance from Vientiane. The clear exceptions at sampling sites F and G (18.2 mg N/l respectively 12.9 mg N/l) might be explained by the discharge of ammonium coming from fish ponds just upstream of sampling site F. Downstream sampling site F, the concentration successively decreases and at the end of the river by sampling site I the level has decreased below detection level. The decreased ammonium levels indicate that the oxygen level in the water increases with increased distance from Vientiane. The high COD levels (figure 14) suggest that the oxygen level is very low close to the city and higher further downstream. With higher oxygen levels the ammonium starts to transforms to nitrite and nitrate (Camargo & Alonso, 2006), which partly can explain decreased ammonium levels downstream.

The nitrite + nitrate levels shown in figure 13 show low values. According to Bydén et. al., (2003) nitrate concentrations that exceeds 5 mg N/l indicates sewage discharge. The reason that the levels are so low can probably be explained by low oxygen level in the river and its tributaries. Because nitrite and nitrate cannot exist in anaerobic environments, it is likely that the nitrogen mostly appears in the form of ammonium. The results show that the middle of the river has the highest values of nitrite + nitrate and then declines towards the outflow into Mekong. The higher oxygen level further downstream can explain the higher concentration. According to Reddy and Tucker (1983), the water hyacinth *Eichornia crassipes* has great capacity to absorb both ammonium and nitrate. This might explain the reduced values at the end of the river. The nitrite + nitrate levels in proximity to Vientiane presented by Whelan et. al (2007) shows higher values compared to our results. This can be due to more oxygen in the water at that time.

The data from figure 14 shows high to extremely high COD values at sampling sites B-D, all of them close to Vientiane. According to the National Environmental Standards of Laos, the wastewater discharge from urban area is not allowed to exceed values of COD beyond 120 mg/l (Pholsena, 2009). Seen to this number, the values at sampling site C and D is far from acceptable. COD is a measure to calculate the oxygen consumption so according to our results the oxygen level is very low in the beginning of the river. The high levels of COD in the beginning of Houay Mak Hiao River mean that large quantities of organic matter are discharged into the water (Bydén et. al., 2003). The organic matter gradually decomposes and the COD values declines below detection at sampling site E, 7.7 km downstream. The result shows that the pH value at all sampling sites lies between 7 and 8 which are neutral to alkaline on the pH scale. The values lie within the allowed limits of wastewater discharge from urban areas in Laos (Pholsena, 2009).

6.4 Conclusions

Some of the landscape changes that have occurred in the last two decades have had devastating consequences for the condition of Houay Mak Hiao River and its ecosystem services. The channelization in Vientiane's drainage system in the beginning of the 21th century as well as the gradual urban wetland area loss in the last two decades has affected the water quality of the river in a very negative way. These changes resulted in significantly decreased water quality which in turn harmed the fish population and the vegetation along the stream. People living along the river, especially the poor will suffer the consequences of these losses of ecosystem services.

The channelization in 2012-2013 destroyed much of the riparian zones and increased the current velocity which led to further deterioration to the water quality and condition of the river. No significant improvements in fish population or vegetation recovery could be found with increased distance from the city. This can be explained by that the effects of the devastating recent channelization have impacted the entire river. However, it is possible to see some differences in the water quality with increased distance from Vientiane. The level of contamination decreases closer to the outflow into Mekong River which can be due to uptake by floating plants and dilution effects.

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.

Appendices

Appendix 1

QUESTIONNAIRE FOR ELDERS AND FISHERMEN ALONG HOUAY MAK HIAO RIVER

Survey Objective: Read out to respondents

We would like to talk to you about your memories and the history of Houay Mak Hiao River. We would like to know about the flooding and fisheries in the past. We also want to know what you think of the changes to the river and how it has affected the local area and its people.

A. General Information

Interviewer name:……………………………………………………………

Date of interview:…………………………………………….(dd/mm/yyyy)

Respondent name:…………………………………………………………..

Name of village:……………………………………………………………

B. Respondent Information

Gender: 1=Male, 2=Female

How old are you?..

How long have you lived in this village?..

What is your is/are your occupation/s?...

C. Memories and history of Houay Mak Hiao River

C.1. Can you describe how the historical condition of Houay Mak Hiao River was **30 years** ago? Talk about your memories of the river and cover the following topics:

- Water quality
- Vegetation extent
- Flooding (how frequently, effects etc.)
- Land-use along the river
- Fish species
- Fish quantities

Appendix 1

C.2. Can you describe the conditions of Houay Mak Hiao River **the years before** the channelization/drainage? Cover the following topics:

- Water quality
- Vegetation extent
- Flooding (how frequently, effects etc.)
- Land-use along the river.
- Fish species
- Fish quantities

D. Conditions of the Houay Mak Hiao River since the channelization/drainage

What changes have you observed in the river **since the channelization/drainage**? Cover the following topics:

- Water quality
- Vegetation extent
- Flooding (how frequently, effects etc.)
- Land-use along the river.
- Fish species
- Fish quantities

E. Are there any other comments you wish to make?

Appendix 1

Fish Species	Quantities **30 years** ago (number of fish per day)	Quantities **5 years** ago (number of fish per day)	Quantities **today** (number of fish per day)
Pa Ko			
Pa Douk			
Pa Keng			
Pa Kadeut			
Pa Ninh			
Pa Nai			
Pa Khaomong			
Pa Sieu			
Pa Kot			
Pa Salit			
Pa Pak			
Pa Kat			
Pa Mat			
Pa Sout			
Pa Souam			
Pa Sathong			
Pa Yen			
Pa Khapkhong			
Pa Kagen			
Pa Thong			
Pa It			
Other species			

Thank you very much for your information and cooperation!

Appendix 2

Location of sampling sites.

Name of sampling site		Coordinates WGS84	
		N coordinates	E coordinates
A	Hong Ke	17˚58'04.46"	102˚48'29.80"
B	Hong Xeng	17˚59'12.11"	102˚38'15.81"
C	Hoa Khoa	17˚58'33.49"	102˚38'54.45"
D	Nong Nieng	18˚00'01.97"	102˚39'09.72"
E	Ban Sok	18˚00'14.94"	102˚40'49.41"
F	Na Kuai	17˚58'13.68"	102˚42'18.73"
G	Ban Nahai	17˚58'12.89"	102˚44'34.75"
H	Footbridge	17˚59'54.19"	102˚47'58.88"
I	Ban Mak Hiao Gate	18˚00'00.18"	102˚44'28.86"

Appendix 3

Fish species that can be found in Houay Mak Hiao River 2013		
No.	**Lao name**	**Scientific name**
1	Pa Ko	*Channa striata*
2	Pa Douk	*Clarias batrachus*
3	Pa Keng	*Anabas testudinens*
4	Pa Kadeut	*Trichogaster trichopterus*
5	Pa Ninh	*Oreochromis niloticus*
6	Pa Nai	*Cyprinus carpio*
7	Pa Khaomon	*Puntius brevis*
8	Pa Sieu noud	*Esomus longimana*
9	Pa Sieukao	*Rasbora rubrodorsalis*
10	Pa Kot	*Hemibagrus filamentus*
11	Pa Salit	*Trichogaster pectoralis*
12	Pa Pak	*Barbodes gonionotus*
13	Pa Sout	*Hampala dispar*
14	Pa Souam	*Omopak krattensis*
15	Pa Sathong	*Xenentodon canciloides*
16	Pa Khapkhong	*Pseudambassis notatus*
17	Pa Kagneng	*Mystus mysticetus*
18	Pa Tongna	*Notopterus notopterus*
19	Pa It	*Lepidocephalichthys hasselti*
20	Pa Lot	*Macrognathus simiocellatus*
21	Pa Lad	*Mastaccembeis armatus*
22	Pa Kar	*Pristolepis fasciata*
23	Pa Boor	*Oxyeleotris marmoratus*
24	Pa Kao	*Wallago attu*
25	Pa Kheung	*Mystus wyckioides*
26	Pa Nou	*Helichophgus waandersii*
27	Pa Sagnua	*Micronema apogon*
28	Pa Khoun	*Wallogo leeri*
29	Pa Har kouay	*Acanthopsoides delphax*
30	Pa Vienphai	*Barbodes altus*
31	Pa Sakang	*Puntioplites falcifer*
32	Pa Ethai	*Osteochilus microcephalus*
33	Pa Var	*Bangana ssp.*