Adaptation to saline intrusion of the groundwater in the coastal area of Vĩnh Châu

Cooperation: Can Tho University and Van Hall Larenstein University of Applied Sciences

Author: Joep Hagenvoort

Project area: Vĩnh Châu, Vietnam

Subject: Adaptation to saline intrusion

Date: 3th of July 2013, Can Tho

Version: Final

Adaptation to saline intrusion of the groundwater in the coastal area of Vĩnh Châu

Author: Joep Hagenvoort
Subject: Adaptation to saline intrusion
Cooperation: Can Tho University and Van Hall Larenstein University of Applied Sciences
Date: 3th of July 2013, Can Tho
Version: Final

Colofon

Cooperation:

Can Tho University
Campus II, 3/2 street
Ninh Kieu district
Can Tho city, Viet Nam
Tel: (84-710) 3832663 - (84-710) 3832660

Van Hall Larenstein
Larensteinselaan 26a
6882 CT Velp
Tel: 026-3695695

Author:

Joep Hagenvoort
joep.hagenvoort@gmail.com
joep.hagenvoort@wur.nl
Mobile: 06 – 17568481 / 841242950694

Supervisor Can Tho University:

Dr. Van Pham Dang Tri
vpdtri@ctu.edu.vn
Mobile: 090 955 20 92

Supervisor Van Hall Larenstein:

Ir. Peter Groenhuijzen
peter.groenhuijzen@wur.nl
Skype: p.groenhuijzen

Preface

This report contains the Bsc-thesis for the Bachelor Land and Water Management at the Van Hall Larenstein University of Applied Sciences. The cooperation of Van Hall Larenstein University of Applied Sciences and the Can Tho University gave me the opportunity to go abroad for my final thesis.

I would like to thank Dr. Van Pham Dang Tri, for his support and advice during my graduation period. Furthermore, I would like to thank Ir. Peter Groenhuijzen and Dr. Pham Van Toan in helping with the whole graduation process during my stay in Can Tho.

It was not always easy to manage in a different country with another culture. The first month was difficult due to problems with my research plan. I want to thank Maartje Wise from Royal Haskoning/DHV for giving me the right advices during this period and also for her feedback at the end of my Bsc-thesis. I get the opportunity to contribute in the DELTAS2013 as a reporter, I want to thank Rien Dam from Deltares for giving me this opportunity.

The fieldwork was not possible without the help of the students Douwe Terpstra, Thanh Hoa Pham and Nguyen Thi Bich Phuong.

Finally, I am grateful of all the support given by family and girlfriend during this bachelor thesis.

6^{th} of June 2013
Joep Hagenvoort

Abstract

The Vietnamese Mekong Delta (hereafter: VMD) covers 39,000 square kilometres of fertile alluvial plain and is home to over 18 million people. Groundwater provides the supply of drinking water to millions in the VMD. The extraction of groundwater has increased rapidly over the past decades and forms the main cause of saltwater intrusion into the coastal aquifers with sea level rise as an accelerator. Saline intrusion in the VMD is a complex system that depends on many factors like magnitude of floods, the ability of freshwater upstream during the dry season as well as the amount of fresh groundwater due to excessive groundwater extraction and timing of the rainy season. The future brings many uncertainties to these factors due to climate change.

The main objective of the research is to provide insight in the current adaptation to the possible increasing salinity of the groundwater in the VMD with a detailed focus on the coastal area of Vĩnh Châu and to understand which lessons can be learned for adaptation to the on-going climate change.

The research is built from a regional to local scale, with the VMD as a regional area and the coastal area of Vĩnh Châu as a local area. First, the delta has been analysed with a literature study. The VMD always had two-sides with floods in the rainy season and water scarcity/saline intrusion in the dry season. Saline intrusion is a natural process that is reinforced by the extraction of groundwater and climate change. According to scenarios in the report Climate Change in the Mekong Delta the dry season becomes drier and the wet season wetter. This could mean an increase of saline intrusion during the dry season with a sea level rise prediction of 65-100 cm for the year 2100. The article Delta at the Crossroads: More Control or Adaptation stated that in the past saline intrusion was obstructed with salinity-protection systems to protect formerly freshwater systems and transform brackish areas into freshwater areas. The building of new canals and control structures bring the saline intrusion to new areas. The land use in the Vĩnh Châu district has changed over the past 20 years from rice cultivation to shrimp farming due to the diversification policy in 2000 that allowed re-entry of seawater in the formerly salinity-controlled area. Aquaculture covers the lower parts of the Vĩnh Châu district and upland crops are cultivated on the higher sand ridges with intercropping of paddy rice in the rainy season. The aquaculture is a solution for saline coastal areas but is currently not sustainable due to high inputs and the economic risk. Deep groundwater is used for irrigation of upland crops and the analysis of the salinity tolerance of the different crops compared to the salinity levels of the irrigation water showed that there is a yield reduction between 0 – 5% for the cultivation of onions. If salinization of the groundwater increases in the future due to climate change predictions, the farmers that cultivate upland crops could face problems of increased yield reduction.

Based on this study, a number of key lessons can be identified for the future with increasing climate change impacts:

- Salinity levels do not cause yield reduction in the current situation. The future with climate change could increase salinity levels which forms a threat for the upland crop production and other factors like high inputs and the economic risk make shrimp farming unsustainable in the future;
- Saline intrusion is not the main problem in the Vĩnh Châu district because of the wide implementation of marine aquaculture. Protection to sea level rise could have priority for the low-lying coastal areas;
- Farmers rely on the deep groundwater but other sources like shallow groundwater and rainwater could make farmers more sustainable;
- Sluice to restore the former salinity-controlled area;
- Efficient groundwater use like optimizing pumping schemes or changing irrigation methods;
- Increase mixed shrimp-mangrove systems to combine ecology, agriculture and economy;
- Role of government for accelerating the adaptation process.

Table of contents

1. Introduction

1.1. Problem description

The Vietnamese Mekong Delta (hereafter: VMD) covers 39,000 square kilometres of fertile alluvial plain extending from Vinh Xuong at the Cambodian border to Vietnam's East Sea. The VMD is home to over 18 million people and makes a substantial contribution to the national Gross domestic product. It includes half of Vietnam's rice production and almost 100% of its rice exports (IUCN, 2011).

Groundwater provides valuable services to the VMD. The groundwater in the VMD supplies water for domestic use, urban/rural water supply, irrigation, aquaculture and industrial sites. Residents in rural and coastal areas are dependent on fresh groundwater because of the availability of fresh water during the dry season due to saline and/or polluted canal water. The extraction of groundwater from aquifers that have hydraulic connection with the sea may cause migration of salt water from the sea towards a well. The consequence is that the freshwater aquifer becomes saline and unusable for drinking purposes. Groundwater extraction has increased rapidly due to the increasing water demand (Wagner, et al., 2012) and declining groundwater levels now pose an immediate threat to drinking water supplies, farming systems, and livelihoods in the VMD (IUCN, 2011).[1] Climate change in combination with increasing groundwater extraction forms a threat for agricultural production, livelihoods and environment throughout the world. Sea level rise and increasing temperatures in the VMD are the main concern for increasing salt water intrusion of the groundwater (Deltares & Delta Alliance, 2011).

The farmers in the Vĩnh Châu district implemented some adaptation strategies to deal with the salinisation problem, like for instance intercropping. An overview of the adaptation strategies to saline intrusion of the groundwater is missing in the Vĩnh Châu district.

1.2.Define pilot area

The VMD serves as the regional research area. After the regional scale the research focuses to a local scale. The research is focused on different scales to understand all the factors that contribute to saline intrusion of the groundwater, with the local scale as detailed focus. The area of interest is the Vĩnh Châu district, in the Soc Trang Province. The Vĩnh Châu district forms the local area because there is already data available from the Can Tho University (CTU) and the area is in recent years heavily affected by saltwater intrusion and droughts (United Nations Development Program, 2010). The regional area with the provinces and local area are presented in Figure 1-1. Vĩnh Châu consists out of 10 communes with an area of 473 km^2 and it is home to 164.000 people (Statoids, 2011).

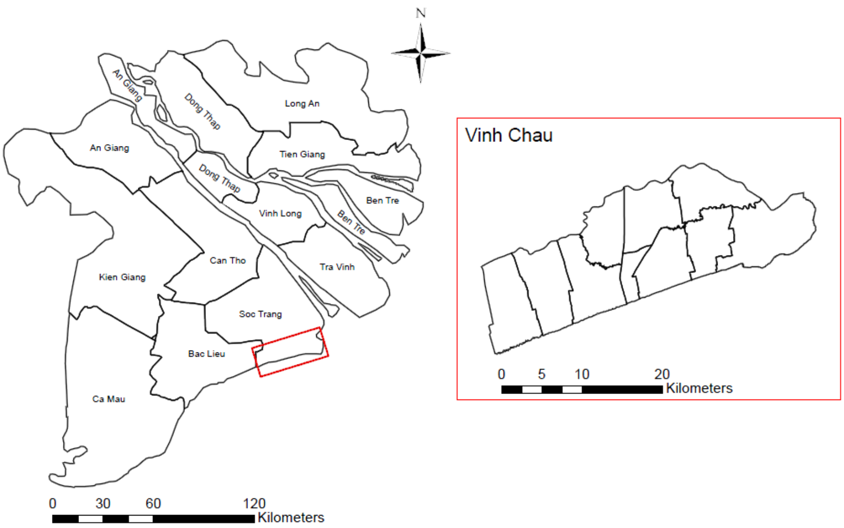


Figure 1-1. Regional focus on the Vietnamese Mekong Delta and the Vĩnh Châu district as local area.

[1] A reduction in groundwater and sediment delivery in the VMD due to sedimentation trapping behind dams, along with human control of routing river discharge across delta plains, contributes to the subsidence of the VMD (Syvitski, 2008)

1.3. Objective

The farmers in the Vĩnh Châu district already implemented some adaptation strategies but an overview of these strategies is missing. The overall objective of the research is to get insight in the current adaptation to the possible increasing salinity of the groundwater in the VMD with a detailed focus on the coastal area of Vĩnh Châu and to understand which lessons can be learned for adaptation to the on-going climate change.

The overview of adaptation strategies is important to provide insight in the current adaptation and sustainability to climate change. The lessons-learned could be used by governments or non-governmental organizations (hereafter: NGO's) in forming or implementing adaptation strategies. The VMD forms an area of interest for NGO's that provide research or finance projects on saline intrusion, mainly based on surface water. This research could provide insight in the adaptation to saline intrusion of the groundwater.

1.4. Main and sub questions

The objective is to provide insight in current adaptation strategies to saline intrusion in the VMD with a detailed focus on the coastal area of Vĩnh Châu. Research on current adaptation strategies for the whole VMD requires a lot of time/materials and therefore the decision is made to focus in detail on the coastal area of Vĩnh Châu. The research is based on the following main question:

'Have farmers in the coastal area of Vĩnh Châu adapted in a sustainable way to the possible increasing salinity of the groundwater in the Vietnamese Mekong Delta and if so, which lessons can be learned for adaptation to the on-going climate change?'

The following sub questions are based on this main question:

Regional scale: Vietnamese Mekong Delta

- What are the causes of saline intrusion in the VMD? And what are the adaptation/controlling measures for the VMD over the past 50 years?
- What are the climate change scenarios and causes for the regional area?
- What are the changes in land/agricultural use in the VMD throughout the years?
- How do other deltas in the world control/adapt to saline intrusion? And are there new techniques for the protection to saline intrusion in the groundwater?

Local scale: coastal area of Vĩnh Châu

- What are the current adaptation strategies due to salinization of the groundwater in the coastal area Vĩnh Châu?
- Which adaptation strategies are necessary for the future?
- What are the conclusions and recommendations for the coastal area Vĩnh Châu due to saline intrusion in the deep groundwater?

1.5. Report structure

The report structure is presented in this sub paragraph, with the following structure: literature study focussing on the VMD, a more detailed focus on the coastal area of Vĩnh Châu and a discussion chapter combining all the data. The report provides the following information:

Chapter 1 – an introduction to the project area, as well as a problem description, the research objective, research questions and the report structure.
Chapter 2 – this chapter describes the methodology that is used for the research.
Chapter 3 – the literature study with a focus on the VMD about main causes saline intrusion, land use changes, climate change scenarios and learning from other deltas in the world.
Chapter 4 – the analysis of the interviews and salinity levels of the groundwater for the salt tolerance of the two main land use types in the coastal area of Vĩnh Châu.
Chapter 5 – discussion about the literature study, interviews and salinity levels of the groundwater.
Chapter 6 – conclusions and recommendations are presented.

2. Methodology

This chapter provides insight in the methodology of the research. First the planning process is described in different phases. The research is built from a regional to local scale and the different scales are discussed. Based on the main and sub questions defined in the previous chapter, the research is divided in several activities carried out in the Vĩnh Châu district. Figure 2-1 schematizes the planning process of the research.

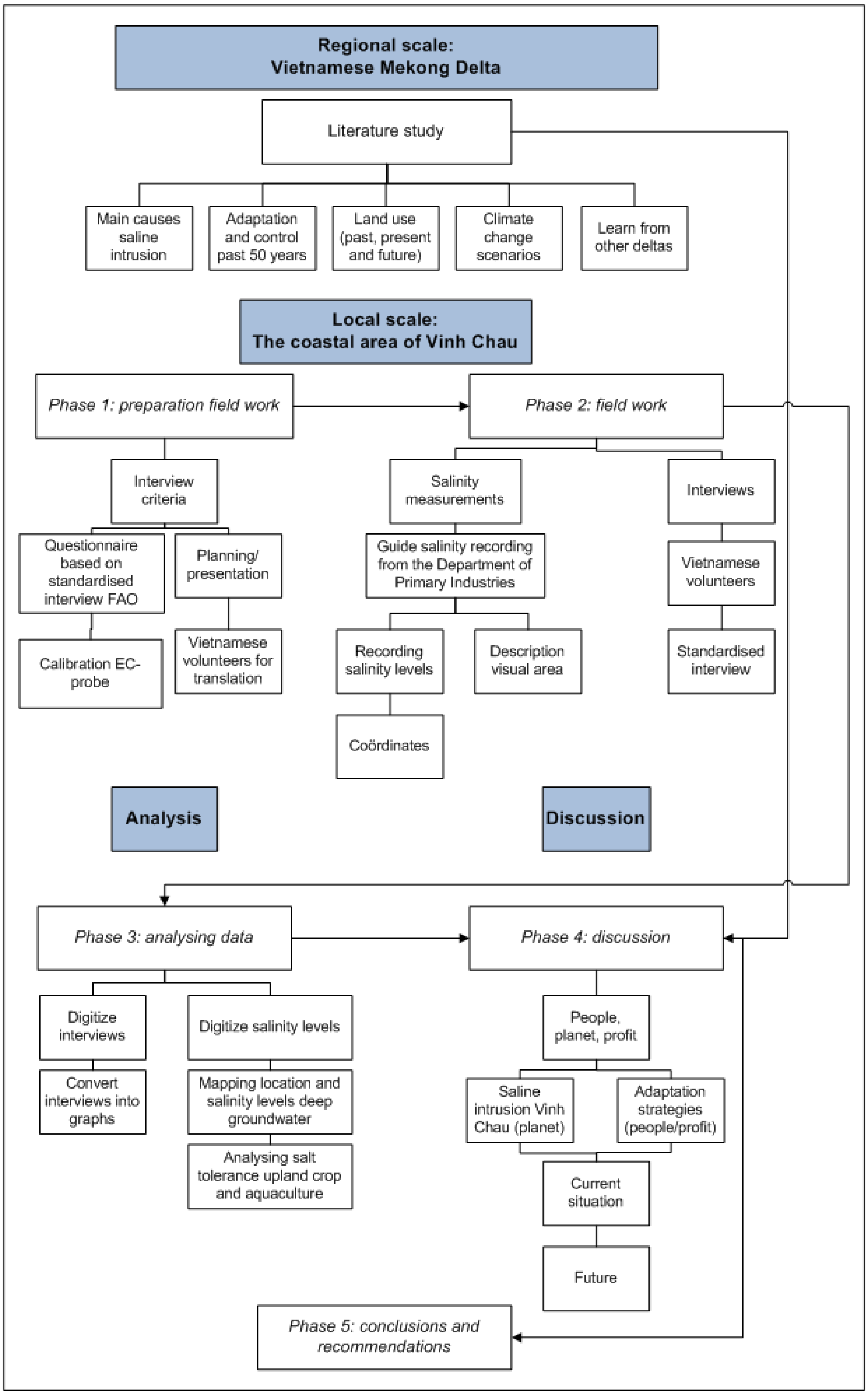


Figure 2-1. Schematization of the planning process.

2.1. Planning process

This subparagraph describes the planning process used in this research. This process is divided in different phases, shown in Figure 2-1.

Phase 1: preparation field work

Interviews are based on a structured standardised interview (Food and Agriculture Organisation, 1997). This means that questions are asked in a manner to ensure no variations between interviews. Most of the questions were set to get a yes or no answer from the farmer and if yes what is their explanation. The questionnaire is presented in Annex 1 .Criteria for the location as well as the choice of farmers is set up before going into the field. Figure 2-2 presents the Vĩnh Châu district together with the transect lines used for the interview locations and groundwater salinity measurement. The criteria for choosing these two transect lines are:

- The previous trainees did interviews in the same area, data availability;
- To provide insight in the difference in salinity levels inland;
- To get a diverse land use pattern for a variation in interviews. Annex 2 presents the land use map of the Vĩnh Châu district;
- The land elevation is in some places higher because of sand dunes. Annex 3 presents the shuttle radar topography mission (hereafter: SRTM) and the officially accepted Digital Elevation Model (hereafter: DEM);
- To get different zones from the agro-ecological map, this gives an indication about the salinity of the soil. Annex 4 presents the agro-ecological map.

Criteria are set up before going into the field to interview the farmers. The reason for setting up these criteria is to get a selection of farmers to interview in the field. There is no data available about the amount of farmers and where the farmers are settled. So criteria for interviewing are set up based on the land use and agro-ecological map, this is discussed with the local government DONRE. The criteria for choosing interviews:

Figure 2-2. Vĩnh Châu with transect lines for interviewing and groundwater salinity measurements.

1. A wide range of different farms is needed to provide insight in the current adaptation to salinity levels (see Annex 2). For example: shrimp farming, rice, onions, vegetables, fruits, salt and Artemia.
2. The farmers must be interviewed on the higher sand-ridges as well as the lower parts (see Annex 3);
3. At least one interview in each zone according to the agro-ecological map (see Annex 4);
4. For the groundwater measurements, the research depends on different groundwater wells at the farms. The segment line is about 10 to 15 kilometres long. The measurement of the groundwater to measure the salinity is not bonded to the transect line.

The following equipment has been used during the field trip for the measurement of the salinity level of the groundwater:

- EC-probe;
- Two identical lab glasses;
- Bottle of calibration solution;
- Bottle of check solution;
- Box for travelling and cleaning material.

The EC-probe that is used in the field is a Basic Conductivity Meter from ORION, Model 105. Calibration of the EC-probe took place before the start of the field trip. The instruction manual from the ORION is used for the calibration (Thermo Electron Corporation, 2003). Annex 5 provides the steps that are followed for calibration.

Phase 2: field work

The interviewing and translation is done by two Vietnamese volunteers. The lesson that can be learned is that the technical knowledge combined with interviewing experience of the interviewer is very important to get good interview results.

The measurements on the salinity levels of the groundwater take place with every interview. It is very important that there is full assistance from the farmer to cooperate in the research. The salinity levels of the groundwater where directly recorded with an EC-probe provided by the CTU, visible in Figure 2-3 (Eijkelkamp, 2013). A guide for measuring the salinity of the groundwater from the Department of Primary Industries about water samples and the recording of their salinity levels is used in the field for the measurements of the salinity levels of the groundwater. Annex 6 presents the steps that are followed. But the reality is different from the theory. It was not always possible to reach the pump to collect the water. In this case the farmer collects the water, which makes the measurement less precise. In some cases the farmer already pumped groundwater in the morning, which was collected in a barrel. Most of the time it was not possible to let the groundwater pump run for a couple of minutes before sampling because the farmer controlled the pump.

Figure 2-3. Interviewing and measuring groundwater.

The plan was to measure the arsenic in the groundwater together with the salinity because of the wide spread health problems occurring from drinking polluted groundwater (Berg, et al., 2001) (Berg, et al., 2006). The CTU has no equipment to measure the arsenic level in the groundwater, so only the salinity measurement of the groundwater is taken into account in this research. Table 2-1 is used in the field to rank the salinity measurements and by using the GPS to note the exact location. Also a visual description of the surrounding area is provided with photos.

Table 2-1. Place and description used to rank the salinity level measurements of the groundwater.

Sample number/Photo number	***Coordinate salinity sample***	***Visual sight of the area***

Phase 3: analysing data

Phase 2 provides information that is needed to be digitized and analysed. This is the start of phase 3. Graphs and the outcomes of the interviews are created, together with the mapping of the groundwater pumps and salinity levels of the groundwater in ArcGIS. The calculation from an EC value (µS/cm) to a chloride concentration (mg/l) is done with the following formula from Deltares:

Chloride concentration (mg/l) = 0.3108 EC (µS/cm) – 170.03 (Oude Essink, et al., 2009)

The reason for this conversion is to classify the groundwater quality. Furthermore is the hydrogeological profile analysed for the different salinity levels to understand the salinity changes from coastline to inland. The sensitivity of the upland crops and aquaculture for salinity levels of the groundwater are analysed, to provide insight in the current situation.

Phase 4: discussion

In this phase the data gained from interviewing and measuring is compared with the results of the literature study. Figure 2-4 presents the research approach. The discussion chapter is conceptualized on the three P's: People, Planet, Profit. The discussion provides insight in the saline intrusion for the Vĩnh Châu district in the current situation and has a focus on the future related to climate change (planet). Furthermore it describes the current adaptation strategies in the Vĩnh Châu district for the main land use types and shows possible adaptation strategies for the future to be more sustainable (people and profit).

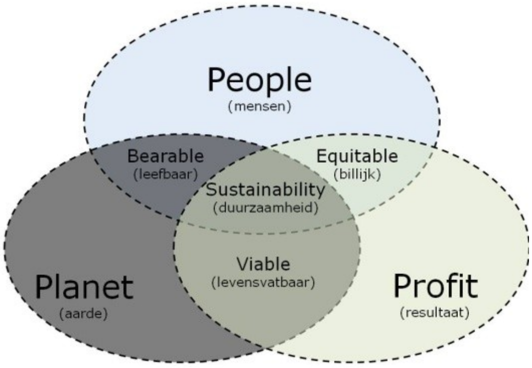


Figure 2-4. Three P's principle (Managementmodellensite, 2013).

Phase 5: conclusions and recommendations

The last phase of the research concludes the main research results and recommendations are given.

2.2. Working with scales

The research is focused on different scales to understand all the factors that contribute to saline intrusion of the groundwater, with the local scale as detailed focus. This subparagraph provides insight in the different scales.

2.2.1. Regional scale: Vietnamese Mekong Delta

The research plan forms the basis for the research. The literature study forms the beginning of the report with a focus on the regional area of the VMD as stated in Figure 1-1. The regional scale is used to understand all the factors that contribute to saline intrusion of the groundwater. The literature study provides insight in the adaptation and controlling measures related to saline intrusion in the VMD over the past 50 years and what the main causes are of saline intrusion. The next step is to gain information about the agricultural land use changes in the VMD throughout the years. The reason for this is to see how the land use has changed and what the reasons are for this change. Climate change plays an important role, especially for the future of the Vietnamese Mekong Delta. This report describes the climate change predictions for the VMD. The last part of the literature study shows how other deltas in the world handle saline intrusion, to see if there any new techniques concerning adaptation to saline intrusion.

2.2.2. Local scale: the coastal area of Vĩnh Châu

The research becomes more detailed after the regional focus on the VMD. The coastal area of Vĩnh Châu serves as the local area (see Figure 1-1). The Vĩnh Châu district forms the local area because there is already data available from the Can Tho University (hereafter: CTU) and the area is in recent years heavily affected by saltwater intrusion and droughts (United Nations Development Program, 2010).

2.3. Activities

This subparagraph provides insight in the activities that are carried out in the Vĩnh Châu district. The activities are based on main and sub questions stated in chapter 1.

2.3.1. Describe factors related saline intrusion Vietnamese Mekong Delta

The research starts with the gathering of information to understand factors related to saline intrusion in the VMD. This is done by a literature study of research documents, project reports and existing databases. The literature study provides the needed background information to answer the main question of the research. First the main causes of saline intrusion in the VMD are described together with the adaptation/controlling measures over the past 50 years. The next step is to describe the climate change factors that influence saline intrusion. The land use changes in the VMD are investigated to understand the adaptation to saline intrusion on a regional scale. The last part focuses on the controlling/adaptation to saline intrusion of other deltas in the world.

2.3.2. Mapping the current saline intrusion in the Vĩnh Châu district

The current salinity levels of the groundwater are used to understand the adaptation to saline intrusion in the Vĩnh Châu district. The measuring the salinity of the groundwater is used to collect the current salinity levels of the groundwater. Maps of the current salinity levels are made by importing coordinates and current salinity levels.

2.3.3. Analysing groundwater quality and salt water tolerance cropping systems in the Vĩnh Châu district

The analysis of the groundwater quality and salt water tolerance of cropping systems is done by comparing the salinity tolerance of the different crops to the current salinity levels. This analysis provides insight in the current yield reduction, in order to understand the current adaptation strategies. Furthermore the groundwater quality is analysed based on data gathered from interviewing, measurements of salinity levels groundwater and literature study.

2.3.4. Analysing current adaptation strategies to saline intrusion in the Vĩnh Châu district

The second analysis is done by combining all the data gathered from interviewing, measurements of salinity levels groundwater and literature study. This analysis provides a list with current adaptation strategies that are needed to quantify the current sustainability. Furthermore, additional adaptation strategies could be proposed in order to make it more sustainable.

3. The Vietnamese Mekong Delta

The VMD is stated as regional area for the literature study. The literature study for the VMD provides insight in the main causes of saline intrusion together with adaptation and controlling measures to saline intrusion over the past 50 years. The next step is to give an insight in the changes of agricultural land use in the VMD for the past, present and future. Furthermore this chapter describes the climate change scenarios for the VMD and investigates how other deltas in the world control/adapt to saline intrusion.

3.1. Saline intrusion Vietnamese Mekong Delta throughout the years

The VMD serves as regional research area. This paragraph provides understanding of the adaptation and/or control to saline intrusion over the past 50 years and what the main causes of saline intrusion in the VMD are.

3.1.1. Main causes saline intrusion

There is a general pattern for fresh groundwater flow in coastal aquifers. The inland recharge areas with the highest groundwater levels flow to the coastal discharge areas which have the lowest groundwater levels. Fresh groundwater makes contact with saline groundwater in the coastal aquifers at the border of land and sea. Figure 3-1 shows the groundwater flow pattern at the transition zone. The salt groundwater is controlled by the amount of freshwater flowing through the aquifer (depends also on other variables like density salt-fresh water and hydraulic properties aquifer). Within the transition zone there occurs mixing of fresh and salt water. (M. Barlow, 2003)

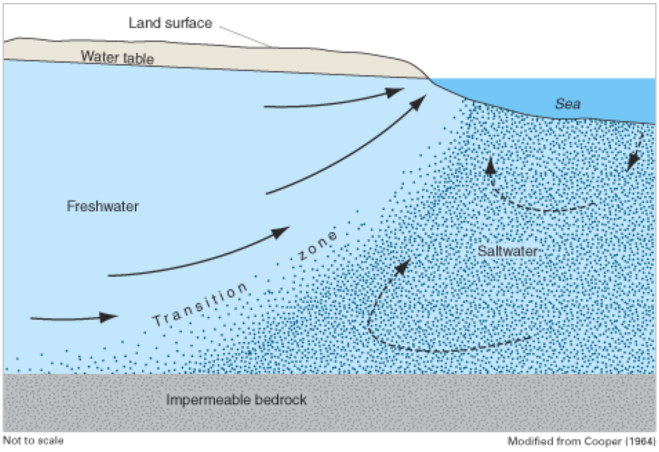


Figure 3-1. Groundwater flow pattern at fresh-saltwater transition zone (M. Barlow, 2003).

The main cause of saltwater intrusion in coastal aquifers is due to excessive extraction of groundwater, with sea level rise as an accelerator for saline intrusion (Abd-Elhamid & Javadi, 2008). Figure 3-2 shows the effect from sea level rise.

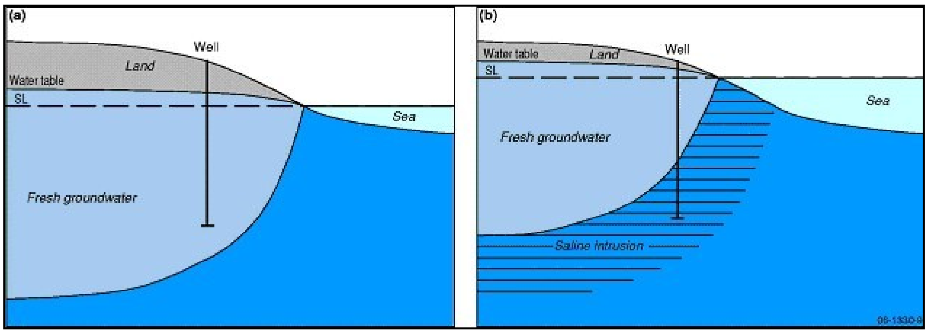


Figure 3-2. a) current coastal aquifer b) same aquifer under a sea level rise scenario. Extraction of groundwater should be reduced or stopped in this case (Australian Online Coastal Information, 2012).

As Figure 3-2 shows, the saline groundwater moves underneath the fresh groundwater. The reason is that salt water has a higher mineral content than fresh water, it is denser and has a higher water pressure. The result is that salt water pushes inland beneath the fresh water (Chang, 2000). This process depends on the following two factors:

- The aquifers permeability. The more permeable, the more affected by saline water.
- The freshwater flow in the aquifer, related to recharge and groundwater extraction more inland.

Main causes saline intrusion Vietnamese Mekong Delta

The report Mekong Delta Water Resources Assessment Studies from Deltares and the Delta Alliance is used to provide insight in the causes of saline intrusion in the VMD (Deltares & Delta Alliance, 2011). Saline intrusion in the VMD is a complex process that depends on many factors. It depends on the magnitude of floods, the ability of fresh water from upstream during the dry season as well as the amount of fresh groundwater due to excessive groundwater extraction, summer-autumn paddy production status and timing of the rainy season. The highest salinities occur late in the dry season (April – early May). When the flood season starts, flood waters from upstream push the salt back to the estuaries. The high salinities in the mid-flood season can usually be found in the estuaries only. When year after year large floods occur, the salt water intrusion is pushed outwards. This is different compared to small floods when the salt water intrusion can reach far upstream the rivers and canals.

The saltwater intrusion becomes worse due to withdrawals of irrigation water upstream of the Mekong River. Because of the rapidly increasing agricultural and urban development there is more and more water withdrawn. (Mekong River Commission For Sustainable Development, 2001)

3.1.2. Adaptation and/or controlling saline intrusion Vietnamese Mekong Delta over the past 50 years

In the article of (Käkönen, 2008) is stated that water in the VMD always had two-sides. On one hand, the Mekong brings alluvium-rich waters which cause many benefits to the area. The other side is that the VMD has been exposed to permanent threat of floods in the rainy season and water scarcity/saline intrusion in the dry season. The last decades measures towards the environment have switched from adaptation to control and also the decision making at farm level to centralized decisions at different scales. The building of large-scale hydraulic control structures targeted the floods in the upper part of the VMD and the saline intrusion in the coastal zone. Most salinity-protection systems were realized in the 1990s (from 40.000 ha to 450.000 ha) but American advisors provided the basis in the Mekong Delta Development Plan during the 1960s. The salinity controlling aimed not only to protect formerly freshwater systems for the increasing salinity but also to transform brackish areas into freshwater areas. The combination of agricultural modernization, agrochemicals and hydraulic control structures gave a boost to the agricultural production in the VMD. This has environmental consequences with an increase of saline intrusion. Another factor is that the new canals and control structures bring the saline intrusion to new areas. In the current situation these salinity structures face challenges because shrimp cultivation in coastal zones needs brackish water conditions.

3.2. Agricultural land use changes Vietnamese Mekong Delta past and future predictions

This paragraph provides insight in the land use change for the VMD. The report Land Use/Land Cover Change In South-East Asia provided by the UNEP Environment Assessment Programme for Asia and the Pacific (1998) is used as reference to classify the land use changes for the VMD (Prasad Giri, et al., 1998). This report shows the land use changes for the VMD from 1965 and 1992-1993. The future of the land use changes is modelled by the Wageningen University (van Dijk, et al., 2013).

Land use changes 1965 – 2000

The VMD provides 45% of the total rice production of the country. 40% of the total area is alkaline and 700,000 ha are affected by saline intrusion. Two land use maps from 1965 and 1993/94 are stated in Annex 8. There was a high pressure on the remaining unused land through artificial reclamation and irrigation, the rice growing areas have expended. Many of the wastelands and dry lands have now converted into rice fields. But also rice fields were converted into sugarcane/coconut plantation, shrimp ponds and salt pan. The reason farmers converted the rice fields is that this are cash crops and therefore more profitable. During the Vietnam War deforestation and land degradation took place. The remaining forests are being converted to rice fields, shrimp ponds and salt pans. In the past single cropping was possible due to flooding, drought and salinity but now the practices of three crops a year are possible. This depends on the water supply and flooding condition. The salinity changes when flooding and frequency of tides change. Saline water intrusion was obstructed with the building of roads and some artificial measures. Around the year 2000, high yielding rice was introduced to create a higher production per unit area, often together with measures to check the salinity level. Some areas become good for shrimp breeding. Cropping patterns and cropping systems changed rapidly in this period in the VMD. (Prasad Giri, et al., 1998)

The occupation of agriculture in the VMD is about 85% of the total area in 2000. The cultivable land has grown rapidly over the past 20 years, the result was an expansion and increased density of irrigation and drainage canals system. An increase of agricultural areas took place from 1976 to 1990, approximately with an increase of 20%. While the total production doubled due to better water management and cropping cycle patterns. The areas of rice cultivation have increased yearly by more than 100,000 ha during the time period 1995-1999. (Le Anh, et al., 2008)

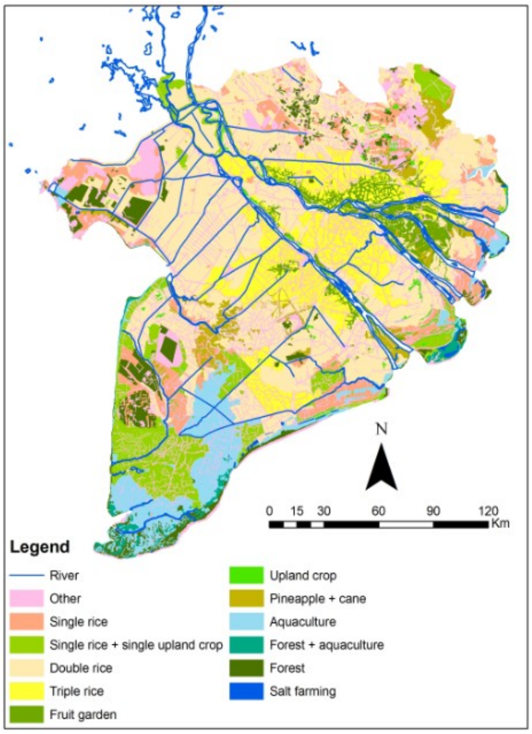


Figure 3-3. Land use map VMD 2006 (Van, et al., 2012).

Current land use 2000 – 2011

The current land use map from 2006 is presented in Annex 9 and Figure 3-3. The VMD is very important for Vietnam's agricultural production. The CTU estimates a rice production of 50% of the nation's rice, 80% of the nation's fruit and 60% of the nation's fish in the VMD. This makes the VMD the largest agriculture and aquaculture production region in Vietnam. The overall view shows that 46% of the total food production in Vietnam comes from the VMD. The rice cultivation is the primary livelihood for 60% of the inhabitants of the VMD. Figure 3-3 shows that the VMD primarily exists out of agricultural area (75% of the VMD), especially paddy rice cultivation. Because of the large amount of agricultural land the VMD irrigate on large scale to get a high agricultural output. The high output is not only crucial for food security but also very important for the Gross Domestic Product (hereafter: GDP) of Vietnam (GDP 27%). (Käkönen, 2008)

Future land use predictions (2030)

Wageningen University made a model to predict the land use change for the VMD in the year 2030, in the report Land-use change, food security and climate change in Vietnam (van Dijk, et al., 2013). Annex 10 shows the predictions for the VMD per scenario on map. The model is based on climate change, economical progress, population growth and food security in Vietnam with two different scenarios. The Business As Usual (BAU) scenario reflects a future with major socio-economic drivers following the current trends. The other scenario is the High Climate Impact (HCI) that reflects a global future with rapid temperature change, high sensitivity of crops to global warming and a CO_2 fertilisation effect at the lower end of published estimates. The focus lies on predictions from the year 2007 till 2030.

The outcomes of the model for land use change in the VMD show an expansion in built-up land between 2007 and 2030 in line with the expected urban population growth in Vietnam. The growth of built-up land in the VMD is heavily concentrated around Ho Chi Minh City and in some areas of the VMD. The expansion of built-up land causes large areas of paddy rice to disappear. (van Dijk, et al., 2013)

Land use changes Vĩnh Châu district

The land use in the Vĩnh Châu district changed over the past 20 years. In 1990 the most common cultivation in Vĩnh Châu was paddy rice. In twenty years this changed to shrimp farming. The land use change is visualized in Figure 3-4.

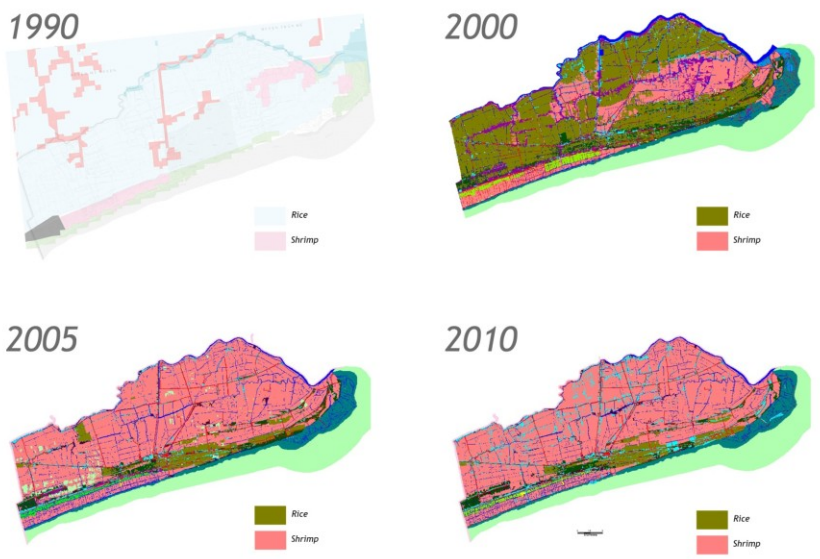


Figure 3-4. Change from paddy rice cultivation to shrimp farming Vĩnh Châu district (Pampus, et al., 2013).

The reason for this rapid change inland use is that the farmers protested against the protection of the salinity-controlled area, this resulted in the government allowing diversification of land use from the year 2000 onward. This diversification policy allowed re-entry of seawater into the formerly salinity-controlled area. The shift from fresh to brackish water had great impact on the ecology and society in the coastal areas. The rice priority policy formed a threat for farmers that were interested in or involved in aquaculture. The poor rice farmers get problems with the new diversification policy because aquaculture is not an accessible opportunity to the poorest farmer due to the required levels of capital. (Käkönen, 2008)

The farmers in the Vĩnh Châu district prefer aquaculture over agriculture development, related to saline intrusion. Shrimp farming needs high inputs and is economically risky. Farmers that cultivate shrimps are not secure of income because of poor quality shrimp seeds, the limited technological knowledge of farmers and poor quality of the intake water. Many of the farming households become poorer and/or indebted, due to shrimp farming failures (Nhan, et al., 2008). The land use change from rice to aquaculture stimulates the saline intrusion of the groundwater.

Increase shrimp farming Vĩnh Châu

The Vĩnh Châu district has a total area of 46.260 ha (United Nations Development Program, 2010). In the Soc Trang province, the land-use changed over the last 10 years with an increase of shrimp farms. In 1995 the aquaculture increased from 7805 ha to 51.706 ha in 2006. In 10 years this is an increase of 662%. This rapid expansion reduced rice growing areas, which declined from 22.000 ha in 2000 to 2585 ha in 2005 (Joffre & Schmitt, 2010).

The Vĩnh Châu district has a total shrimp farming area between the 18.000 and 20.000 ha (Trang Hoang, 2011). 14.000 ha in the Vĩnh Châu district is used for cultivating the black tiger shrimp (Vietfish International, 2010). 1691 ha is used in 2005 for growing onions (Joffre & Schmitt, 2010).

3.3. Climate Change scenarios Vietnamese Mekong Delta

This paragraph provides insight in the climate change predictions for the VMD. Insight is provided based on climate change effects that increase saline intrusion of the ground water, these effects are the prediction of changes in rainfall and sea level rise. The following analysis of climate change in the VMD is based up on the report climate change in the Mekong Delta (Ministry Of Natural Resources And Environment, 2010).

Climate change scenarios

The National Institute of Meteorology, Hydrology and Environment (hereafter: IMHEN) made a prediction of climate change in Vietnam. The official report was presented in 2009. IMHEN used three climate change scenarios for Vietnam:

- Low emission (B1);
- Average (B2);
- High emission (A2).

The scenarios were elaborated for five areas of Vietnam with a time frame of ten years till 2100 (2020, 2030, ..., 2100). This research focuses on the years 2020, 2050 and 2100. The values are given per 3-month averages: December to February, March to May, June to August and September to November.

3.3.1. Current and predicted changes in rainfall Vietnamese Mekong Delta

Current pattern rainfall

There are 13 meteorological stations spread out through the VMD which record data about the rainfall and evaporation. The VMD has an average rainfall of 1733 mm, which falls mainly in the rainy season (from May to November). Annex 11 provides the average rainfall for the VMD on map. Table 3-1 shows the average rainfall per month in the VMD.

Table 3-1. Average rainfall in the VMD (mm).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
9	5	15	58	187	233	235	246	264	295	143	43	**1733**

January to March has a very low average rainfall. During this dry period sea water level rises due to wind surges which can lead to drought spells and saline intrusion, which has a major impact on agriculture. There is a variation in rainfall in the VMD, the minimum average rainfall is about 1680 mm and the maximum lies around 2405 mm in a wet year. Figure 3-5 presents the statistical data of rainfall in the VMD. Statistical results of the average rainfall in the VMD show that the variation is fairly stable.

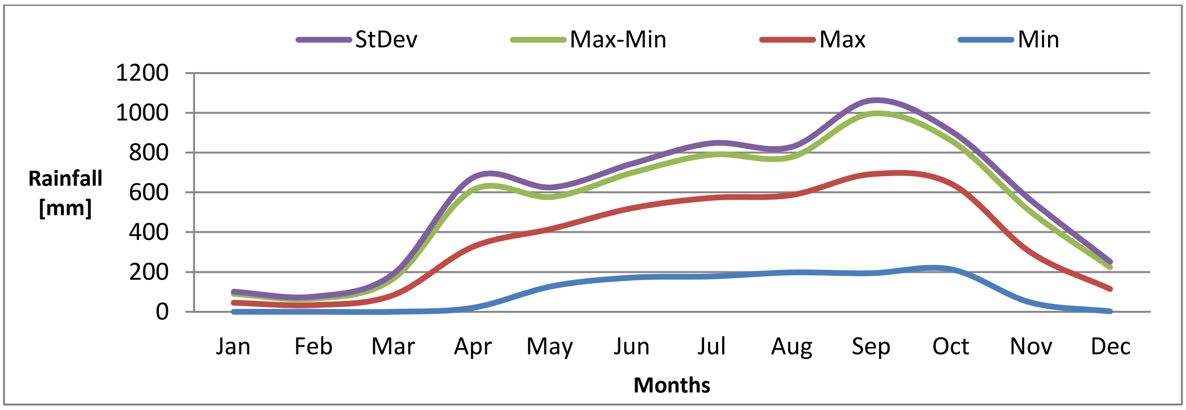


Figure 3-5. Variation of rainfall in the VMD (mm).

The reason for this stable variation is that the VMD is affected by the meteorological El Niño and La Niña phenomenon (ENSO). When El Niño occurs, the average rainfall is lower in these years and the number of days with rainfall is lower. Another case is that the rainy season starts later, it becomes shorter and droughts can increase. The opposite happens during La Niña. The annual rainfall becomes higher, number of days with rainfall increase and the rainy season starts earlier and lasts longer. But this is not always the case because it also depends on the intensity of ENSO and many other factors.

Prediction rainfall changes Vietnamese Mekong Delta

All the climate change scenarios show a decrease in rainfall in the dry season (December – May) and an increase of rainfall in the rainy season (June – November). Table 3-3 presents the outcomes of the Ministry of Resources and Environment assessment on rainfall changes in percentage for the years 2020, 2050 and 2100.

Table 3-2. Rainfall changes in percentage for the VMD relative to the period of 1980-1999.

Scenario	Monthly period	2020	2050	2100
B1	Dec - Feb	-2.7	-7.7	-10.1
	Mar - May	-2.6	-7.2	-9.4
	Jun - Aug	0.3	0.8	1.1
	Sep - Nov	2.6	6.3	8.5
B2	Dec - Feb	-3.0	-8.1	-15.8
	Mar - May	-2.8	-7.5	-14.3
	Jun - Aug	0.3	0.9	1.6
	Sep - Nov	2.6	6.8	13.0
A2	Dec - Feb	-3.3	-7.4	-19.6
	Mar - May	-3.0	-7.2	-18.2
	Jun - Aug	0.4	0.8	2.1
	Sep - Nov	2.8	6.5	16.5

3.3.2. Prediction sea level rise related to climate change

Recent change sea level rise

Data about sea level rise provided from the marine stations at the coast of Vietnam indicate that the rise in the current situation is approximately 3 mm/year (period 1993 – 2008). This sea level rise is almost equal to the worldwide sea level rise.

Prediction sea level rise

The three scenarios from the Ministry of Resources and Environment are used in their report to predict the sea level rise. Table 3-4 provides the sea level rise predictions by the different scenarios.

Table 3-3. Scenarios for sea level rise (cm) relative to the period of 1980-1999.

Scenario	Decades in the 21st Century		
	2020	2050	2100
Low (B1)	11	28	65
Average (B2)	12	30	75
Highest (A1)	12	33	100

These results show that in 2100, the sea level could rise with 65 cm to 100 cm compared to the period of 1980 – 1999.

Effects of sea level rise on floods and drainage of the lowlands in the Vietnamese Mekong Delta

Increasing rainfall and sea level rise related to climate change impacts makes inundation more extreme and more difficult to drain effectively. Because the elevation of the VMD is low, the estimated sea level rise can result in large areas of inundated coastal plains. Annex 12 shows the elevation map for the VMD. Table 3-5 presents per scenario the expected inundation for the VMD.

Table 3-4. Inundated area VMD for 2100 per scenario.

Scenario	Inundated area (km^2)	Percentage of inundated (%)
Low (B1)	5133	12,8
Average (B2)	7580	19,0
Highest (A1)	15116	37,8

Effects of sea level rise on saline intrusion Vietnamese Mekong Delta

The VMD has a dense canal system as shown in Annex 13. These canals eventually drain into the sea, and the Tien river and Hau river flowing through the plain into the sea, shown in Figure 3-6.

The rivers flow into the sea through different exits with a width range of hundreds of meters to several kilometres. These topographical/geographical aspects provide the right conditions for saline intrusion to go deep inland. Another aspect is the Chuong wind. This occurs at November to April (strongest in February/March).

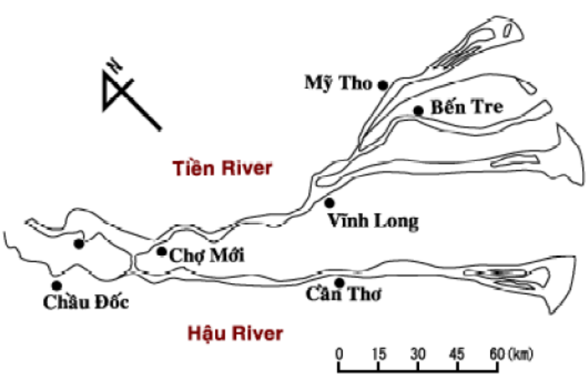


Figure 3-6. Visualization Mekong River.

Together with West South Monsoon wind, rainfall, Mekong river discharge and human activities that contribute to an increase of salinity intrusion. Sea level rise, impacts of high tide and low discharge in dry season contribute to deeper saline intrusion. Annex 14 gives an indication about the saline intrusion in the VMD, 2003. Deep intrusion, high salinity and long-lasting salinization occurred frequently in the VMD provinces in 2005. The salt sea water went 60 – 80 km deep into the land in the Tien and Hau river. This causes a lot of economical losses to agricultural production in the VMD.

3.4. Learning from other deltas over the world

This subparagraph describes the controlling of saline intrusion for two selected deltas over the world, to investigate if there are new techniques concerning the adaptation/controlling of saline intrusion.

Delta selection

The Ganges-Brahmaputra-Meghna in Bangladesh (2) and the Mississippi River Delta (1) in the United States of America are analysed in this section. The reason for this selection is that the delta in Bangladesh is similar to the VMD and the Mississippi River Delta could be seen as a more developed delta. Figure 3-7 shows the location of both deltas.

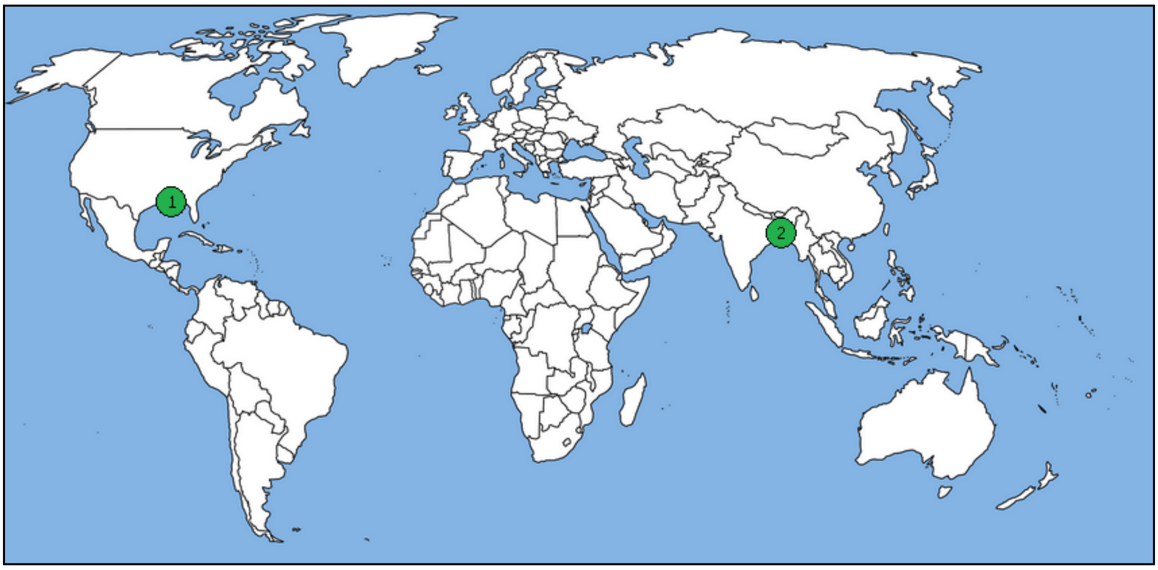


Figure 3-7. 1) Mississippi River Delta, 2) the Ganges-Brahmaputra-Meghna delta.

3.4.1. Strategies to control/adapt to saline intrusion in the Mississippi delta

The Mississippi delta is an intensively managed river system for more than 100 years. This human disturbance has led to more recent environmental impacts, like increasing salinity (DuBowy, 2013). The main problem for the Mississippi Delta are the extreme conditions of land loss, this is worsened by climate change and sea level rise (Bucx, et al., 2010). The Mississippi delta is shown in Figure 3-8.

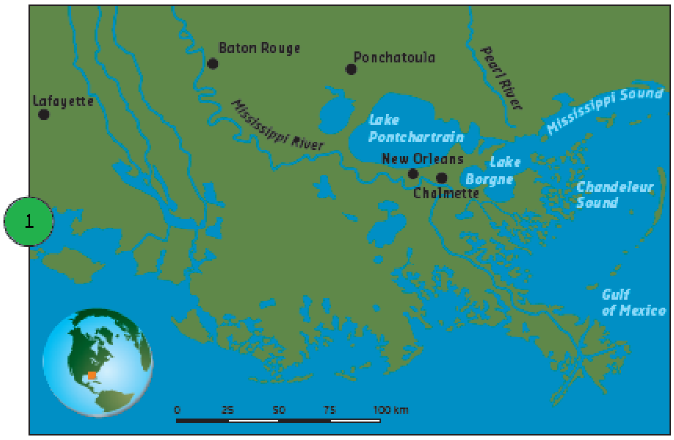


Figure 3-8. The Mississippi delta (Bucx, et al., 2010).

The rising sea level combined with lower freshwater from upstream leads to increased saline intrusion. Hydrologic restoration could be a measurement to reduce saltwater intrusion. The impacts are reduced by a management approach to restore the natural drainage patterns such as backfilling of canals, restoration of natural drainage features, closure of deep navigation channels and putting locks in others. This restoration is only effective if it is done in conjunction with freshwater diversions so that river water is used most effectively. This can be achieved by using siphons or gates. The diversion is a high capital cost that requires low annual operation and maintenance cost. (Day Jr., et al., 2005)

A series of freshwater diversions are currently in the planning, construction or operational phase (DuBowy, 2013). The government plays a major role in all of these projects.

3.4.2. Strategies to control/adapt to saline intrusion in the Bangladesh delta

The Ganges-Brahmaputra-Meghna has a surface area of some 100,000 km^2, this delta that is formed by three rivers is the largest in the world. It is also one of the most densely populated regions on earth. The Bangladesh delta is shown in Figure 3-9. (Bucx, et al., 2010)

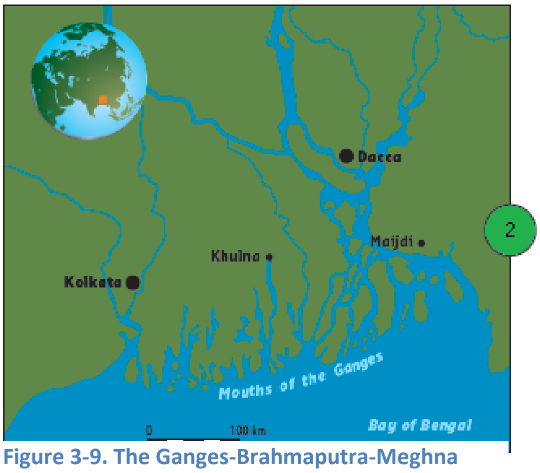


Figure 3-9. The Ganges-Brahmaputra-Meghna delta (Bucx, et al., 2010).

The comparative assessment (2010) from the Delta Alliance states that the current situation in this delta can be described as unsustainable (Bucx, et al., 2010). Salinization of the groundwater in the coastal areas is one of the critical issues in this country. If there are no improvements of technological developments and Governance aspects in the future, the overall resilience and sustainability decreases in the future. The adaptive measurements for this delta are mostly focussed on technical aspects like flood protection.

Bangladesh already has strategies to deal with reduced freshwater availability. The water sector planners find freshwater resource management is an important aspect for the adaptation and incorporate this in the 25-year water sector plan that is currently under development. Those who develop drought- and saline-tolerant rice varieties were quick to see the importance of incorporating climate change considerations into their research programmes. But the stakeholders that are involved in agricultural extension work did not recognize the importance of adaptation. The high-level policymakers are less concerned about the impacts of climate change on the overall economy of Bangladesh. (Huq, et al., 2004)

3.4.3. New techniques to control saline intrusion

Management solution

Coastal aquifer management forms a possible solution to control saline intrusion. The management of pumping schemes must be optimized to prevent or at least minimize upconing or lateral migration of saline groundwater, see Figure 3-10. But increasing demand of fresh groundwater exceeds supply and must be supported by other measures to ensure sufficient availability of water. Supported measures could be the long distance water transfer from more humid regions, artificial recharge of surplus water during wet periods, recycling of water, desalinization and water rationing. The different types of water use have to be defined so that water of a specific quality can be allocated to different users. (Post, 2005)

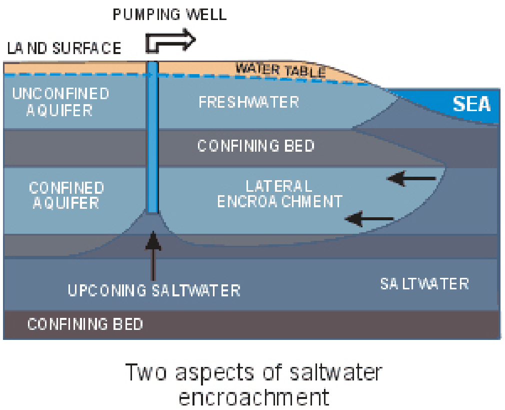


Figure 3-10. Upconing and lateral migration salt groundwater (HoseSolutions, 2013).

Technical solution

The natural recharge process of aquifers occurs very slowly. The extraction of groundwater at a greater rate than the natural replenishment causes declining of groundwater levels, which could lead to seawater intrusion. Artificial recharge could become increasingly important in the future of groundwater management. Figure 3-11 shows the implication of a recharging well. The artificial recharge could be implemented by surface water infiltration into aquifers by some artificially planned operation. Other sources of water could be direct precipitation, imported water or reclaimed waste water. (Musatea, et al., 2009)

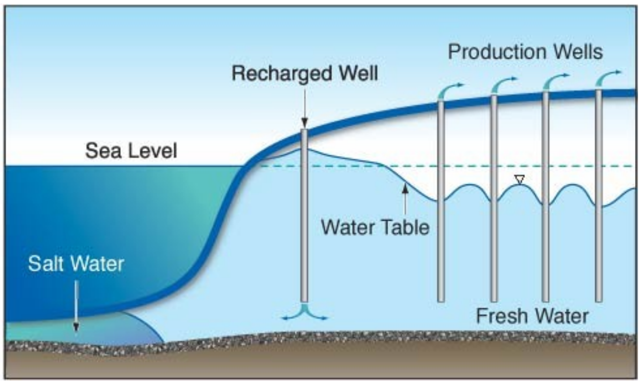


Figure 3-11. Providing fresh water by a recharging well (Solinst, 2012).

4. The coastal area of Vĩnh Châu

This chapter provides insight in the current salinity levels of the groundwater and how the farmers adapt to the salinity in the coastal area of Vĩnh Châu. Interviews and saline level measurements of the groundwater are performed and the analysis of the data is described in this chapter.

4.1. Cultivation types

Figure 4-1 presents the Vĩnh Châu district with the transect lines and location of the interviews together with the measurements on the salinity of the groundwater.

Figure 4-1. Location interviews and salinity level measurements of the groundwater.

Transects of interviewing and groundwater salinity measurements

In total there are 29 interviews and salinity level measurements of the groundwater. Annex 15 presents a better view of Figure 4-1.

In the Vĩnh Châu district several types of farms can be found, the vast majority of the farms belong to the aqua cultural type. On the higher sand ridges upland crop are located and also some fruit farming is present in the Vĩnh Châu district. During the interviews a variation of types has been visited. Table 4-1 presents the interviewed farm types. Annex 16 presents a description of every farm.

Table 4-1. Cultivation type with farm number.

Agricultural type	Farms
Upland crop	6, 8, 9, 12, 13, 14, 15, 16, 17, 18, 19, 24, 29
Salt winning	-
Fruit farming	27
Aquaculture	1, 2, 3, 4, 5, 7, 10, 11, 20, 25, 26, 28
Cattle breeding	21, 22, 23, 25

4.2. Groundwater usage and quality

The focus of the interviews and salinity level measurements of the groundwater is to provide insight in the water usage and quality of the groundwater for farming. Annex 1 presents the interview questions. The results of the interviews are placed in graphs and diagrams, which are stated in Annex 17.

Figure 4-2 presents the main cultivation from the interviewed farms.

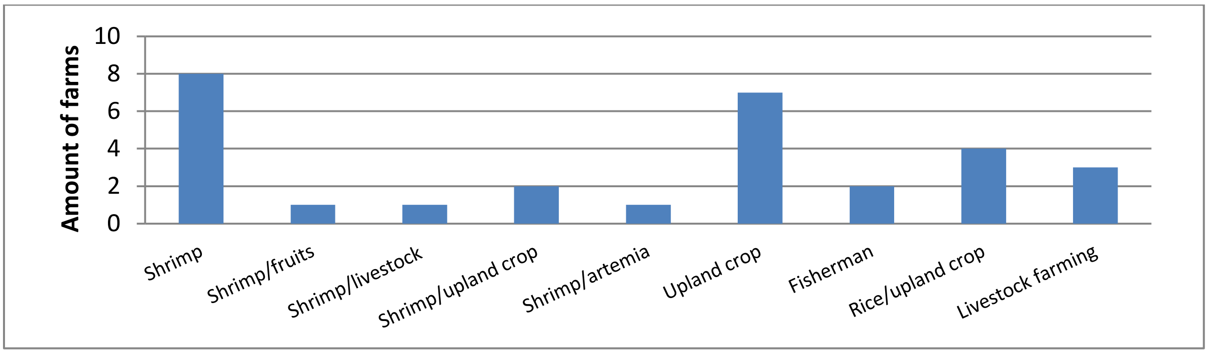


Figure 4-2. Main cultivation interviewed farms.

As shown in figure 4-2, the majority of the interviewed farms in the Vĩnh Châu district cultivate upland crop or shrimps. Out of 29 farms, 12 cultivate shrimp and 13 cultivate upland crop. Aquaculture and the cultivation of upland crops are seen as the two major land use types for this research.

Groundwater quality concerning salinity

The salinity levels of the groundwater are measured during every interview and the farmers are asked how they think about the quality of the groundwater concerning the salinity. From the 29 farmers about 86% think the quality of the groundwater is good for their specific use. Only 14% think that the quality concerning salinity is bad for their specific use.

The answers of the farmers on the interviews show some variation, the majority of the farmers believe that the groundwater is of good quality in the dry season as well as the wet season. However, not all the farmers share this opinion. Among the farmers that state the groundwater is of good quality, one part describe it is good for their purpose which is shrimp farming or good enough for the irrigation of their croplands. A minority of farmers (farm 23 and 26) stated that the quality of the groundwater is to salt. Both farms can be found in the northwest of the Vinh Chãu area. The farmer from farm 11 states that the groundwater is not always of good quality. He tried several places to place his groundwater pump and he couldn't get fresh groundwater on every spot. There is no data available about the depth that the farmer tried to get fresh groundwater.

Groundwater usage

The extraction of groundwater in the coastal area of Vĩnh Châu is very common. All the farms have access to a personal groundwater pump and most farms use the groundwater for irrigation. Some of them use the groundwater for domestic use but most farmers use rain- or mineral water for drinking purposes. Figure 4-3 shows the depths of the groundwater pumps in meters below ground level. The average depth of the groundwater pump is around 110 meter minus ground level. The groundwater pumps differ between 50 to 200 meters beneath ground level. There is one groundwater pump situated in the shallow groundwater aquifer, this pump is located at farm 6 and is at the moment not in use because of the dry season. See Annex 17 for the usable and unusable groundwater pumps per farm. Some farmers didn't know the depth of their groundwater pump and these have a value of zero.

Groundwater licensing and controlling

The interview of the People's Committee by the CTU provides information about the management structure of the groundwater pumps in the Vĩnh Châu district. The management of local groundwater extraction is assigned to the Department of Natural Resources and Environment along with the People's Committee since 2005. A licence is needed to extract groundwater on a local scale. The maximum depth of the groundwater pump is stated at 110 – 115 meters. A depth of 320-350 meter is licensed for the water supply companies. The licensing for household groundwater pumps is implemented since 2010. (Cong, 2013)

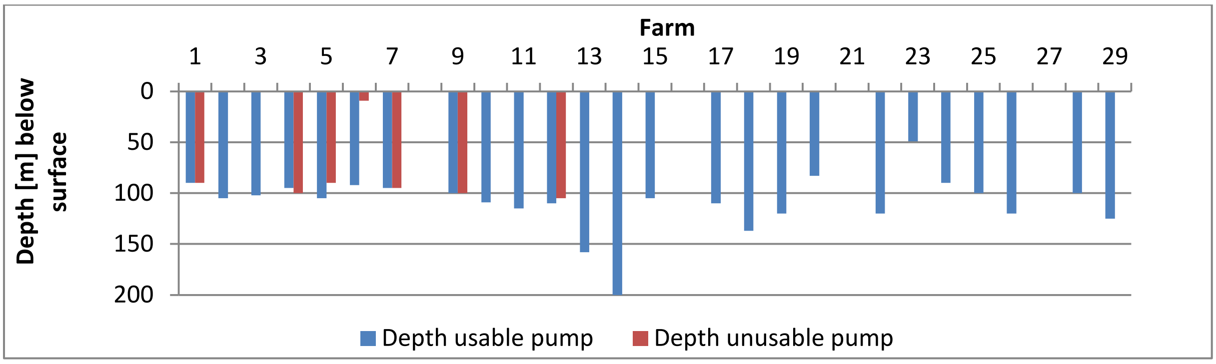


Figure 4-3. Depth groundwater pumps per farm.

More groundwater use than 10 years ago

Although the use of groundwater is a natural habit for farmers, the majority (55%) of the interviewed farmers does not have any idea whether they use more groundwater nowadays compared to a decade ago. From the interviewed farmers that know if there is a difference in usage the majority uses more than a decade ago and the minority uses less or the same amount of groundwater (35%).

There are different reasons for an increase usage of groundwater then 10 years ago but most common reason is that farmers nowadays have access to their own electrical groundwater pump instead of a hand pump.

Capacity of the groundwater pumps

The capacity of the groundwater pump is important to know the amount of extraction. Amongst the questioned farmers in the Vĩnh Châu district several pumps with different capacities have been found. The majority of the pumps have a capacity of 1.5 Horse Power (Hereafter: HP), the biggest pump has a capacity of 2.5 HP. Some of the farmers tell that the pumping of groundwater goes on all day for shrimp farming, most farmers that cultivate upland crops tell that they use their pump only several times a day.

Usage other water sources

The interviewed farmers are asked about which other water sources they use besides groundwater. 38% of the farmers indicate that they do not use other water sources besides the groundwater. The other 62% use other water sources, most of them harvest rainwater for domestic use and some use water from the river. Only 3% of the interviewed farmers use water from the water company.

Rapid runoff

Floods occurs in case of heavy rains and this could form a problem for the farmers in the Vĩnh Châu district. Therefore the farmers are asked if there is rapid runoff and were the water goes when it rains. The majority of the interviewed farmers (69%) stated that rapid runoff takes place during precipitation. Most of the interviewed farmers tell that rapid runoff only occurs in case of heavy rainfall, when there is normal rainfall the rainwater infiltrates in the soil. When runoff occurs it flows to the canals and river.

Adaptation to Climate Change

The interviewed farmers are asked whether they took adaptation measures and if they experienced problems with a changing salinity level themselves. 10% of the farmers took adaptation measures (more locations for the groundwater pump to get fresh groundwater and mixing of river and groundwater for shrimp farming), 90% stated that they did not adapt to the salinity levels of the groundwater. 90% of the farmers tell that they don't see a change in salinization of the groundwater and therefore they did not have to take adaptation measures.

Food secure in current situation

Important is that the farmers make a decent living from their work in the present and in the future. 55% of the interviewed farmers stated that they live from their work and do not expect problems in the future. About 28% foresee problems in the future and 14% more already face problems concerning food security.

The majority of the farms that foresees problem in the future base it on the fact that in the last year the raising of shrimp failed. From all the interviewed farmers two are food insecure in the current situation and nine farmers foresee problems in the future.

4.3. Analysing current salinity levels groundwater

Measurements on the salinity of the groundwater are executed during every interview. This paragraph provides insight in the salinity levels of the groundwater in the Vĩnh Châu district and discusses the hydrogeological profile based on current salinity levels.

4.3.1. Data salinity level measurements

The location of the interview with the salinity level of the groundwater is displayed in Figure 4-4. Annex 18 presents the detailed salinity levels per farm. The depth of the groundwater pumps is displayed in Annex 19.

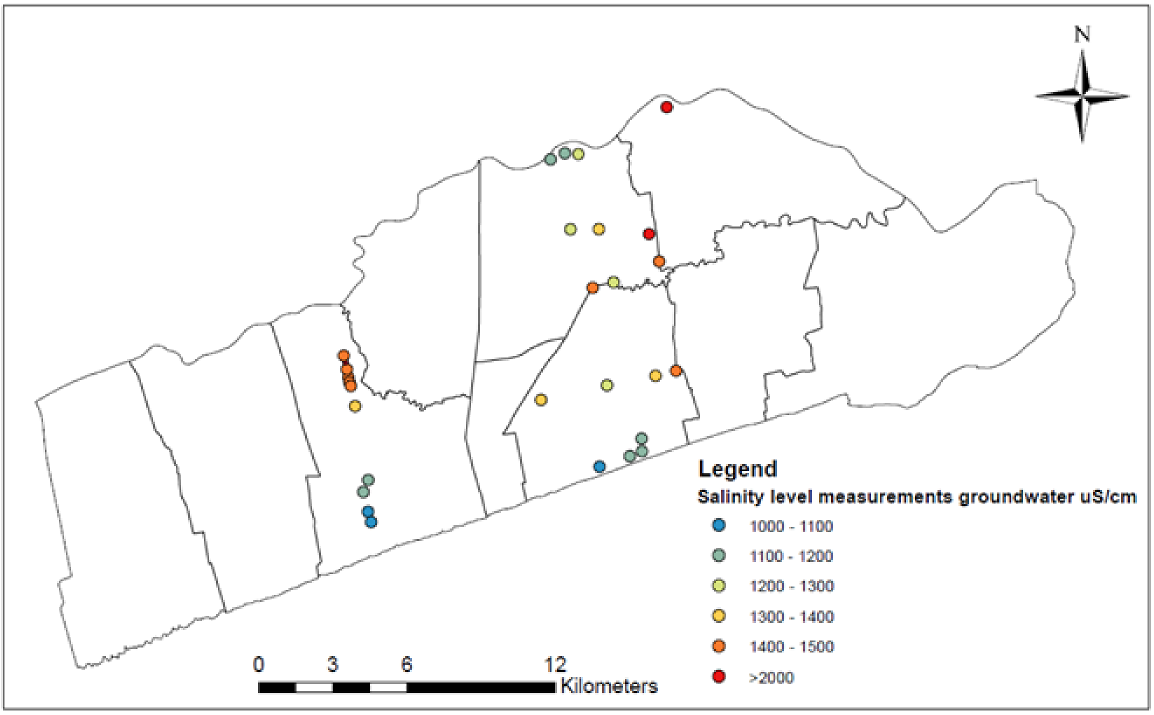


Figure 4-4. Salinity levels of deep groundwater in Vinh Chau, measured from 3th – 5th April 2013.

The salinity levels are measured from the coast to the border of Vĩnh Châu. The reason for this is to provide insight in the changes of the salinity levels of the groundwater from the sea to inland. It is visible in Figure 4-4 that the EC values near the coast are lower than the values more inland. The salinity measurements only take place for the deep groundwater. The average depth of the 29 groundwater pumps is 110 meters. The reason for this is that there is only one shallow groundwater pump available and this pump is unusable because of the dry season.

In the dry season farmers often use groundwater for irrigation and in the rainy season, the cultivation changes mostly to rain fed rice. The outcomes of the interviews showed that in the farmer's opinion no problems occurred due to the salinity of the groundwater. In the dry season most farmers tell that the quality concerning the salinity of the groundwater was good for irrigation and during the rainy season the crops are rain fed and salinity levels formed no problem. It could be true that there occur no visual/cultivation problems concerning the salinity of the groundwater in the dry season but it could also be the case that the irrigation and cultivation become more optimal. The following analysis shows if the main crops/cultivation is optimal in the current situation and what happens when the salinity increases in the future.

The most frequent farming system in Vĩnh Châu is crop rotation. Rice (rainy season) and upland crop (dry season) like onions located on the higher parts. The land use more inland is mostly aquaculture like shrimp farming, Artemia and some fruit gardens. The analysis of the sensitivity to the salinity of the groundwater is done for the main land use types used during the dry season, which are the following cultivation types:

- Upland crops:
    - Onions, Allium cepa L. (United Nations Development Program, 2010);
    - Cabbage;
    - Chilli;
    - Corn.
- Aquaculture:
    - Black Tiger Shrimp (Vietfish International, 2010);
    - Artemia franciscana (Khoi, et al., 2006).

Definition groundwater salinity

There are many different definitions and classifications about the salinity of groundwater. The chloride concentration in the groundwater is calculated because of its dominance and is used for the classification of the groundwater. The definition of the salinity of the groundwater depends strongly on the crop choice of the farmer. Groundwater for agricultural use is classified as fresh until 150 mg Cl-/l, Table 4-2 gives the definitions used in this report. (Oude Essink, et al., 2008)

Table 4-2. Classification salinity groundwater in chloride concentration (Oude Essink, et al., 2008).

Classification	Chloride concentration (mg Cl-/l)
Very fresh	< 30
Fresh	30 – 150
Light brackish	150 - 300
Brackish	300 - 1000
Salt	1000 - 5000
Very salt	> 5000

4.3.2. Analysing current salinity levels Vĩnh Châu based on hydrogeological profile

The results show that the average chloride concentration is about 246 mg/l. With a maximum of 495 mg/l and minimum of 159 mg/l. Annex 20 gives the results of the chloride concentration together with graphs that show the salinity changes from the coast line to inland. Annex 21 provides insight in the hydrogeological profile for the VMD. The range of the groundwater pump depths is between the 50 – 200 meters. The hydrogeological profile presented in Annex 21 shows that this concerns four different aquifers, with a different quality of salinity per aquifer (aquifers: qh, qp_3, qp_{2-3} and qp_1). This conclusion is confirmed by comparing the EC and chloride values with the different depths of the groundwater pumps, stated in Annex 22. The article of (Wagner, et al., 2012) provides insight in the geohydrological system of the VMD and is used to discuss the salinity levels in Vĩnh Châu.

Holocene (qh)

The hydrogeological profile shows that the underground of the shallow underground exists out of fine to coarse sand. The shallow aquifer is stated as qh with a depth of 30 meters. This aquifer has a yield from low to medium (0.1 – 2.0 l/s). Holocene aquifers mostly carry salty or brackish water, sand dune sediments provide limited recharge of fresh groundwater. From the 29 farmers, only one farmer had a shallow groundwater pump that is no longer in use, therefore no shallow groundwater measurements took place in this research.

Upper Pleistocene (qp_3)

The top of the aquifer starts approximately at 40 meters below ground level and has a thickness of 20 meters in the area of Vĩnh Châu. This aquifer is weakly confined. One out of the 29 farmers had a pump at 49 meters deep. The salinity measurement showed an EC value of 2139 µS/cm (494 Cl- mg/l). Based on Table 4-2 the salinity is defined as brackish groundwater. The EC value at this depth is the highest from all the 29 measurements.

Upper-Middle Pleistocene (qp_{2-3})

This aquifer is divided into a low permeable upper part that consists out of silt and clay, which can be found at a depth of approximately 80 meter. This layer has a thickness of 55 meters (range 80 to 135 meters deep). The lower part consists out of high permeable fine to coarse sand. The aquifer qp_3 has several hydraulic windows connecting to the qp_{2-3} aquifer. This aquifer contains low saline groundwater, has a yield and provides groundwater that has generally good quality. 26 out of the 29 measured groundwater pumps have a depth between 80 to 135 meters. The results show a very divers pattern of EC and Chloride values (see Annex 22).

Lower Pleistocene (qp_1)

The lower Pleistocene aquifer is originally alluvial. The aquifer starts at a depth of 135 meters and ends at approximately 220 meters. The lower part of the aquifer consists out of permeable fine to coarse sand. This aquifer has several hydraulic windows with the aquifer qp_{2-3}. Water supply commonly uses the yielding of the lower Pleistocene for exploitation of water. In Vĩnh Châu two out of the 29 groundwater pumps have a depth that reaches the lower Pleistocene aquifer (160 and 200 meters deep).

Changes salinity coast line – inland

The salinity levels presented in four different segment lines provide insight in the salinity changes from the coast line to the inland of Vĩnh Châu (see Annex 20). A visible trend could be defined in all four graphs. The salinity levels in the deep groundwater are lower near the coast line and increase further inland. It is not clear what the reason is of this change in salinity.

4.4. Analysing upland crop and aquaculture sensitivity to current salinity levels groundwater

All the chloride values are between the 160 - 500 mg Cl-/l. This means that the groundwater is classified as light brackish to brackish water, conform Table 4-2. But what would it mean for the different upland crops and aquaculture in the Vĩnh Châu district?

4.4.1. Analysis salt tolerance upland crop

The analysis of the saline tolerance of upland crop is done for onions, cabbage, chilli and sweet corn. Annex 23 provides the salt tolerance for the upland crops from the Food and Agriculture Organization (hereafter: FAO). The EC values at each farm are compared to the threshold for the specific crop.

Irrigation method

The deep groundwater is used for irrigation of upland crops in the Vĩnh Châu district. Figure 4-5 shows the irrigation method that is used. This type of irrigation is very labour intensive and the watering rate is usually more than can soak into the ground, so more water use than necessary. The positive site is that each plant gets a lot of attention and it is easy to adjust the irrigation schedule to changing weather. It gives a better adaptive management because of its extensive on-site time. (Alexander, 2003)

Figure 4-5 Major irrigation method used for most of the upland crops (Nguyen Cuong Irrigation System, 2012)

Onions, *Allium cepa L.*

Table 4-3 shows the EC values for the farmers that cultivate onions in Vĩnh Châu.

Table 4-3. EC values onion farms.

Onion farms	EC value irrigation water [mS/m]	mS/cm = dS/m
6	142.13	1.42
8	111.68	1.12
9	115.56	1.16
12	115.35	1.15
14	111.97	1.12
15	107.29	1.07
16	139.89	1.40
17	124.87	1.25
19	142.25	1.42
24	126.42	1.26
29	144.64	1.45

Cultivation takes place for their bulbs and sometimes basal portions of the flattened leaf blades. In general the onion can be considered sensitive for salinity based on yield reduction. Figure 4-6 shows the salt tolerance of several vegetable species. (Shannon & Grieve, 1999)

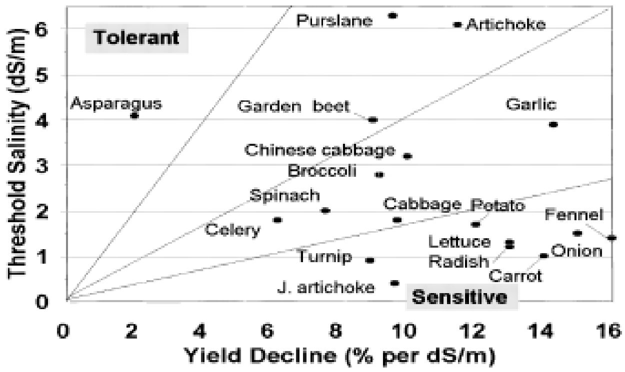


Figure 4-6. Tolerance salinity for several vegetables as rated by the salinity threshold and percent yield decline (Shannon & Grieve, 1999).

When salt stress occurs the leaves change from rich green to dull blue-green and leaf tips express burn symptoms. The initial yield decline starts at a threshold EC of 1.4 dS/m and a yield reduction of 50% occurs at 4.1 dS/m. (Shannon & Grieve, 1999)

According to the FAO the threshold EC of onion occurs at a level of 1.2 dS/m with a slope of 16% per dS/m (Food and Agriculture Organization, 1999). For this research a range of 1.2 dS/m to 1.4 dS/m causes the beginning of salt stress. Table 4-3 shows that some farms use groundwater with an EC value between 1.0 – 1.5 dS/m. This would mean that at this level the initial yield decline starts and yield reduction occurs (range yield reduction between 0-5%). If the salinization of the groundwater increases in the future due to climate change predictions, these farmers could face problems with the cultivation of onions.

Cabbage

Several farms cultivate onions together with cabbage, these are farm 12, 14, 15, 16, 17, 19, 29 (see Table 4-3). Cabbage is rated as moderately sensitive to salinity. The threshold (EC) salinity is 1.8 dS/m (see Figure 4-6 and Annex 23) with a slope of 9.7% per dS/m (Food and Agriculture Organization, 1999). If salt stress occurs the cabbage heads are generally more compact, and the leaves are fleshier than under non-saline conditions. (Shannon & Grieve, 1999)

The EC values lie between 1.0 – 1.5 dS/m for the farmers that cultivate cabbage in Vĩnh Châu. Under these conditions no salt stress occurs for cabbage.

Chilli, *Capsicum annuum L.*

From the 29 interviews there are three chilli farms. Table 4-4 gives the EC values of the groundwater at the three farms.

Table 4-4. EC values chilli farms.

Chilli farms	EC value irrigation water [mS/m]	mS/cm = dS/m
9	115.56	1.16
18	130.18	1.30
29	144.64	1.45

According to the FAO the threshold EC of chilli occurs at a level of 1.5 dS/m with a slope of 14% per dS/m (Food and Agriculture Organization, 1999). The EC values of the chilli farms lie between 1.1 and 1.5 dS/m. This would mean that these values are still lower than the threshold and that there is no salt stress in the current situation.

Sweet corn, *Zea mays L.*

There are two farms that cultivate corn in this research. Table 4-5 provides data about the EC values of the groundwater that is used for irrigation.

Table 4-5. EC values corn farms.

Corn farms	EC value irrigation water [mS/m]	mS/cm = dS/m
9	115.56	1.16
19	142.25	1.42

The threshold EC for corn is 1.7 dS/m. As shown in Table 4-5, the EC values are below the threshold. This would mean that no salt stress and no yield reduction occur due to the salinity of the groundwater.

4.4.2. Analysis salt tolerance aquaculture

Aquaculture plays an important role in the Vĩnh Châu district, with a total cultivation area between the 18.000 and 20.000 ha (Trang Hoang, 2011). This sub paragraph provides insight in the water sources that are used for cultivating shrimps and Artemia together with the quality of the water concerning salinity. Furthermore the salt tolerance is given in the form of a range. Other factors like for instance oxygen, temperature and light production are not taken into account in this research.

Usage water sources

Marine conditions are needed for the cultivation of Black Tiger shrimps and Artemia Franciscana. This is done by mixing groundwater and river water in the shrimp plots (see Figure 4-7). The previous research, Rapid Rural Appraisal Vĩnh Châu, stated that the Vĩnh Châu district is not provided with fresh water from the Hau river due to tidal influences (Pampus, et al., 2013). Because of the high influence from the sea, this river water is not useable for agriculture but makes it possible to have saltwater aquaculture further inland. The growth and survival of the shrimp depends on the salinity of the water.

Figure 4-7. Empty shrimp plot with visible saline soil (left) and a shrimp farm in production (right) in Vĩnh Châu district.

Shrimp farming, Black Tiger shrimp

The ideal salinity range of Black Tiger shrimps is ranged (by different reports stated by N. Pushparajan and P. Soundarapandian) between the 10.000 – 30.000 mg/l (sea water has a salinity of 25.000 mg/l stated by Waterwatch Australia). When the salinity becomes too high the shrimps grow slowly but they are healthy and resistant to diseases. If the level of salinity becomes too low the shell is weak and prone to diseases. (Pushparajan & Soundarapandian, 2010)

One pond located at farm 10 is measured with a salinity level of 31.000 mg/l. This salinity level is compared to the ideal range, to high. It means that the shrimps grow slower but are still healthy and resistant to diseases. Table 4-6 displays the salinity levels of the groundwater located at the shrimp farms.

Table 4-6. Salinity levels groundwater shrimp farms.

Shrimp farms	EC value irrigation water [mS/m]	mS/cm = dS/m
1	142.23	1.43
2	143.40	1.43
3	147.71	1.48
4	148.49	1.48
5	141.11	1.41
7	137.15	1.37
11	107.41	1.07
24	126.42	1.26
25	138.79	1.39
26	212.16	2.12
27	141.03	1.41
28	125.24	1.25
29	144.64	1.45

Artemia franciscana

One out of the 29 farmers produced Artemia, located at farm 11. A common aspect for all Artemia biotopes is their high salinity. Artemia production forms an ideal adaptation measure to high salinities. (Blackwell Science Ltd, 2003)

5. Adaptation strategies

This chapter discusses all the data from the literature study, interviews and salinity levels of the groundwater. To provide insight in the current adaptation strategies related to salinization of the groundwater in the coastal area of Vĩnh Châu and which adaptation strategies could be implemented for the future with climate change. The combining of the data has a focus on the three P's: People, Planet and Profit.

5.1. Saline intrusion in the Vĩnh Châu district (planet)

This subparagraph discusses the environmental situation of saline intrusion in the VMD and in special for the Vĩnh Châu district. It provides insight in the current situation of the saline intrusion and also the future with a focus on the climate change scenarios for the VMD.

5.1.1. Current situation

Saline intrusion is a natural process in a coastal area, this due to the connection of fresh groundwater with saline groundwater at the border of land and sea (see Figure 3.1). Käkönen stated in the article Delta at the Crossroads: More Control or Adaptation that the water in the VMD always had two-sides. On the one hand the VMD has been exposed to permanent threat of floods in the rainy season and water scarcity/saline intrusion in the dry season. The saline intrusion is a complex system that depends on many factors which is discussed in the report Mekong Delta Water Resources Assessment Studies from Deltares and the Delta Alliance, like for instance the ability of fresh water from upstream during the dry season as well as the amount of fresh groundwater due to excessive groundwater extraction. Another factor which could increase the saline intrusion is the sea level rise. When the sea level raises further, the salinity boundary moves more inland. In the current situation this boundary, as stated in Annex 14, changes due to distinctions between West sea and East sea's tide.

Salinity levels deep groundwater Vĩnh Châu

The measurements take place from the 3th till the 5th of April 2013, this is the end of the dry season. So the salinity levels should be at its highest during this period. The land in Vĩnh Châu can be grouped in two groups. In the lower parts there is shrimp cultivation and upland crops are cultivated on the higher sand ridges (see Annex 2). Deep groundwater is used by the farmers in Vĩnh Châu for the irrigation of upland crops and to mix with rain/river water for aquaculture.

The results of salinity measurements of the deep groundwater showed that the salinity increases from the coast to inland. The salinity levels near the coast (on the higher sand ridges) show a chloride level from 150 to 200 mg/l. This can be classified as light brackish water. More inland the deep groundwater reaches levels from 250 to 500 mg/l, which can be classified as brackish water (see Annex 20). The depths of the groundwater pumps various between 50 to 200 meters, which covers four different aquifers (see Annex 21). Annex 22 shows the change of chloride concentration on the different depths. This shows that the hydrogeology of the VMD is a complex system and many factors play a role in the quality of the groundwater.

Salinity levels vs. upland crops

The comparison of the irrigation water quality to the salinity tolerance of the different cultivation types shows that there is no yield reduction due to salt stress for cabbage, chilli and sweet corn. 1691 ha is used in 2005 for growing onions in Vĩnh Châu (Joffre & Schmitt, 2010). At some onion farms salt stress occurs. The range of 1.2 dS/m to 1.4 dS/m causes the beginning of salt stress for onions with a yield reduction of 16% per dS/m according to the FAO. Table 4-3 shows that some farms use groundwater with an EC value between 1.0 – 1.5 dS/m. But according to the interviews with the farmers no problems occurred due to salinity levels of the groundwater for irrigation. If the salinization of the groundwater increases in the future due to climate change predictions, these farmers could face problems.

Salinity levels vs. aquaculture

Vĩnh Châu has a total shrimp farming area between the 18.000 and 20.000 ha (Trang Hoang, 2011) and 14.000 ha is used for cultivating the Black Tiger shrimp (Vietfish International, 2010). The aquaculture in Vĩnh Châu needs marine conditions, this is done by mixing groundwater and river water (salt related to tidal influences) in the shrimp plots. The ideal range of Black Tiger shrimps is ranged (by different reports stated by N. Pushparajan and P. Soundarapandian) between the 10.000 – 30.000 mg/l chloride. When the salinity in the shrimp pond becomes too high no problems occurs, it grows slower. But with a low salinity level the shell is weak and prone to diseases. There are no problems for the production of Artemia because of their high salinity that is needed.

5.1.2. A look in the future

The IMHEN made a prediction of climate change in Vietnam, based on three scenarios (low emission, average and high emission) for the year 2100. The dry season becomes drier and the wet season wetter. This could mean an increase of saline intrusion during the dry season and more floods in the wet season for the VMD. The temperature in both seasons increases more or less the same with a prediction ranges from 1 to 3 ^{0}C. Sea level rise could have a great impact on the saline intrusion in the VMD. The low emission scenario predicts a sea level rise of 65 cm for the year 2100 and the high emission scenario a prediction of 100 cm. The topographical aspects of the rivers provide the right conditions for saline intrusion to go deep inland. Another important aspect is the Chuong wind, which occurs during the dry season (November to April). Together with West Monsoon wind, decrease of rainfall, low river discharge and increased human activities contribute to an increase of saline intrusion, causing deeper saline intrusion in the dry season. The SRTM and DEM in Annex 3 show the elevation of the Vĩnh Châu district. This map shows that most of the area lies around sea level. If the predictions become reality in 2100 the Vĩnh Châu district could be flooded by the sea unless control measures take place to protect the area from the sea. Figure 5-1 visualises the predicted sea level rise.

Figure 5-1. Prediction sea level rise.

5.2. Adaptation strategies Vĩnh Châu district

The last decades measures towards the environment have switched from adaptation to control and also the decision making at farm level to centralized decisions at different scales. Control measures took place in the form of large-scale hydraulic control structures targeting the floods in the upper part of the VMD and saline intrusion in the coastal zone. The combination of agricultural modernization, agrochemicals and hydraulic control structures gave a boost to the agricultural production in the VMD. The consequence is an increase of saline intrusion, also because the canals and control structures bring the saline intrusion to new areas. This subparagraph provides insight in the current and future adaptation strategies for the coastal area of Vĩnh Châu.

5.2.1. Current adaptation strategies (people)

Aquaculture

The land use in the Vĩnh Châu district changed the past 20 years from paddy rice cultivation to shrimp farming. This adaptation initiative started by protests from the farmers against the protection of the salinity-controlled area. The result is that the government allowed diversification of land use from the year 2000 onward. The diversification policy allowed re-entry of seawater into the formerly salinity-controlled area. The increase of aquaculture in the Vĩnh Châu district stimulates the saline intrusion of the groundwater and is not preferible.

Figure 5-2 shows the shrimp farming plots in the Vĩnh Châu district. From the 13 interviewed shrimp farmers, one farmer stated to be food insecure in the current situation and five farmers foresee problems.

Figure 5-2. Shrimp plots Vĩnh Châu district.

Upland crops

Farmers use crop rotation systems located on the higher sand ridges in the Vĩnh Châu district. In the dry season farmers often use deep groundwater for irrigation and in the rainy season, the cultivation changes mostly to cultivating rain fed rice. Figure 5-3 shows the cultivation of upland crops in the dry season for the Vĩnh Châu district. Also additional functions are implemented like livestock and fruits for own use. The interviews show that from the 13 farmers that cultivate upland crops, one is food insecure in the current situation and four farmers foresee problems. Almost all the farmers (86%) state that the quality of the groundwater due to salinization is of good quality.

Figure 5-3. Cultivation of upland crops in the Vĩnh Châu district.

5.2.2. Impact current adaptation strategies (profit)

Aquaculture

The shift from fresh to brackish water has great impact on the ecology and society in the coastal area. The poor rice farmers get problems with the new diversification policy because aquaculture requires high inputs and is economically risky. Farmers that cultivate shrimps are not secure of income because of poor quality shrimp seeds, limited technological knowledge of the farmer and poor quality of the intake water. Figure 5-4 shows a poor shrimp farmer in the Vĩnh Châu district.

Figure 5-4. Poor shrimp farmer in the Vĩnh Châu district.

Upland crops

The groundwater is used as irrigation in the dry season. No salt stress occurs with the current salinity levels of the groundwater for cabbage, chilli and sweet corn. Salt stress only occurs for the cultivation of onions. The salinity levels of the irrigation water causes in the current situation a yield reduction of 0-5% for some farmers. If the salinization of the groundwater increases in the future due to climate change predictions, the farmers that cultivate upland crops could face problems of increased yield reduction.

5.2.3. Possible adaptation strategies

The prediction of land use change by the Wageningen University for the VMD in the year 2030 shows that there could be an expansion of built-up land. This is in line with the urban population growth and is heavily concentrated around Ho Chi Minh City and some other areas in the VMD. Migration could take place from rural to urban areas. Annex 10 presents the prediction for the VMD per scenario. This could also be the case for the Vĩnh Châu district because 14% is food insecure and an aditional 28% forsee problems in the future (from the 29 interviews). So farmers must find other ways to be food secure. If the sea level rises with 65-100 cm for the year 2100 and no control measures take place around the coast, the Vĩnh Châu district could be flooded by the sea for most of the area. In this case migration is probably the best option.

Efficient groundwater use

Coastal aquifer management can form a possible solution to control saline intrusion. The management of pumping schemes can be optimized to prevent upconing or lateral migration of saline groundwater. This management strategy forms a solution for the future together with support measures like long distance water transfer from more humid, recycling of water, desalinization and water rationing. The target group of this measure are the water supply companies as they pump large quantities.

In the current situation all the 29 farmers have a groundwater pump in the deep aquifers with an average depth of 110 meters. One farmer has a shallow groundwater pump of 9 meters deep, it is out of use during the dry season. During the rainy season this shallow aquifer becomes usable. This water source could be used in the rainy season instead of the usage of deep groundwater. A licence is needed to create a new well since 2010. The maximum depth is set at 110 - 115 meters. The results of the interviews showed that seven of the 29 farmers have a groundwaterpump deeper than 115 meter.

Another factor is that the irrigation of upland crops is done by hand, which means that a lot of water is lost by evaporation and overuse. A change in irrigation method saves valuable deep groundwater. The quality of the irrigation water (deep groundwater) for upland crops can be classified as light brackish water and could become brackish in the future due to climate change. Yield reduction takes place for the onions in this situation.

Increase rainwater harvesting

The dry season gets drier in the future due to climate change. On the contrary the wet season gets wetter. The rain is already used in the wet season for intercropping to switch to paddy rice cultivation. Most of the times heavy rains occur and rapid runoff takes place, this is confirmed by 69% of the 29 interviewed farmers. Rainwater storage during the dry season could be a solution for irrigation of the upland crops. In the current situation 45% of the 29 farmers used rainwater harvesting by collecting rain from the roof (see Figure 5-5). The rainwater is mostly used for domestic use and not for irrigation in the dry season. Further research based quantity of rainwater that is needed for irrigation.

Figure 5-5. Rainwater harvesting (Engineers without borders institute, 2013).

Increase the mixed shrimp-mangrove system

The predicted sea level rise forms a threat to the current land use. The lower part of the Vĩnh Châu district could be flooded when no controll measures by the government take place. The mixed shrimp-mangrove (or silvofishery) system could form an adaptation strategy (see Figure 5-6). This integrates ecology, agriculture and is reachable to small-scale, family-based operations. It is possible for poor farmers to operate this system because the farms are by definition low input systems that typically not use supplemental feed or fertilization. The black tiger shrimp is the "best choice" for this system, according to Seafood Watch (Bridson, 2013). Further research is needed about implementation of the system.

Figure 5-6. Mixed shrimp-mangrove system (Viet Nam News, 2013).

Sluice to prevent saline intrusion of surface water

The building of a sluice prevents saline intrusion from the surface water and keeps freshwater in the Vĩnh Châu district. However most of the land use in the Vĩnh Châu district has changed from rice to marine aquaculture over the past 20 years. The building of a sluice would mean a change from brackish to fresh water (restoration former salinity-controlled area), with negative consequences for farmers that produce marine aquaculture in the Vĩnh Châu district. Further research is needed.

Innovation

Artificial recharge of aquifers could be a technical solution to prevent saline intrusion. This can be implemented by surface water infiltration into aquifers by some artificially planned operation. Other sources of water are direct precipitation in the rainy season, imported water or reclaimed waste water. More research is needed for the implementation of the artificial recharge wells. Also the introduction of salt-tolerance crops could be a solution for the future.

Bottom up or top down approach

The government plays an important role in the adaptation process, this is also the case in the Mississippi delta. The Bangladesh delta has a more bottom up process, there are already strategies to deal with reduced freshwater availability but the high-level policymakers are less concerned about the impact of climate change on the overall economy of Bangladesh. The farmers in the Vĩnh Châu district are poor and have a lack on education/knowledge, their future look is not further than the next cropping season. The government could have a leading role because of their 'eagle view' by investing in these poor areas or by accelerating the innovation process. Subsidies could have a positive impact for the farmers to buy shrimp input or arrange a rainwater storage tank. Increasing knowledge can be implemented by broadcasting educational programs on local television.

Farmers protested against the protection of the salinity-controlled area. This resulted in the diversification policy from the year 2000 and showed that farmers have the power to create a bottom-up process.

6. Conclusions and recommendations

The main objective of the research is to provide insight in the current adaptation to the possible increasing salinity of the groundwater in the VMD with a detailed focus on the coastal area of Vĩnh Châu and to understand which lessons can be learned for adaptation to the on-going climate change. This chapter provides conclusions based on the main objective and recommendations are given.

6.1. Conclusions

From previous chapters, it has become evident that groundwater provides valuable services to the VMD. The extraction of groundwater increased rapidly over the past decades and forms the main cause of saltwater intrusion into the coastal aquifers with sea level rise as an accelerator. Saline intrusion in the VMD is a complex system that depends on many factors like the magnitude of floods, the ability of freshwater upstream during the dry season as well as the amount of fresh groundwater due to excessive groundwater extraction and timing of rainy season. Climate change could have an impact on these factors. According to scenarios for the VMD based up on the report climate change in the Mekong Delta the dry season becomes drier and the wet season wetter. This could mean an increase of saline intrusion during the dry season together with a sea level rise prediction of 65 – 100 cm for the year 2100. If these predictions become reality in 2100 the Vĩnh Châu district could be flooded by the sea unless control measures take place to protect the area from the sea.

6.1.1. Current adaptation: aquaculture in the coastal area of Vĩnh Châu

The land use in the Vĩnh Châu district changed the past 20 years from rice cultivation to shrimp farming. The increase of aquaculture in the Vĩnh Châu district stimulates the saline intrusion of the groundwater and is not preferible. The diversification policy in 2000 allowed re-entry of seawater in the formerly salinity-controlled area. Shifting from fresh to brackish water had great impact on the ecology and livelihood in the coastal area. Poor rice farmers get problems with the new diversification policy because aquaculture requires high inputs and is economically risky. Farmers that cultivate shrimps are not secure of income because of poor quality shrimp seeds, limited technological knowledge of the farmer and poor quality intake water. Saltwater aquaculture is a solution for saline coastal areas but in the current status not sustainable due to other factors like high inputs and the economic risk.

6.1.2. Current adaptation: upland crops in the coastal area of Vĩnh Châu

The farmers that cultivate upland crops are located on the higher sand ridges and cultivate paddy rice during the rainy season (intercropping). Deep groundwater is used during the dry season for the irrigation of cabbage, chilli, sweet corn and onions. The shallow groundwater is not available in the dry season and no pumps are located in the shallow aquifer. The analysis of the salinity tolerance of the different crops compared to the salinity levels of the irrigation water shows that there is no yield reduction in the current situation due to salt stress for cabbage, chilli and sweet corn. Salt stress only occurs for the cultivation of onions. The salinity levels of the irrigation water causes in the current situation a yield reduction of 0-5% for some farmers. If the salinization of the groundwater increases in the future due to climate change predictions, the farmers that cultivate upland crops could face problems of increased yield reduction.

6.1.3. Lessons learned

Based on this study, a number of key lessons can be identified for the future with increasing climate change impacts:

- The salinity levels of the deep groundwater that is used for irrigation of upland crops and mixing water for aquaculture do not cause yield reduction in the current situation. The future with climate change could increase salinity levels which forms a threat for upland crop production and other factors like high inputs and the economic risk make shrimp farming unsustainable in the future;
- Saline intrusion is not the main problem in the Vĩnh Châu district because of the wide implementation of marine aquaculture. Protection to sea level rise could have priority for the low-lying coastal areas;
- Farmers rely on the deep groundwater but other water sources like shallow groundwater and rainwater could make farmers more sustainable.

6.2. Recommendations

The following recommendations could make Vĩnh Châu more sustainable:

Develop a management strategy on regional scale

A management strategy on a regional basis could form a solution. This could be implemented by optimizing pumping schemes of water supply companies together with support measures like long distance water transfer, recycling of water, desalinization and water rationing. A local approach is to make more use of the shallow groundwater during the rainy season. In the current situation all the 29 farmers have a groundwater pump in the deep aquifers with an average depth of 110 meters. Another factor is that the irrigation of upland crops is done by hand, which means a lot of water is lost by evaporation and overuse. A change in irrigation method will save valuable deep groundwater.

Rainwater harvesting with the roof as catchment

Rainwater harvesting (rainy season) and storage (dry season) could be a solution for the irrigation of the upland crops. In the current situation rainwater harvesting is mostly used for domestic use. Further research could be based on the quantity of rainwater harvesting that is needed for irrigation during the dry season.

Increase mixed shrimp-mangrove system

The predicted sea level rise forms a threat to current land use if no controll measures by the government take place. In this case mixed shrimp-mangrove systems could form an adaptation strategy. This system integrates ecology, agriculture and is reachable to small-scale, family-based operations. Further research based on the implementation of this system is needed.

Sluice to prevent saline intrusion of surface water

The building of a sluice would mean a restoration of the former salinity-controlled area, with consequences for the marine aquaculture in the Vĩnh Châu district.

Implementation of new innovations (recharge wells and salt-tolerance crops)

The development of new techniques increases in the future and could form a solution to prevent or adapt to saline intrusion. For example the artificial recharge wells and salt-tolerance crops.

Bottom up or top down approach

The land use change from rice to aquaculture could be seen as a bottom up approach and show that farmers do have the power to make a difference. But like the more developed Mississippi delta shows that it is important to have a government that is aware of the problems and can have a leading role in accelerating the adaptation process.

7. Reflection

This chapter presents a critical reflection of the method and results. It provides the learning process that could help other students in doing research abroad.

Interviewing

An employee of the local government DONRE joined during the field trip. This has the positive effect that we went very fast through the area. But communication is in some cases difficult and it sometimes goes too fast. It is hard to control the locations and this could affect the research. This is visible at the segment line 1 in Figure 4-1. The interviews are close to each other and they must be more spread over the area to get a better indication about the salinity levels of the groundwater inland. This occurred at day 1 of the field trip and this learning process is implemented at day 2 and 3, visible in segment line 2.

There is a dependency for interviewing and translation during the field trip. The interviewing during the field trip is visible in Figure 7-1. It is difficult for a translator with no technical knowledge about groundwater to notice what is important to know and what not. The translator is a volunteer, a good motivation is very important with interviewing. This affected the results of the research because the interview did not give us detailed information. The lesson that can be learned from interviewing in an international environment is that the technical knowledge combined with the experience of the interviewer is from utmost importance.

Figure 7-1. Interviewing in Vĩnh Châu.

Measuring salinity groundwater

The best idea is to calibrate the EC-probe before every measurement. In this research the calibration took place one time before the start of the field trip. The reason for this is that there is not enough during the field trip for calibration. This could have a negative effect on the research.

The plan is to measure the salinity level of the shallow groundwater (soil level – 10 meters deep). But there is only one shallow groundwater pump with a depth of 9 meter from the 29 farmers. The shallow groundwater pump is out of use because it could not pump water. The reason for this is that the measurement took place in the beginning of April, the end of the dry season. Shallow groundwater is only available in the rainy season. Figure 7-2 visualizes the salinity level measurement of the groundwater.

In some cases it is not possible to reach the groundwater pump, this is the case with the first four interviews. In those cases the farmer collects groundwater for the measurement in his own cup. This could have a negative effect on the salinity level measurements.

Figure 7-2. Salinity measurements groundwater.

Analysing data

In this research only the salinity levels of the groundwater are measured. Therefore it is hard to analyse the aquaculture because of the mix between groundwater and sea/river water. Only one pond located at farm 10 is measured.

There is no historical data available concerning the salinity of the deep groundwater in the Vĩnh Châu area. This report is only based on current salinity data and predictions are made by combining climate change predictions.

References

Abd-Elhamid, H. F. & Javadi, A., 2008. *An Investigation into Control of Saltwater Intrusion Considering the Effects of Climate Change and Sea level Rise.* Naples, School of Engineering, Computing and Mathematics, University of Exceter.

Alexander, B., 2003. *Irrigation Systems For Restoration & Mitigation Sites.* Olympia, Sound Native Plants.

Australian Online Coastal Information, 2012. *Saline intrusion.* [Online]
Available at: www.ozcoasts.gov.au
[Accessed 16 May 2013].

Berg, M. et al., 2001. Arsenic Contamination of Groundwater and Drinking Water in Vietnam: A Human Health Threat. 28 June.pp. 2621-2626.

Berg, M. et al., 2006. Magnitude of arsenic pollution in the Mekong and Red River Deltas - Cambodia and Vietnam. *Elsevier,* 1 November, Issue 372, pp. 413-425.

Blackwell Science Ltd, 2003. *Live Feeds in Marine Aquaculture.* Oxford: Blackwell Science Ltd.

Bridson, P., 2013. *Black tiger shrimp,* s.l.: Seafood Watch.

Bucx, T., Marchand, M., Makaske, B. & van de Guchte, C., 2010. *Comparative assesment of the vulnerability and resilience of 10 deltas,* Delft-Wageningen: Delta Alliance International.

Chang, M., 2000. *Salt Water vs. Fresh Water - Ghyben-Herzberg Lens.* [Online]
Available at: www.geography.about.com
[Accessed 16 May 2013].

Cong, N. C., 2013. *People's Committee of Vinh Chau town* [Interview] 2013.

Day Jr., J. W. et al., 2005. Implications of global climatic change and energy cost and availability for the restoration of the Mississippi delta. *Elsevier,* Issue 24, pp. 253-265.

Deltares & Delta Alliance, 2011. *Mekong Delta Water Resources Assesment Studies,* s.l.: Vietnam-Netherlands Mekong Delta Masterplan project.

Department of Primary Industries, 2011. *Farming and Management.* [Online]
Available at: www.dpi.vic.gov.au
[Accessed 6 March 2013].

DuBowy, P. J., 2013. Mississippi River Ecohydrology: Past, present and future. *Elsevier,* Issue 13, pp. 73-83.

Eijkelkamp, 2013. *EC-probe for salinity measurement.* [Online]
Available at: www.eijkelkamp.com
[Accessed 22 February 2013].

Eijkelkamp, 2013. *Water sampling and field analysis set.* [Online]
Available at: www.eijkelkamp.com
[Accessed 22 February 2013].

Engineers without borders institute, 2013. *Water Supply & Sanitation.* [Online]
Available at: www.ewb.org.au
[Accessed 29 May 2013].

Food and Agriculture Organisation, 1997. *Chapter 5: Personal Interview.* [Online]
Available at: http://www.fao.org/docrep/W3241E/w3241e06.htm#conducting the interviews
[Accessed 27 February 2013].

Food and Agriculture Organization, 1999. *Agricultural drainage water management in arid and semi-arid areas,* s.l.: FAO.

HoseSolutions, 2013. *Salt Water Barriers.* [Art] (Hose Solutions Inc.).

Huq, S. et al., 2004. Mainstreaming adaptation to climate change in Least Developed Countries (LDCs). *Climate Policy,* 4(1), pp. 25-43.

IUCN, 2011. *Groundwater in the Mekong Delta,* s.l.: Mekong Water Dialogues.

Jarvis A., H. R. A. N. E. G., 2006. *Hole-filled seamless SRTM data V3, International Centre for Tropical Agriculture (CIAT).* [Online]
Available at: http://srtm.csi.cgiar.org
[Accessed 25 March 2013].

Joffre, O. M. & Schmitt, K., 2010. Community livelihood and patterns of natural resources uses in the shrimp-farm impacted Mekong Delta. *Aquaculture Research,* 41(12), pp. 1855-1866.

Käkönen, M., 2008. Mekong Delta at the Crossroads: More Control or Adaptation?. *BioOne,* 3(37), pp. 205-212.

Khoi, C. M., Guong, V. T. & Merckx, R., 2006. Predicting the release of mineral nitrogen from hypersaline pond sediments used for brine shrimp Artemia franciscana production in the Mekong Delta. *Elsevier,* Issue 257, pp. 221-231.

Le Anh, T., Chu Thai, H., Miller, F. & Bach Tan, S., 2008. *Flood and Salinity Management in the Mekong Delta, Vietnam,* s.l.: s.n.

M. Barlow, P., 2003. *Ground Water in Freshwater-Saltwater Environents of the Atlantic Coast,* Denver: U.S. Geological Survey, Information Services.

Managementmodellensite, 2013. *People planet profit.* [Online]
Available at: www.gertjanschop.com
[Accessed 27 May 2013].

Mekong River Commission For Sustainable Development, 2001. *Saltwater intrusion in the Mekong River Delta.* [Online]
Available at: ns1.mrcmekong.org/envir_training_kit/English/Case%20Studies/PDF/CS18%20-%20Mekong%20River%20Delta%20Saltwater%20Intrusion.pdf
[Accessed 20 March 2013].

Mekong-Group, n.d. *Mekong-Group Fish Union Of The Mekong.* [Online].

Ministry Of Natural Resources And Environment, 2010. *Climate Change In The Mekong Delta,* Ho Chi Minh City: s.n.

Misnu, D. K., 2010. *The three P mantra (People, Planet, Profit).* [Online]
Available at: www.development.wanakalapa.com
[Accessed 27 May 2013].

Musatea, C., Singhal, N. & De Costa, G., 2009. *Salinity Intrusion, its Management and Control - Future Scenarios case of the Waiwhetu Aquifer.* s.l., Open Polytechnic.

Nguyen Cuong Irrigation System, 2012. *Agricultural news.* [Online]
Available at: www.nguyencuong.com.vn
[Accessed 10 May 2013].

Nhan, D. K., Be, N. V. & Trung, N. H., 2008. *Chapter 4: Water Use and Competition in the Mekong Delta, Vietnam,* Can Tho: Can Tho University.

Oude Essink, G. et al., 2009. *Voorkomen en dynamiek van regenwaterlenzen in de Provincie Zeeland - resultaten van een verkennende en provinciedekkende meetcampagne,* Utrecht: TNO Bouw en Ondergrond.

Oude Essink, G. et al., 2008. *Zoet-zout studie Provincie Flevoland,* Utrecht: Deltares.

Oude Essink, G., van Baaren, E., de Lange, W. & de Wit, A., 2008. *Beschouwing van de effecten van een zout Volkerak-Zoommeer op het grondwatersysteem,* Utrecht: Deltares.

Pampus, A., Overbeek, M. & Bouwmeester, R., 2013. *RRA Vinh Chau,* Can Tho: s.n.

Post, V. E. A., 2005. Fresh and saline groundwater interaction in coastal aquifers: Is our technology ready for the problems ahead. *Springer Link,* 1(13), pp. 120-123.

Prasad Giri, C., Pradhan, D., S. Ofren, R. & Kratzschmar, E., 1998. *Land Use/Land Cover Change In South-East Asia,* Bangkok: UNEP Environment Assesment Programme for Asia and the Pacific.

Pushparajan, N. & Soundarapandian, P., 2010. Recent Farming of Marine Black Tiger Shrimp, Penaeus Monodon (Fabricius) in South India. *African Journal of Basic & Applied Sciences,* Volume 2, pp. 33-36.

Shannon, M. & Grieve, C., 1999. Tolerance of vegetable crops to salinity. *Elsevier,* Issue 78, pp. 5-38.

Solinst, 2012. *Pump/Recharge Rate Affects Saltwater Intrusion.* [Art] (Solinst).

Statoids, 2011. *Districts of Vietnam.* [Online]
Available at: www.statoids.com/yvn.html
[Accessed 7 March 2013].

Syvitski, J. P., 2008. Deltas at risk. Issue 3, pp. 23-32.

Texas, U. o., 2012. *Bangladesh.* [Art] (The University of Texas at Austin).

Thermo Electron Corporation, 2003. *Orion Aplus Basic Conductivity Meters,* s.l.: Thermo Electron Corporation.

Trang Hoang, T., 2011. *Vinh Chau District Overview.* [Online]
Available at: www.stipc.soctrang.gov.vn
[Accessed 5 May 2013].

Tri, D. P. V., 2013. *Land use map Vinh Chau.* Can Tho: Can Tho University.

Tuong, T. P. et al., 2003. Impact of seawater intrusion control on the environment, land use and household incomes in a coastal area. *Paddy Water Environ,* pp. 65-73.

United Nations Development Program, 2010. *Developing a community-based model on onion-based cultivation crops to adapt to climate change impact (droughts and saline intrusion) in Vinh Chau District, Soc Trang Province,* Can Tho: s.n.

van Dijk, M. et al., 2013. *Land-use change, food security and climate change in Vietnam,* The Hague: Wageningen UR.

Van Hall Larenstein, 2008. *River Delta Management,* Velp: Van Hall Larenstein.

Van, P. D. T. et al., 2012. A study of the climate change impacts on fluvial flood propagation in the Vietnamese Mekong Delta. *Hydrology and Earth System Sciences,* Issue 16, pp. 4637-4649.

Viet Nam News, 2013. *Mangrove trees protect villagers from hard times.* [Online]
Available at: www.vietnamnews.vn
[Accessed 29 May 2013].

Vietfish International, 2010. *Soc Trang: Black tiger shrimp output reaches 1.4MT per ha.* [Online]
Available at: www.vietfish.org
[Accessed 5 May 2013].

Wagner, F., Bui Tran, V. & G. Renaud, F., 2012. Groundwater Resources in the Mekong Delta: Availability, Utilization and Risks. *Springer Environmental Science and Engineering,* pp. 201-220.

Wikipedia, 2013. *Vietnamese Mekong Delta.* [Online]
Available at: en.wikipedia.org/wiki/Mekong_Delta
[Accessed 7 March 2013].

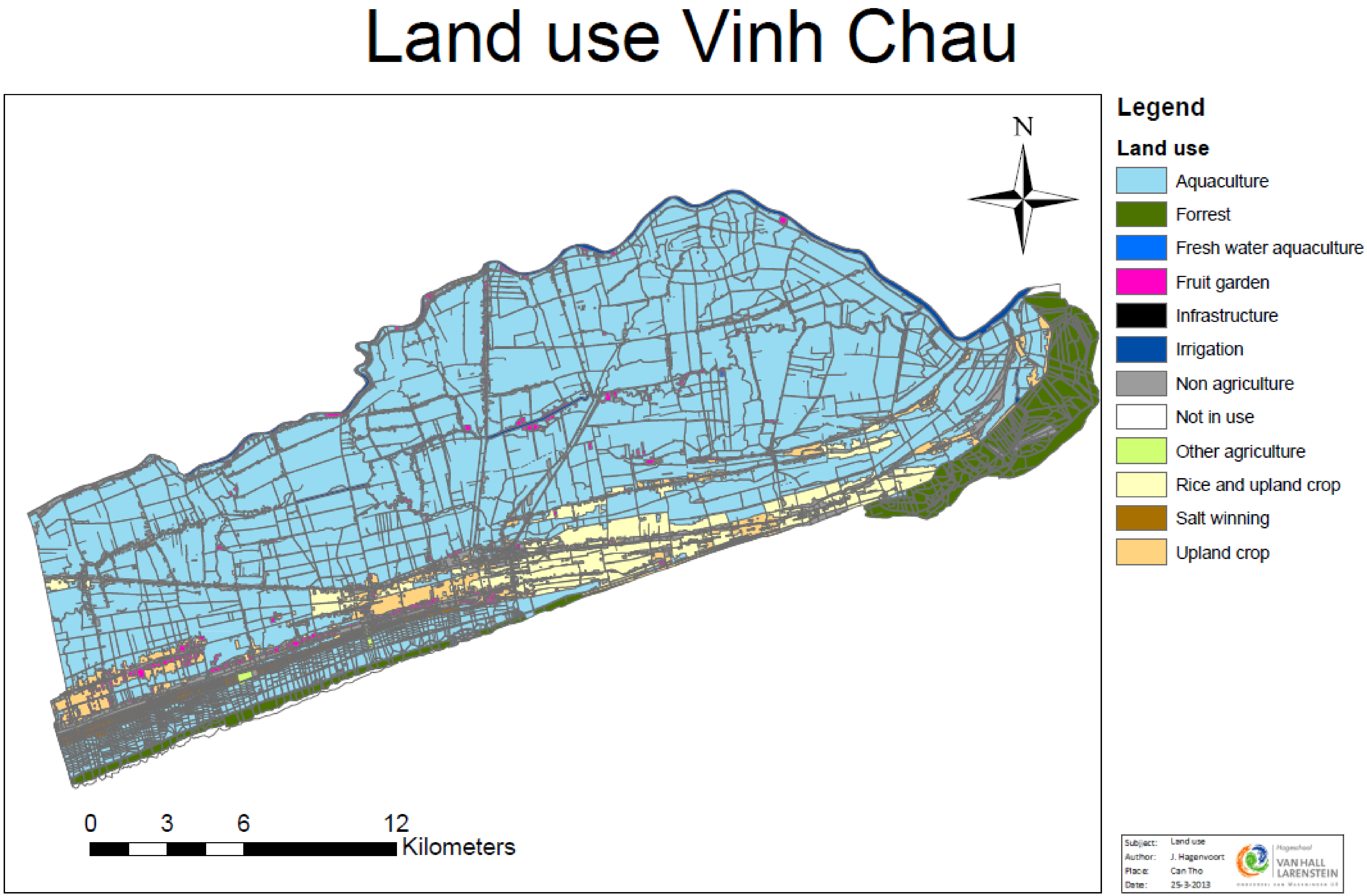
Annexes

Annex 1: Questionnaire groundwater survey

Groundwater salinity adaptation survey ***Câu hỏi khảo sát về sự thích nghi nước ngầm bị nhiễm mặn***	Usable pumps (Máy sử dụng được)		Unusable pumps (Máy không sử dụng đc)	
How many usable/unusable groundwater pumps do you have in your house? *Ông/bà có bao nhiêu máy bơm nước sử dụng được trong nhà?(bao gồm cả máy có thể và không sử dụng được)*	1	2	1	2
Coördinates *Tọa độ*				
What is the depth of the groundwater pump(s) in meters? *Máy bơm nước có thể bơm được nước ở độ sâu bao nhiêu mét?*				
Do you use now a day's more groundwater than in the past (10 years ago)? *Hiện tại ông/bà có sử dụng nước ngầm nhiều hơn trước đây (10 năm trước) không?*				
How many times a day and how long do you use groundwater for irrigation? And what is the capacity of the pump? *Ông/bà sử dụng nước ngầm bao nhiêu lần 1 ngày và trong thời gian bao lâu để phục vụ canh tác? Và công suất của máy bơm (được sử dụng cho nông nghiệp)là bao nhiêu?*				
What kind of crops do you cultivate? (Farming system and when do you produce/harvest?) *Ông/bà đang trồng cây gì? (hệ thống canh tác và khi nào ông/bà thu hoạch?)* *(các loại cây trông có thay đổi theo mùa không?)*				
Is the groundwater always of good quality during the year for your specific crop? How do you describe the quality? *Chất lượng nước ngầm có luôn ở trạng thái tốt để phục vụ sản xuất nông nghiệp? Chất lượng của nó thế nào?*				
Did you take any adaptation measures to deal with the salinization problem? If yes, what did you do? *Ông/bà có biện pháp nào để thích nghi với sự nhiễm mặn trong nước ngầm không? Nếu có, ông/bà đã làm gì?*				

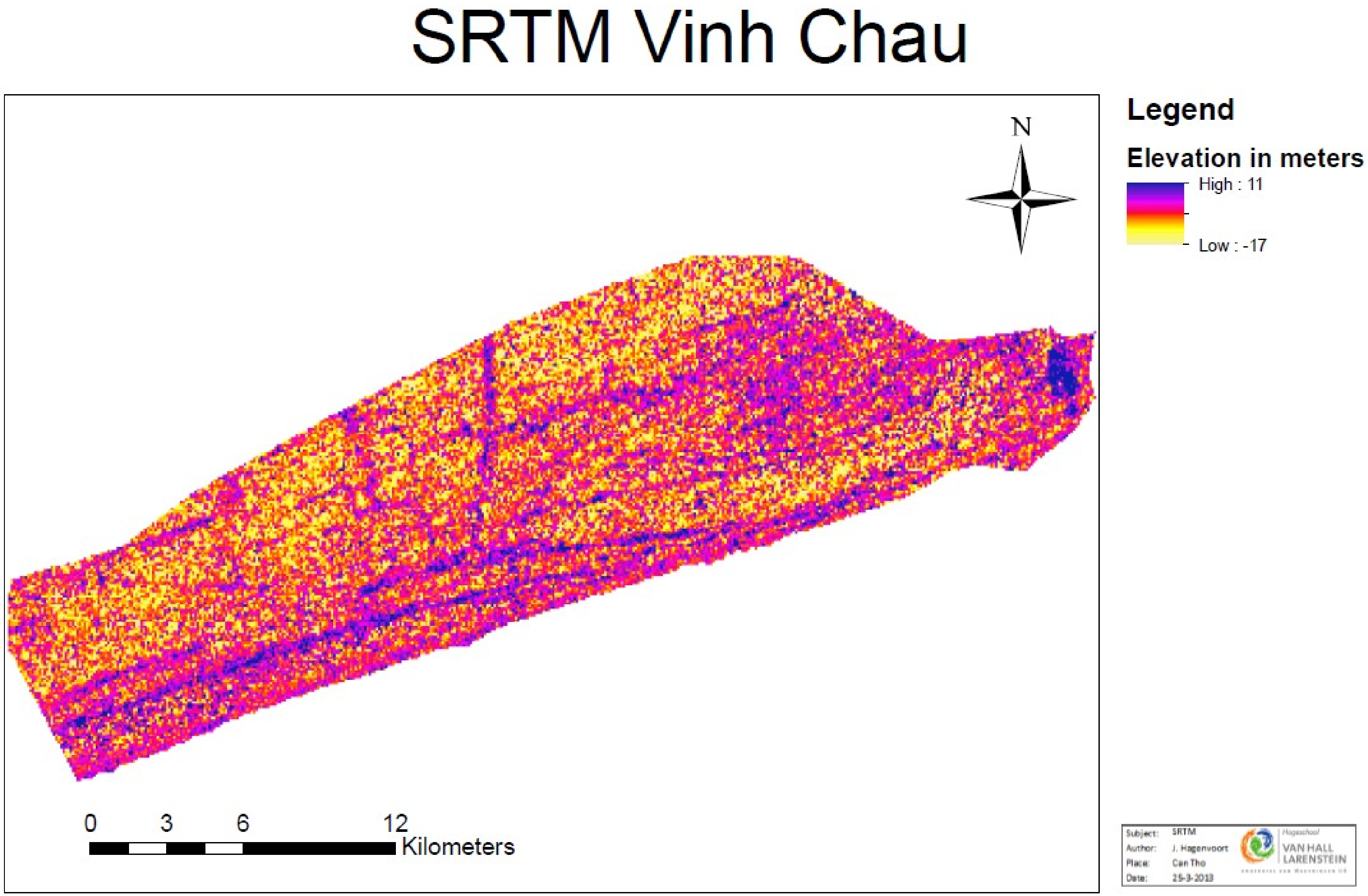
Do you use other sources to obtain water, like for instance rainwater harvesting? If yes what are your sources? *Ông/bà có sử dụng nguồn nước nào khác (như là nước mưa) không? Nếu có, nguồn nước từ đâu?*	
Is there rapid runoff when it rains? Where does the rainwater go? *Nước chảy tràn khi trời mưa không? Nước mưa sẽ chảy đi đâu?*	
Can you earn enough money in the current situation (concerning water quality)? If yes, do you think will change negative/positive in the future? *Ông/bà có kiếm đủ tiền trong tình trạng hiện nay (liên quan đến về chất lượng nước) không? Nếu có, ông/bà có nghĩ về sự thay đổi tiêu cực/tích cực trong tương lai?*	
Will you think the salinity of the groundwater change in June? *Ông/bà có nghĩ sự nhiễm mặn của nước ngầm sẽ thay đổi vào tháng 6 (mùa mưa)?*	
Taking photos and describing the farm: **How many photos were taken:** **Where are they on the camera:** **Coördinates and time of taking at the farm:**	

Annex 2: Land use map Vĩnh Châu



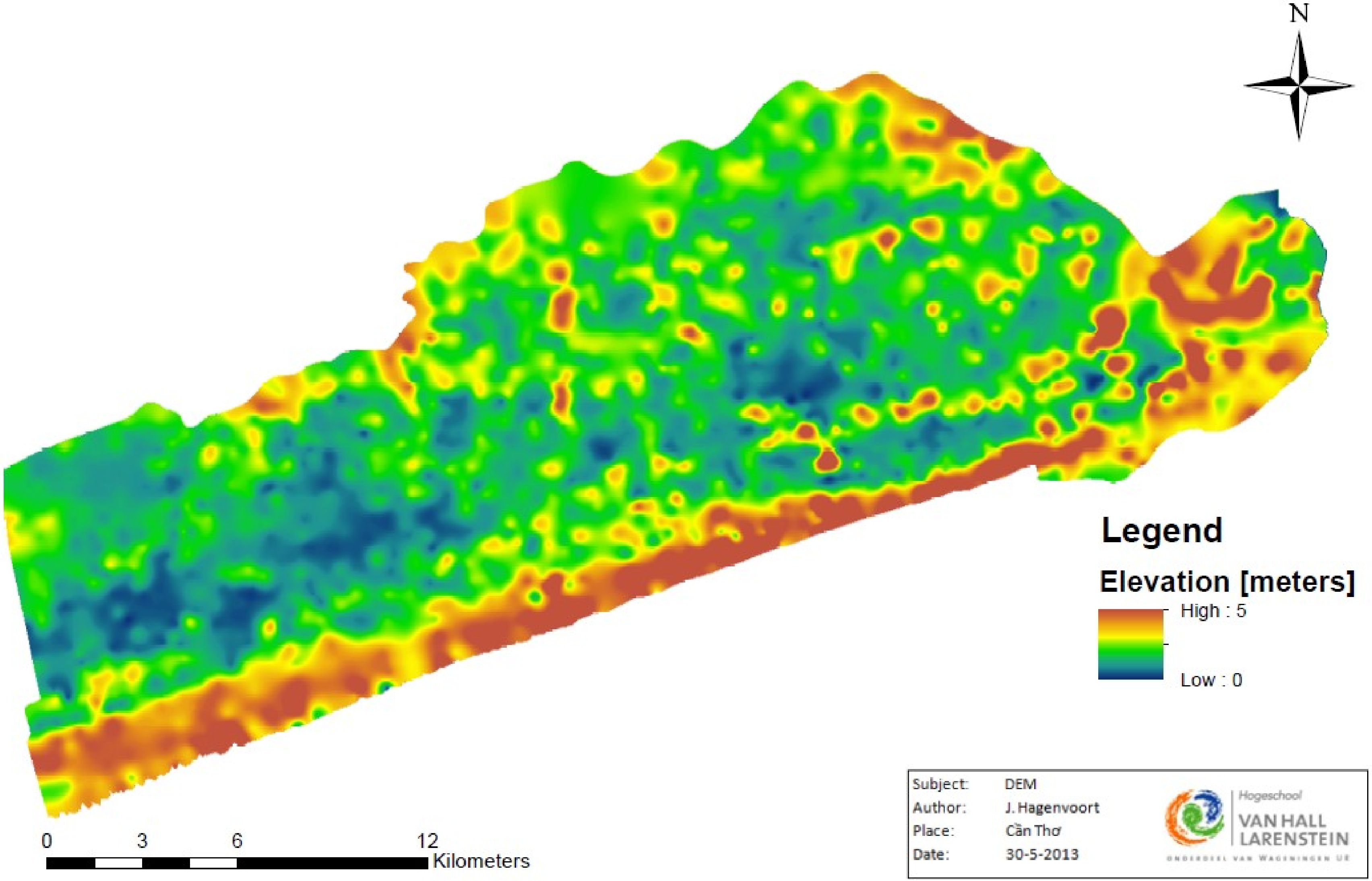
Land use map of the Vĩnh Châu district (Van PD Tri, Can Tho University, 2013)

Annex 3: SRTM and DEM Vĩnh Châu

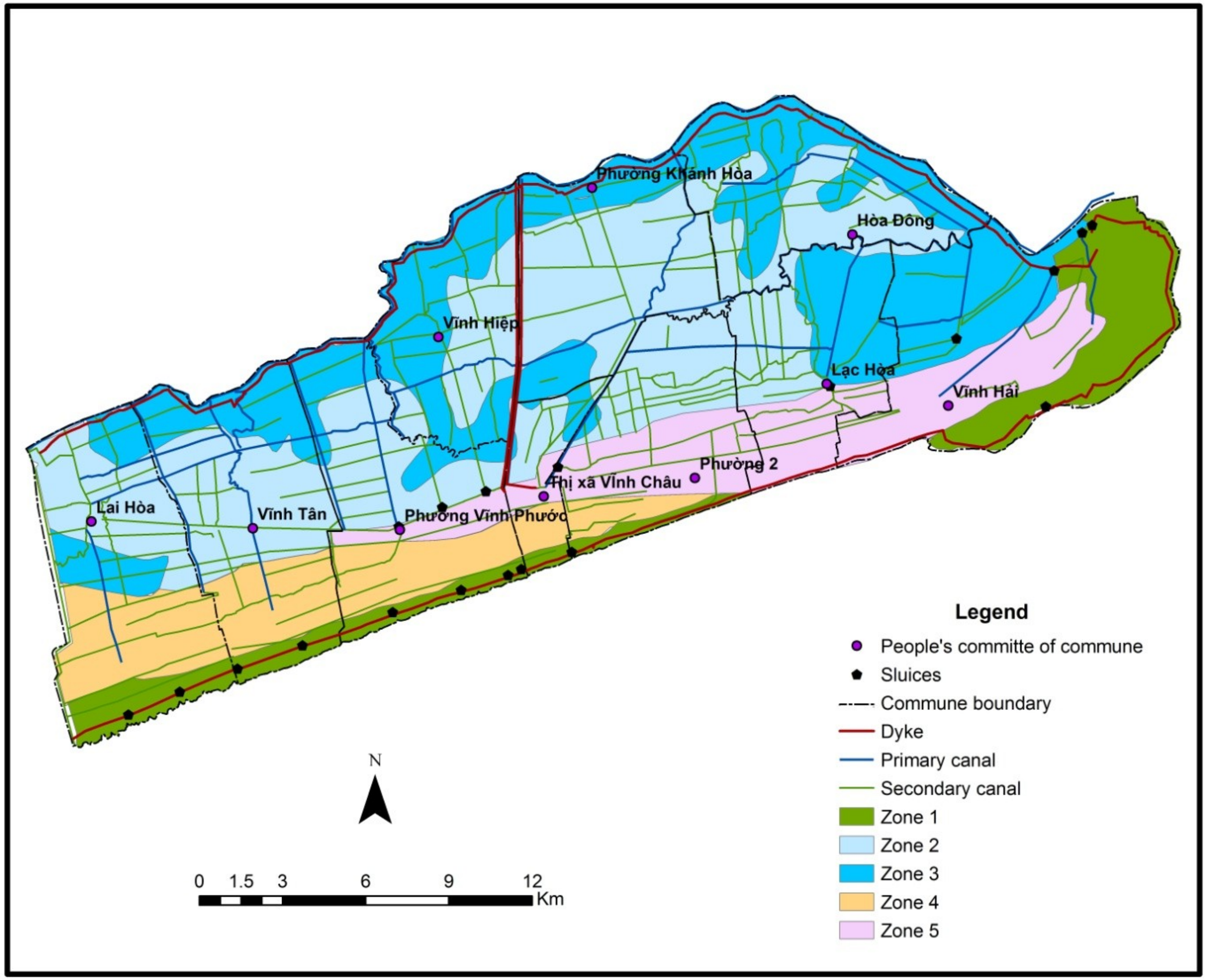


The digital elevation model of the Vĩnh Châu district (Jarvis A., 2006)

Digital Elevation Model Vinh Chau



Annex 4: Agro-ecological map Vĩnh Châu



Zone 1: Accounting for 10.5% of the district area; high salinity of the soil, mainly mangrove forest and saltwater aquaculture.

Zone 2: Accounting for 36.2% of the district area; high salinity of the soil, farmers are specializing in shrimp farming.

Zone 3: Accounting for 29.1% of the total area of the district; highest salinity of the soil, mainly shrimp farming.

Zone 4: Accounting for 11.3% of the district area; under average soil salinity, alternating sand-dunes with many farming systems: Rice, onions, vegetables, fruits and closes to the sea; salt, Artemia and shrimp farming can be found.

Zone 5: Accounting for 12.9% of the district area; low salinity of the soil, higher elevated sand-ridges with many rotation cultivation systems: Rice, onions, vegetables, fruits on top of the sand ridge, shrimp, salt and Artemia at the bottom.

Agro-ecological map of the Vĩnh Châu district with an indication about salinity of the soil (unpublished document from Van PD Tri, Can Tho University, 2013)

Annex 5: Calibration for EC-probe

Chapter IV
Operation

Calibration of the Cell Constant

It is recommended to calibrate the cell constant against known conductivity standards as the conductivity cell constant may shift with time. The Orion 105Aplus calibrates by a cell constant adjustment method. The Orion 115Aplus and 145Aplus calibrate either by adjusting the cell constant or by performing a Direct Calibration. For best results, calibrate at the chosen reference temperature.

Calibration for TDS and Salinity must be performed in the conductivity mode using conductivity standards.

Calibration – Cell Constant Adjustment Method (Orion 105Aplus, 115Aplus and 145Aplus)

Note: To return to active measurement modes from the calibration mode, press the MODE key.

1. Disable the temperature compensation by entering the SETUP mode, scrolling the temperature coefficient (S-1) down to 0 and pressing the **YES** Key. Press the **MODE** key to return to the measurement.
2. Initiate calibration by pressing the **CAL** key. The "CALIBRATE" indicator and the last cell constant will appear on the display.
3. Immerse the conductivity cell in the standard. Slightly agitate the cell to remove any air bubbles.
4. Enter the cell constant printed on the cell cable or estimate the cell constant of the cell you are using. Use the ▲ or ▼ key to move the decimal point, then press the **YES** key to accept the decimal placement. Enter the cell constant value by scrolling each digit with the ▲ or ▼ key, then accepting the value by pressing the **YES** key. The meter automatically returns to the measurement mode.
5. Compare the displayed value of the standard to its specified value at the standard's temperature (See table page 8).
6. If the correct standard value is not displayed, calculate the cell constant adjustment factor (Q) using the following formula:

$$Q = \frac{\text{Standard Value}}{\text{Displayed Value}}$$

   Multiply the original cell constant by the factor Q to obtain the new cell constant:

   Q x cell constant (original) = cell constant (new).

7. Repeat steps 2 through 6 until the desired calibration accuracy is obtained.
8. Once the appropriate cell constant has been established, the temperature compensation feature may be enabled by changing the temperature coefficient in **SETUP** mode (see step 1).

Table of Conductance vs. Temperature for Orion Conductivity Standards.

Temp. °C	12,896 µS Standard Orion 011006	1413 µS Standard Orion 011007	100 µS Standard Orion 011008
25	12896	1413	100
26	13142	1441	102
27	13389	1468	104
28	13637	1496	106
29	13885	1524	108
30	14135	1552	110
31	14385	1580	112
32	14636	1608	114
33	14888	1636	117
34	15141	1665	119
35	15394	1693	121
36	15648	1722	123
37	15903	1751	125
38	16158	1780	127

(Thermo Electron Corporation, 2003)

Calibration process		
Temperature in degrees	31	
Calibration solution/standard value (µS/m)	1580	
Displayed value (µS/m)	130.5	
Specified value at the standard's temperature (25 degrees in µS/m)	1413	
Cell constant adjustment factor (Q)	Standard value / Displayed value	
Q	12.10727969	Entered on screen EC-probe
Calculated iterative in 4 steps		
Conductivity standard Orion 011007	1413	
Displayed value (µS/m)	925	
Q	1.708108108	Entered on screen EC-probe
Displayed value after iterative calculation	**1580**	

Annex 6: Guide for measuring the salinity of the groundwater

This contains a guide directly from the Department of Primary Industries about water samples and the recording of their salinity levels. (Department of Primary Industries, 2011)

Salinity units

TDS is recorded in milligrams of dissolved solid in one litre of water (mg/L). Parts per million (ppm) is equivalent to mg/L but it is not a favoured unit.

EC measures the charge carrying ability (ie conductance) of liquid in a measuring cell of specific dimensions. It is necessary to clearly define the units of both conductance and length when talking ECs. To say a water sample is 2000 EC, is like saying a table is 2000 long, without specifying millimetres, centimetres or metres. The standard EC unit used by the Victorian Salinity Program and the Murray Darling Basin Commission is microSiemens per centimetre (µS/cm) at 25^{o}C.

You will however see other units and need to be aware of the relationships between them. µS/cm relates to other units as follows:

1000 µS/cm = 1 deciSiemen/metre (dS/m)
1000 µS/cm = 1 milliSiemen/centimetre (mS/cm)
10 µS/cm = 1 milliSiemen/metre (mS/m)

Collecting your water sample

- Make sure that your collecting container is very clean.Previous contents could affect your result. Use a container with an opening large enough to take the EC meter. Do not use jars which smell (eg.vegemite, pickle jars) if samples are to be kept for a while.

- Choose a sample which is representative of the body of water being considered. It needs to be a sample which is like most of the water you want to get information about.*If you don't collect a representative sample you're wasting your time*. Try not to take your sample too close to the surface, bottom or sides of the waterbody

    - *Flowing Water* - For rivers and creeks try to take your sample in a place where the water if flowing. Sample well below any stream> junction (a rule-of-thumb is the equivalent of 10 stream widths downstream) to allow good mixing.

    - *Still Water* - eg. Dams, swamps and lakes. Saline water is denser than fresh water. This means, that in a still water body, the saline water will settle to the bottom. If you have an offtake pipe from the base of the dam, sample water from here.

    - *Groundwater* - Stock bores can be tested at the trough. However, the water should be freshly pumped. The salinity of water sitting in an unused trough may be higher than the actual groundwater salinity level due to concentration of the salts through evaporation. Investigation bores may be tested using a bailer to collect a water sample. Make sure you ask the permission of the individual or department responsible for the bore.

- Rinse the container two or three times with some of the water to be sampled.

- Collect the sample.

Taking your salinity reading

- Ensure your EC meter has been calibrated (see notes below).
- Remove the protective cap, switch the meter on and insert the probe into the water sample up to the immersion level.
- Move the probe up and down to remove bubbles from around the electrodes.
- This will ensure good contact is achieved between water and electrodes (do not swirl it around as this may actually drive water out of the probe).
- Allow the probe to reach the temperature of the water before taking a reading.
- Temperature has a significant impact on the salinity reading. EC units are standardised to a temperature of 25^{o}C. Some meters automatically correct the reading taken at water temperature to a reading at 25^{o}C.
- If the meter has automatic temperature compensation, wait about 30 seconds before taking your reading if the water and probe are about the same temperature. If the water is much colder than the probe, allow a longer period, say two minutes before taking a reading.
- If the meter has no temperature compensation take the temperature of the sample and use a correction table to get the right value.
- Read the display, and record the result as mentioned below.
- Rinse the probe with tank water and drain off any excess water, between each sample and at the end of sampling for the day. This will prevent false readings due to salt residues on the meter from the last sample.

Recording your results

The results of any sampling, should be recorded in a notebook for future reference. The information should include:

- Name of collector
- Date of sampling Salinity levels fluctuate throughout the year. The date of sampling becomes important then when comparing readings.
- Sampling location. Make a note of where the sample was taken from. Further samples may then be taken from the same site in the future.
- Water source Make a note of the water source. eg. River, Creek, Lake, Dam, Swamp, Drain, Groundwater Bore, etc.
- EC reading. Readings should all be recorded as microSiemens per centimetre (µS/cm). See Salinty units (page 1) to convert readings in other units to µS/cm.
- Temperature reading. If the meter has no automatic compensation, record temperature and adjust resulting EC value from a calibration table.

Calibration

EC meters should be calibrated regularly to ensure they are reading accurately.

The best idea is to **calibrate your meter before each sampling session.**

You will need :

Bottle of Calibration Solution:

Bottle of Check Solution

Clean measuring bottle with a lid and opening large enough to take the EC meter probe.

- Select a calibration solution about midway within the range of readings you are likely to record.

- Rinse measuring bottle with calibration solution. (Discard the solution). Pour 100 ml of the Calibration solution into the measuring bottle.
- Put the EC meter into the solution, allowing time for it to adjust for temperature.
- Using a small screw driver or the calibration tool provided, turn the screw until the display reads the same as the known salinity of the calibration solution.
- Discard calibration solution. DO NOT pour the remaining solution back into the original bottle, as this will contaminate your calibration solution.
- Use the check solution to test the accuracy of the calibration.
- An unopened bottle of calibration solution has a shelf life of about two years.

Care of your meter

Rinse the probes with tank water after you have finished testing to prevent salt build up.

To improve performance, clean the stainless steel electrodes periodically by rinsing in pure alcohol (eg. methylated spirits) for 10 to 15 minutes.

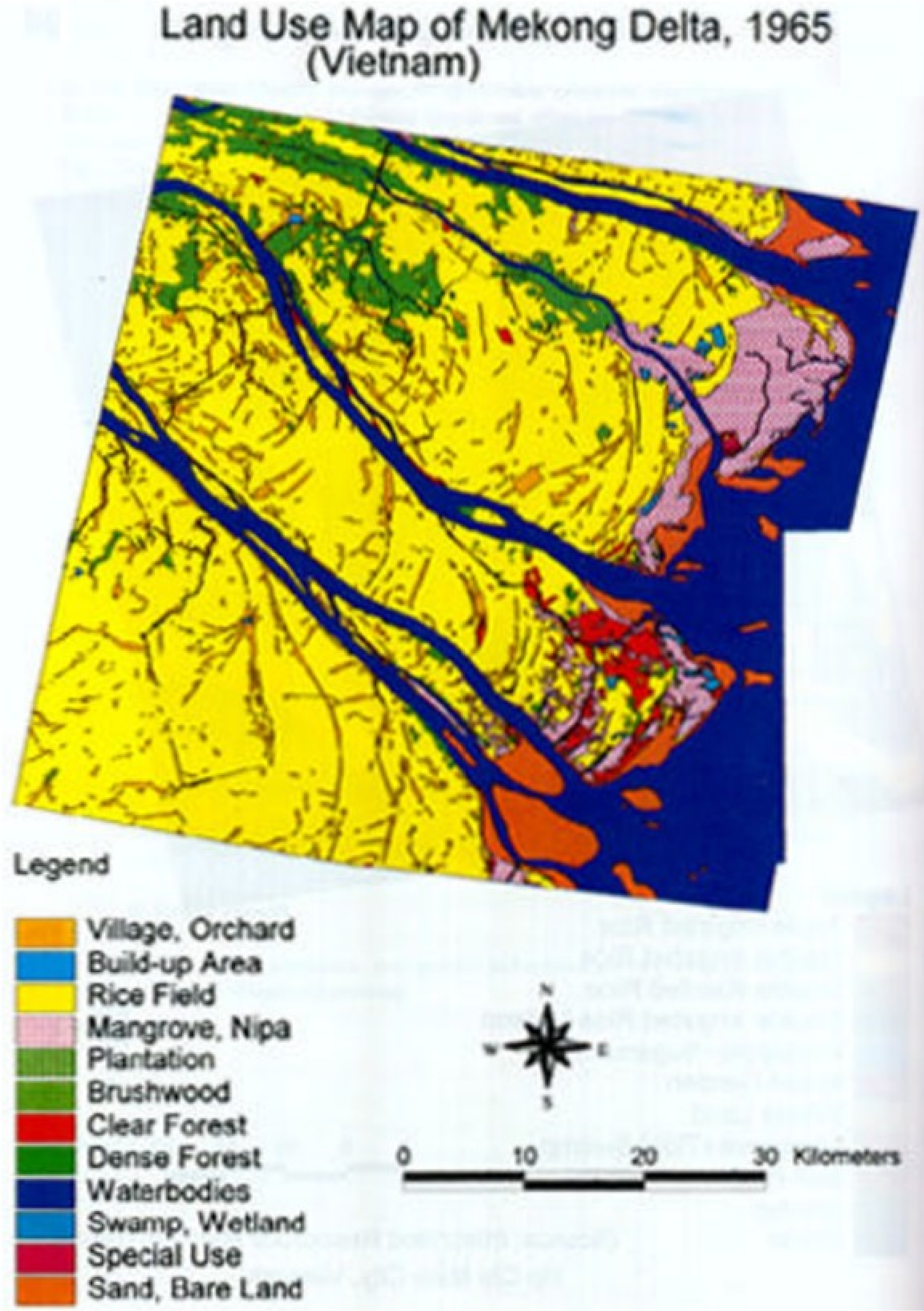
Variations in readings or a faint display can indicate battery failure. Replace the batteries.

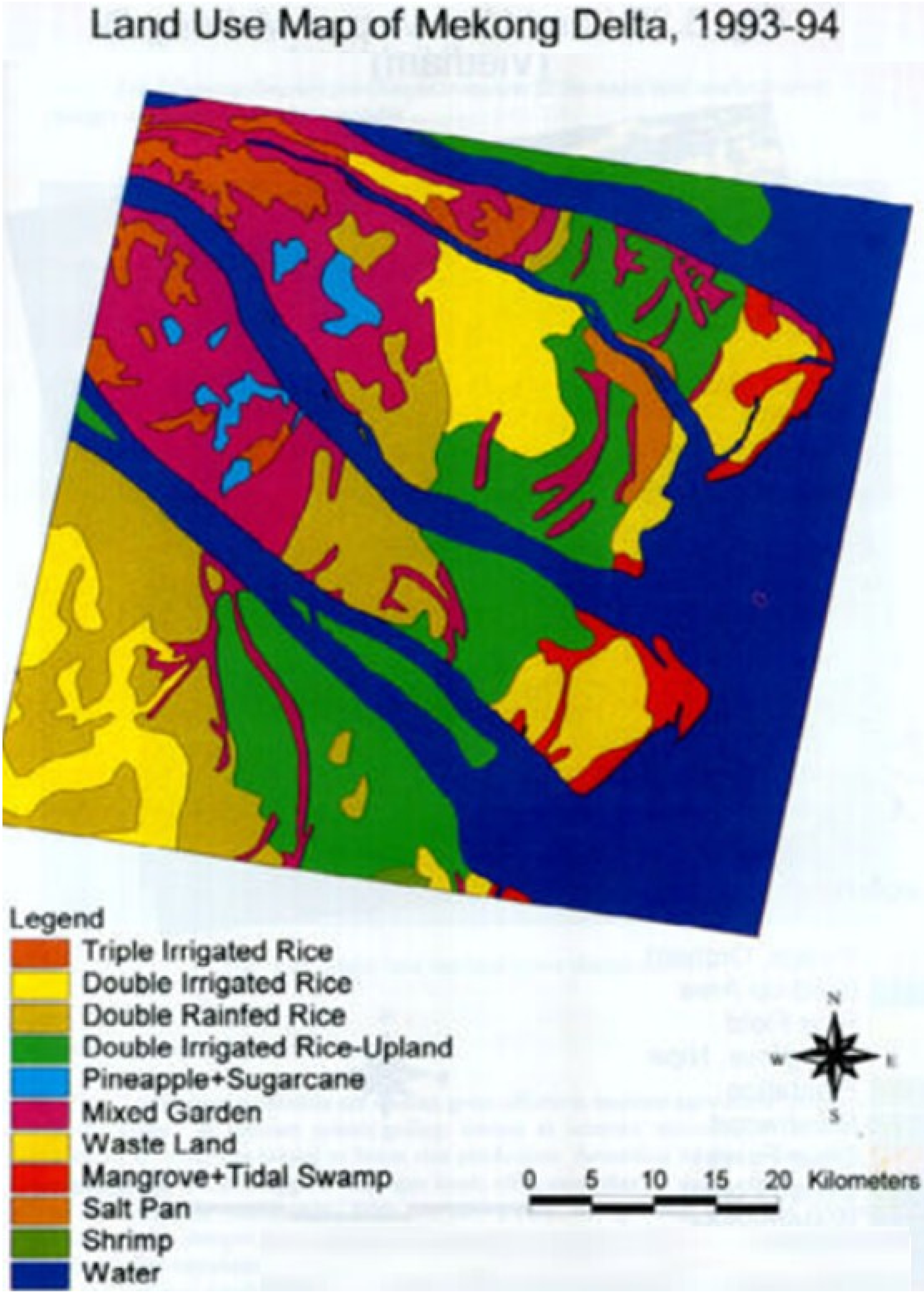
A note on accuracy

Pocket Salinity Meters such as the TDScan 4 and the DiST 4 when properly calibrated have a resolution of 100 µS/cm (i.e. they read to the closest 100 µS/cm). However, if samples are not collected properly or the meter has not been calibrated, large errors can occur.

Groups undertaking a salinity monitoring program comparing readings from site to site and from year to year, should use a meter with a resolution of at least 10 µS/cm.

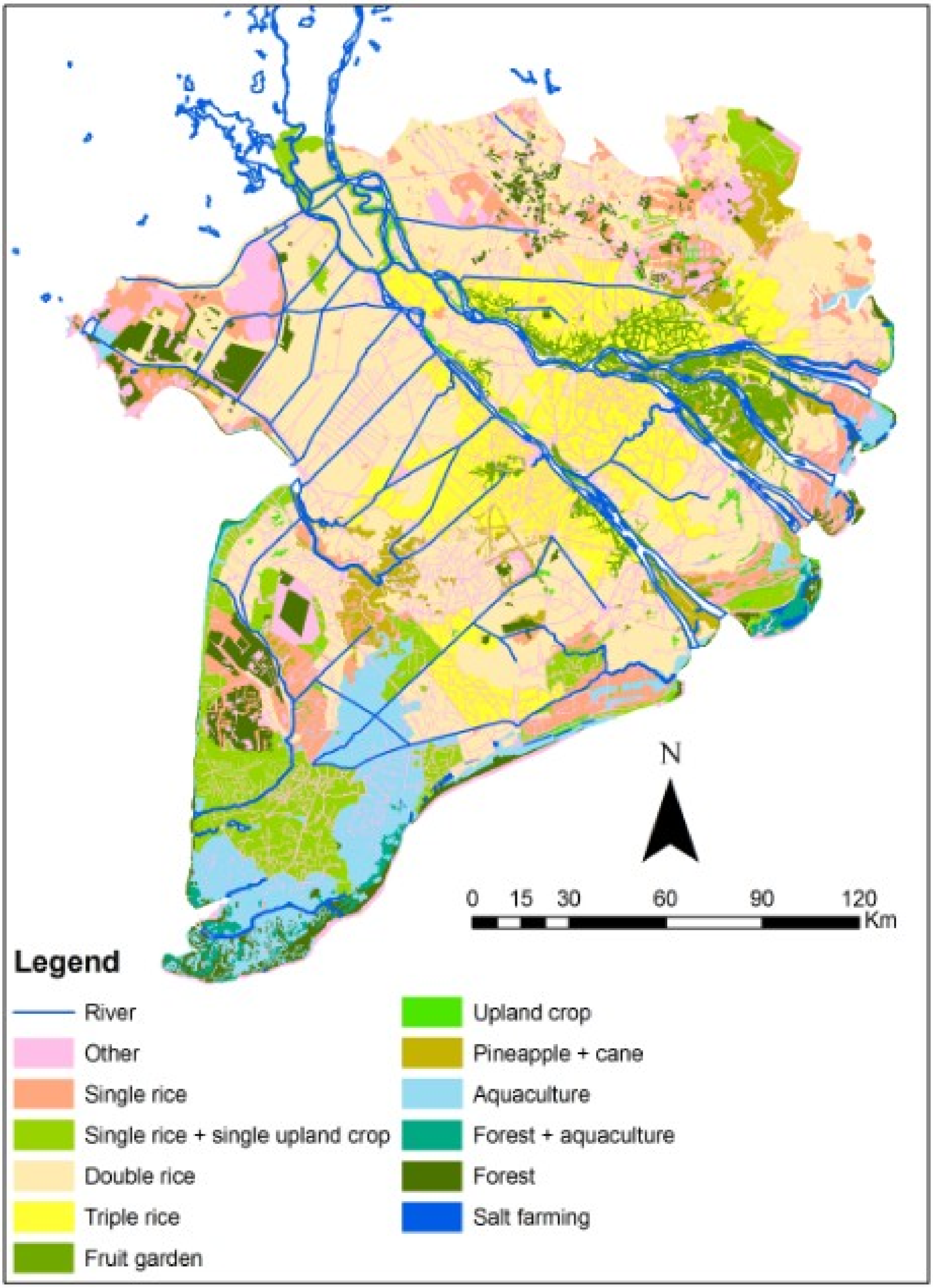
Annex 8: Land use map 1965 and 1993/94





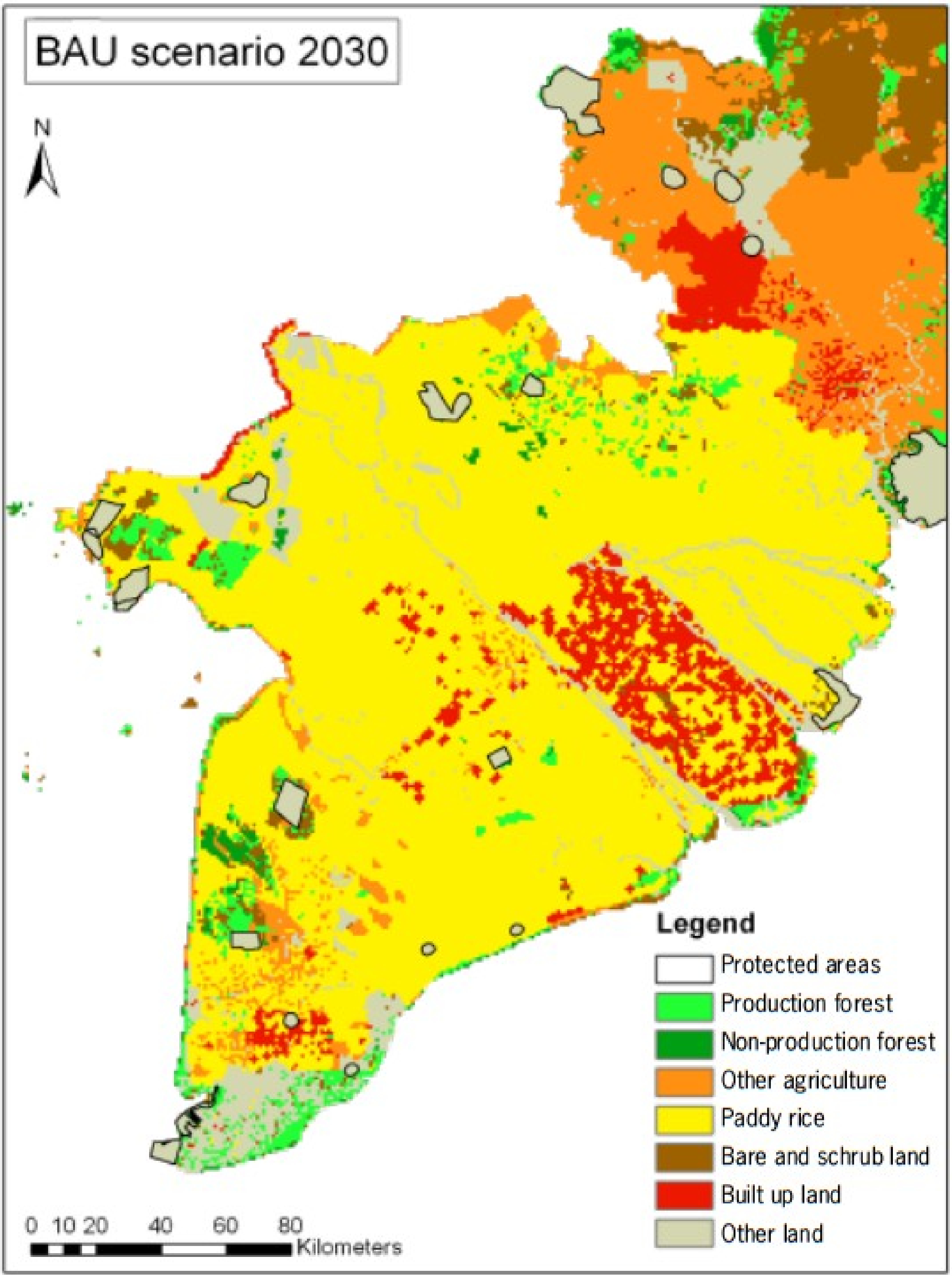
Land use maps from 1965 and 1993-'94 for the VMD (Prasad Giri, et al., 1998)

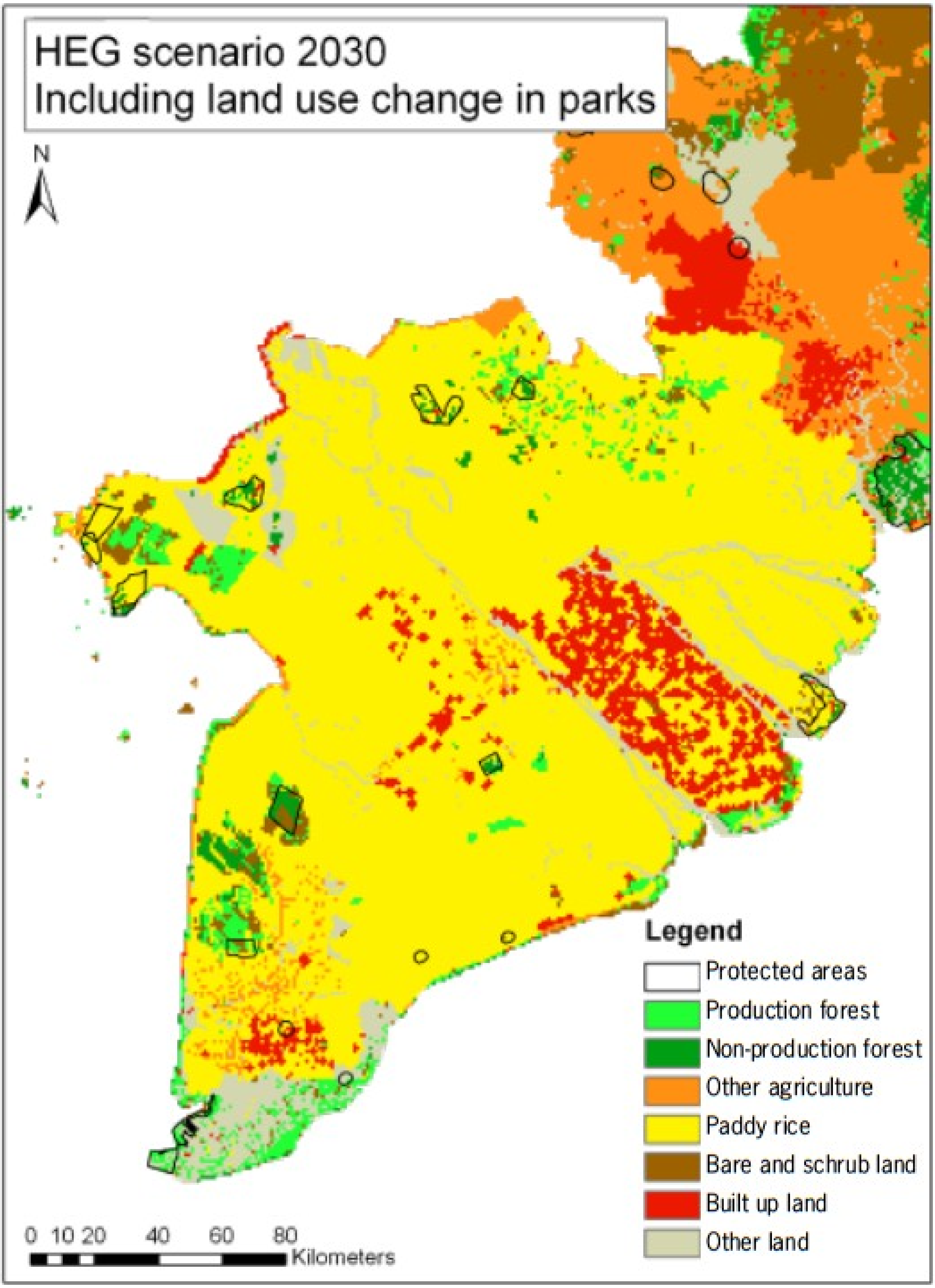
Annex 9: Land use map VMD 2006



(Van, et al., 2012)

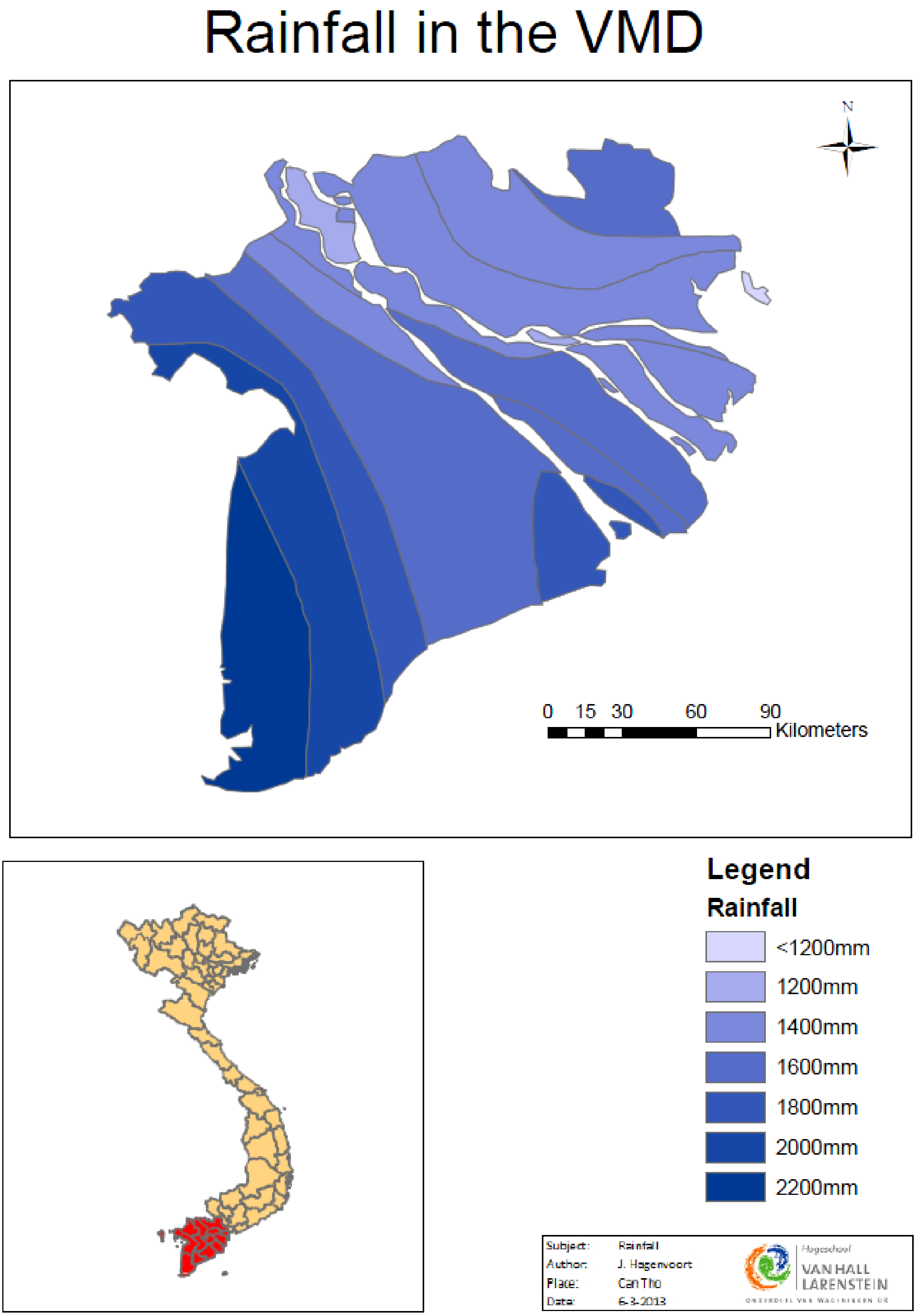
Annex 10: Prediction land use change VMD 2030



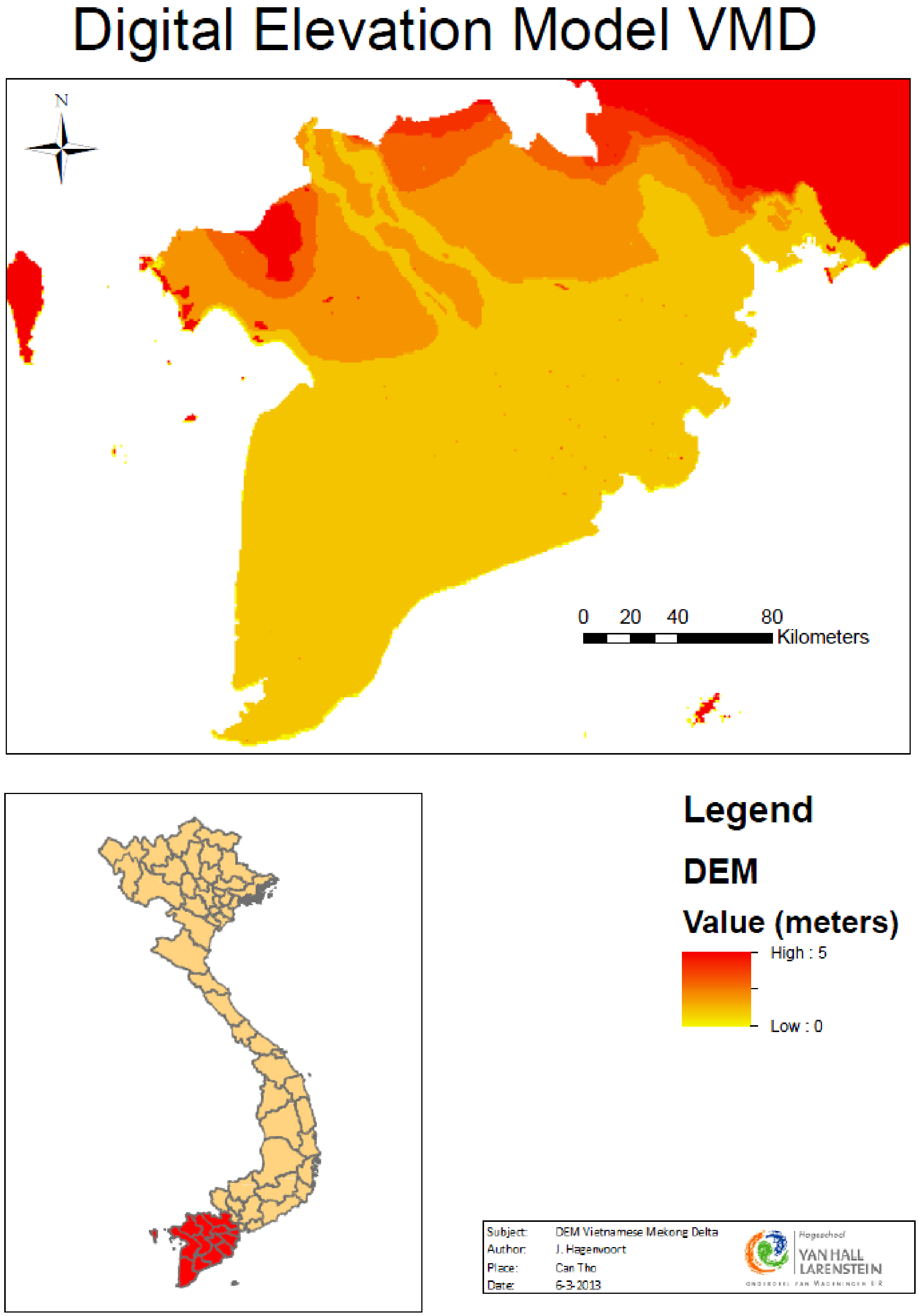


Future scenarios land use VMD (van Dijk, et al., 2013)

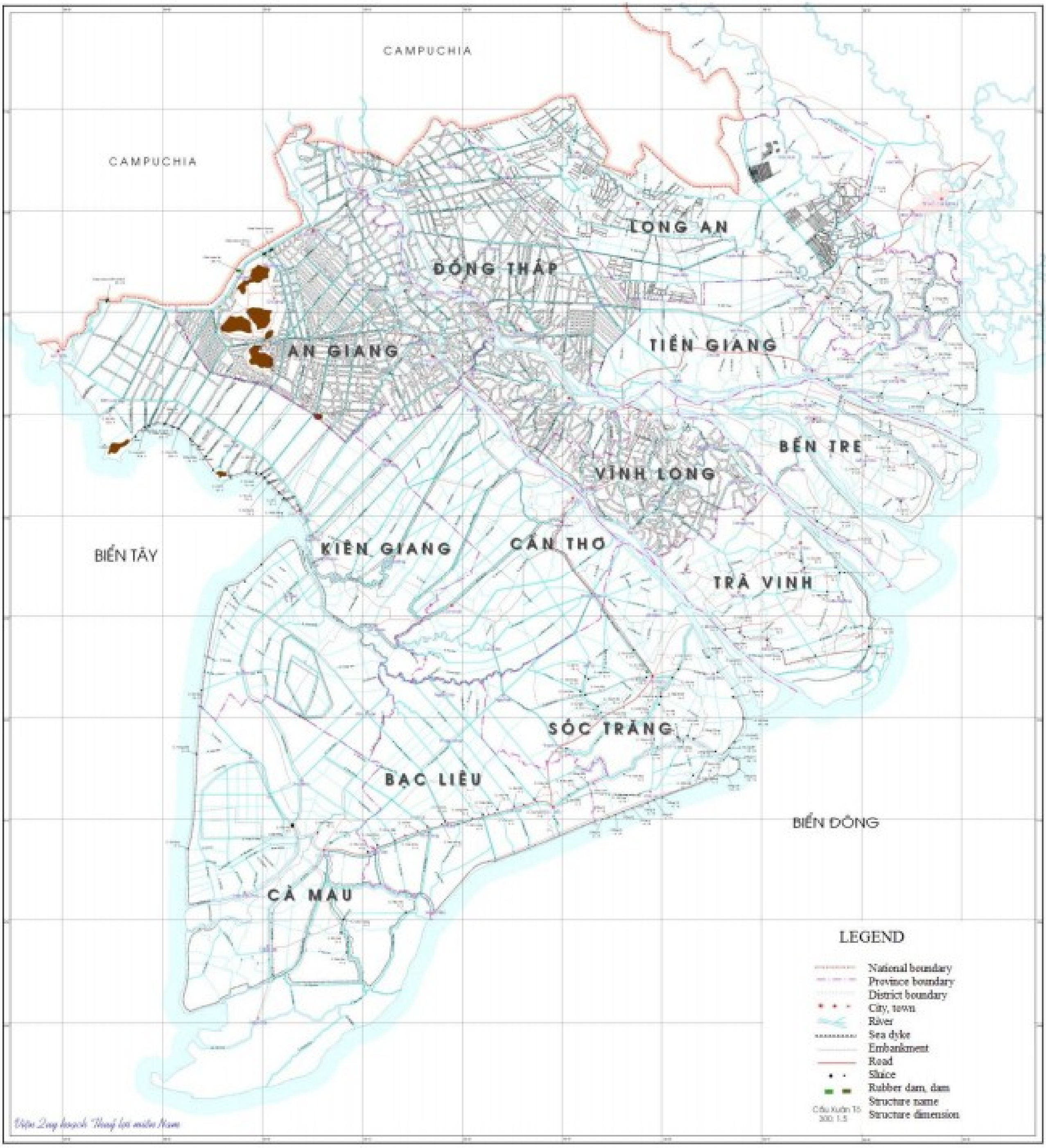
Annex 11: Average rainfall VMD 2003



Annex 12: Elevation map VMD 2003



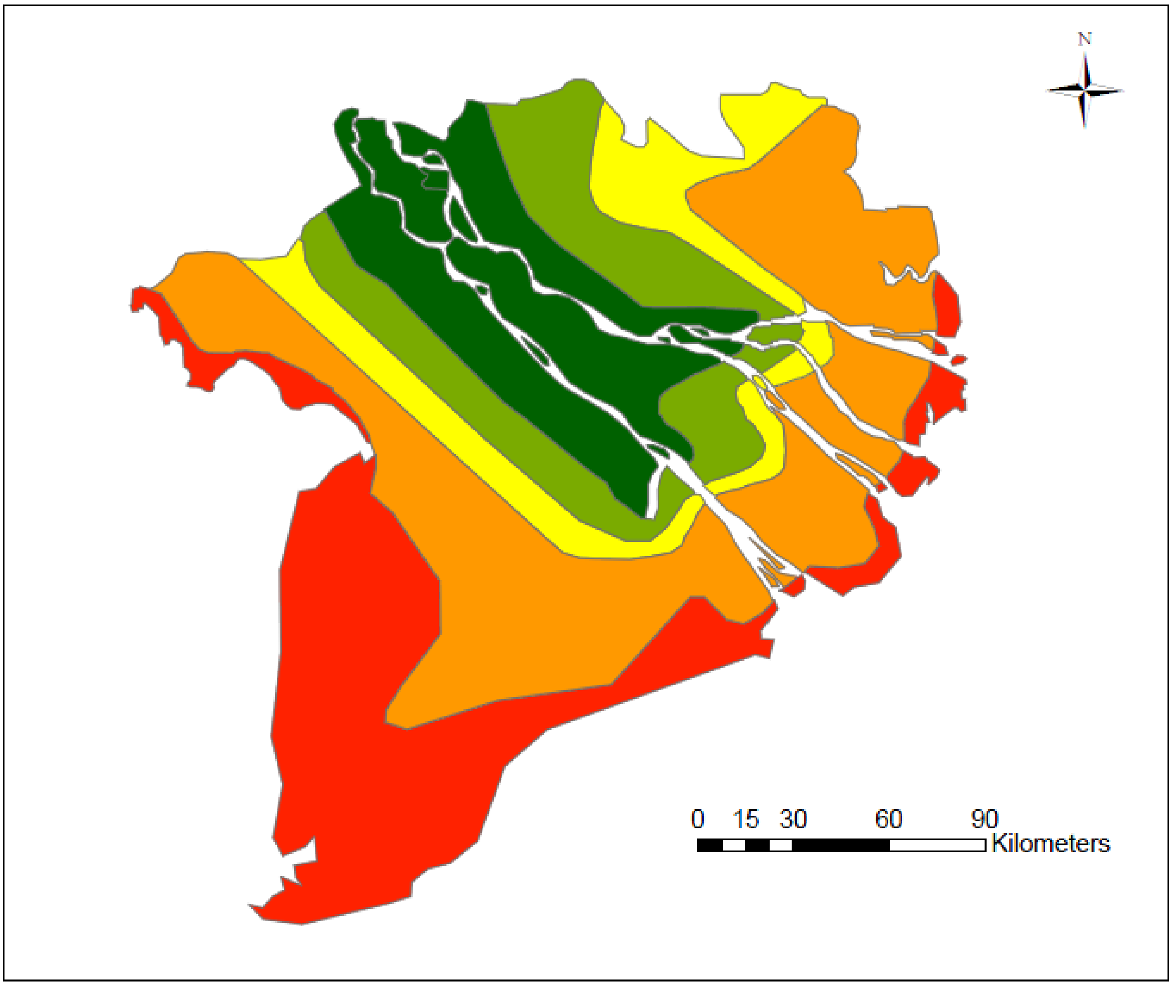
Annex 13: Canal system VMD

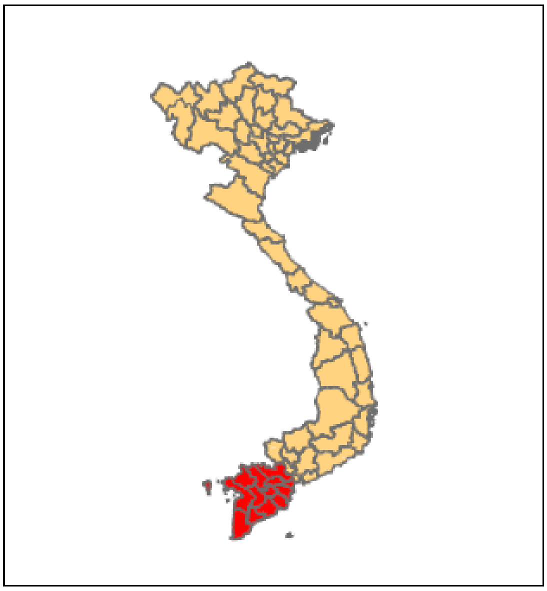


(Deltares & Delta Alliance, 2011)

Annex 14: Saline intrusion VMD 2003

Saline intrusion in the VMD





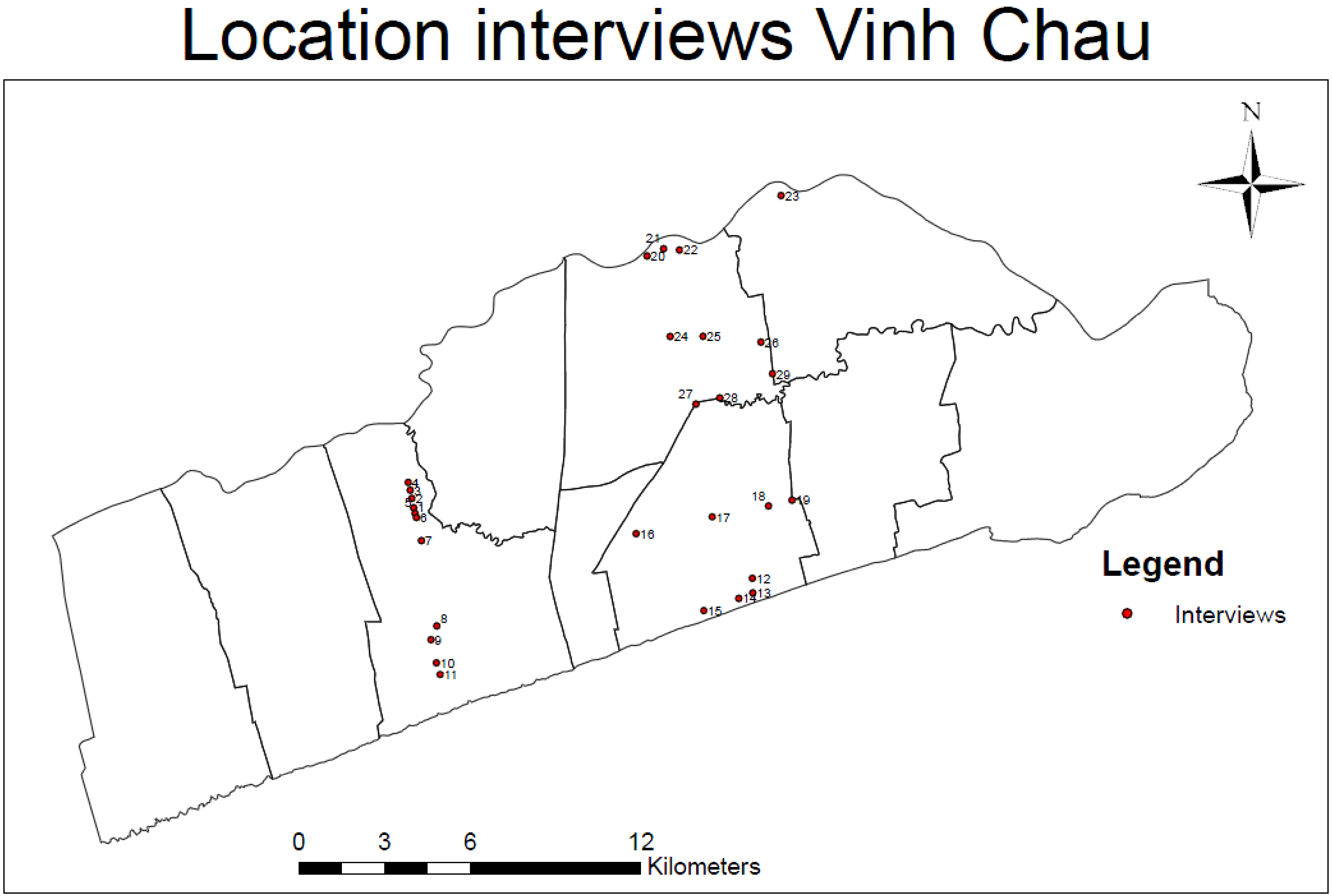
Legend

- fresh water at all season
- fresh water (easy to improve)
- fresh water depends on season
- fresh water (hard to improve)
- saline at all season

Subject:	Saline intrusion
Author:	J. Hagenvoort
Place:	Can Tho
Date:	6-3-2013

Hogeschool VAN HALL LARENSTEIN

Annex 15: Interview and measurement locations Vĩnh Châu



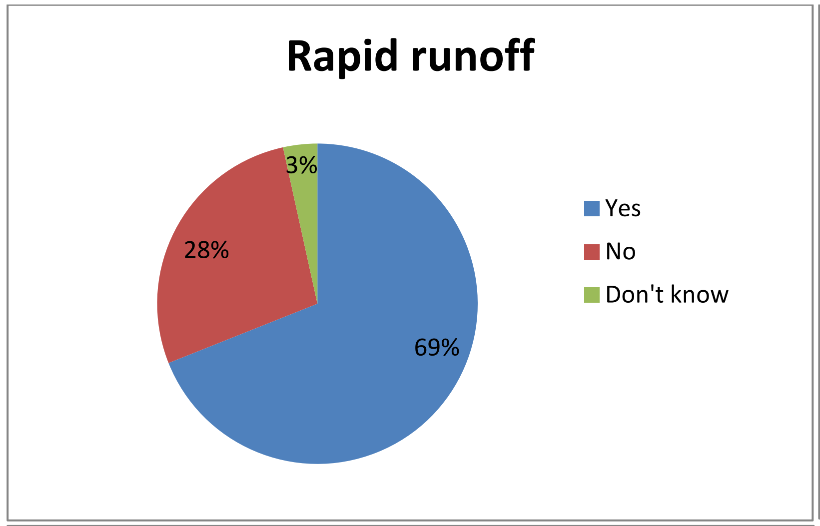
Annex 16: Farm description

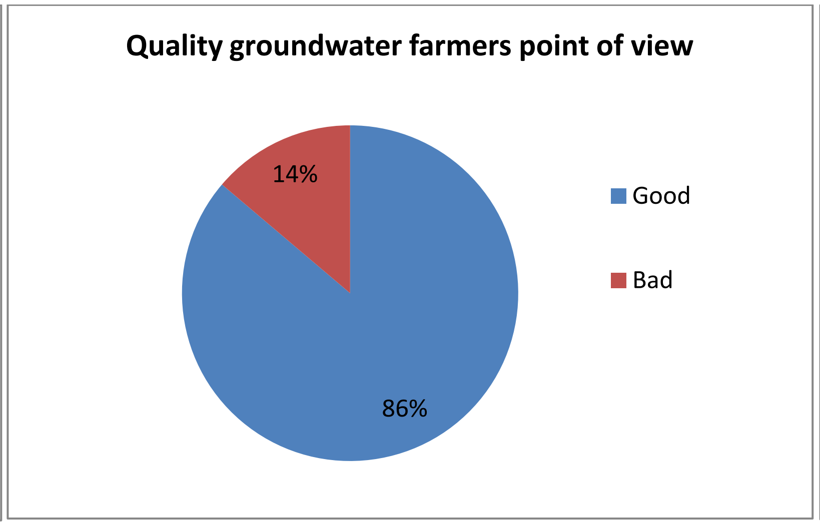
Farm	Description
1	Shrimp is the most important product from this farm. The groundwater pump is found on the backside of the house in a small shack. Water is located in the ditch near the house, the shrimp pond on the back doesn't contain water. Very dry soil, house surrounded by trees that produce mango/mangos teen for own use.
2	Shrimp is the most important product from this farm. The ditch in front of the house is filled with water from the canal with the help of a water pump. Also some trees available to produce fruit (mango, plum and jack fruit) for own use. Dry pond at the back of the house.
3	Shrimp is the most important product from this farm, the groundwater pump is located in front of the house under a small roof. The farm also cultivates some fruit (plum, mango, banana, jack fruit, banana and papaya). Shrimp pond is filled with water.
4	Shrimp is the most important product of this farm. Dry soil can be found in an empty pond, also ponds with water present for the shrimp production. Groundwater pump outside covered with a cardboard box, also an old unused hand pump can be found. The farm also cultivates some fruits. (banana, mango, mangos teen and other tropical fruits)
5	Compared to other farms a very large house can be found at this farm, main product is shrimp but also pigs are being raised and they cultivate plum and mango.
6	The groundwater pump is located in the middle of the house on a concrete foundation, the main product from this farm is union. Trees grow in the close area of the house, further away there are fewer trees to be found.
7	This farm raises pig and shrimp. A sand/clay soil is found in the area.
8	A farm quite near the village Vinh Chãu, more buildings in the direct area. Fruit trees are present in the garden in the back, for own use. The main product that they produce is onion and sugar apple. Groundwater pump on some tiles on the back of the house, covered by a roof.
9	The groundwater pump is located in the back of the house, the pump seats in a small concrete well and is covered by a concrete cover. On the back of the house a deep corn field is present. The farm produces corn, onion, chili and also raises chicken.
10	This farm produces fish, next to this farm salt is being produced. There is a hand pump on the side of the road next to the fish pond. The groundwater that comes from this pump is only being used for domestic purposes such as drinking, cooking and washing.
11	The area around this farm is very dry, the farm is a bit secluded from other farms and many ponds can be found in the direct surroundings of this farm. Besides the shrimps also pigs are being raised at this farm.
12	In the wet season this farm stores rainwater in a tank. The crops they grow are onion and cabbage in the dry season and rice in the wet season. The farm is surrounded by a green environment. The electrical groundwater pump is located in a hole in the ground.
13	This farm is located in a green environment, the electrical water pump is situated at the back of the house covered by a roof. This farm cultivates carrot and raises duck.
14	This farm cultivates cabbage in the dry season and rice in the wet season. There is more agriculture to be found near this farm. In front of the farm there are ponds.
15	Behind and on one side of the house canals are located, the electrical groundwater pump is situated outside in a concrete well. On the courtyard some coconut palms and next to it some dry agricultural ground is situated. This farm cultivates onion and cabbage in the dry season and rice in the wet season.
16	The electrical groundwater pump is located in a shack behind the house, the agricultural grounds are situated on dry soil. This farm cultivates several herbs, onion and cabbage.
17	This farm is situated next to the road and the house is build next to some other houses. Around the house some coconut and banana trees can be found. The electrical groundwater pump is situated outside at the rear end of the house. The banana and coconut trees are for own use and besides that they cultivate onion and cabbage for commercial use.
18	This farm is situated near some green croplands. A small waterway is situated next to the cropland and is constantly being filled with water. The croplands get sprayed with water, on the courtyard some palm trees are situated. This farm cultivates chili and tomato in the dry season and rice in the wet season. Besides the cultivation of crops also ducks are being raised. The electrical groundwater pump is situated outside near the back of the house.

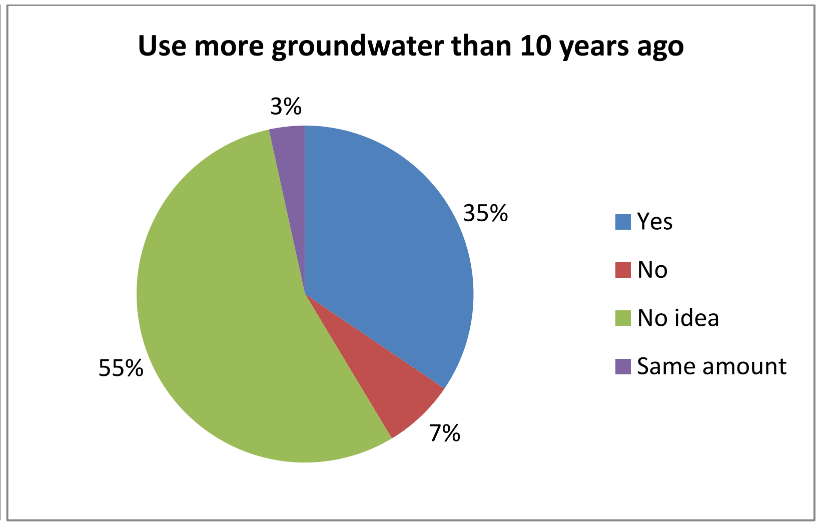
19	The electrical groundwater pump is situated on the back of the house without any cover. This farm cultivates corn, cabbage, onion, soybeans and raises ducks.
20	The electrical groundwater pump is situated outdoors on the side of the house. Behind the house several ponds are located. The environment is green with grass and trees on the courtyard. The main product from this farm is fish.
21	This farm is situated in a reasonable green environment, there are a lot of trees on the courtyard of the farm and on the courtyard of the neighbours. The colour of the water is very green in one waterway, another one is dry. The electrical groundwater pump is situated outside at the back of the house. This farm raised pigs and chicken.
22	Behind this farm a dry pond is situated, a hand groundwater pump is located in the back of the house. The pump is outside but gets cover from a small roof. The farm has a remote place in the area and near the farm a lot of trees can be found. The farm now raised pigs and when they have money from the government they start raising shrimp again.
23	This farm is near the river, in the courtyard some papaya is situated. Compared to houses in the immediate environment the house that belongs to this farm is big and luxurious. The electrical groundwater pump is located in the back of the yard in a barn where also pigs are being raised.
24	This farm produces shrimp and onion. Besides that they also have some chicken, pig and ducks. The electrical groundwater pump is situated on a concrete tile and it´s on the outside next to the house. This farm is situated in a green environment and some other houses can be found next to the house of this farm.
25	On the back of this large house some ponds are located, the electrical groundwater pump is situated near the road on the front of the house. This farm raises shrimp and pig.
26	This farm is situated in an area with almost no trees. This farm produces shrimp. The pond on the other side of the house is empty, the pond on the side of the house is filled with water. The groundwater is being pumped up on a concrete block and then runs off to the canal next to the pond.
27	This farm has a big house and is situated near the meander of the river. The electrical groundwater pump is built into the wall of the house. There are many trees in the courtyard to produce plum, mango and coconut. This farm also raises shrimp.
28	The electrical groundwater pump is located on the other side of the road, it is situated in a hole in the ground. Around this hole trees can be found. This farm has a pond on the backside of the house to produce shrimps. For personal use they also grow fruit, raise chicken and duck.
29	The hand pump is located in a small shack between the house and the river. In front of the house a pond can be found where they raise shrimp. Next to this pond there is an electrical groundwater pump. Besides raising shrimp they cultivate chili, onion and green bean as well.

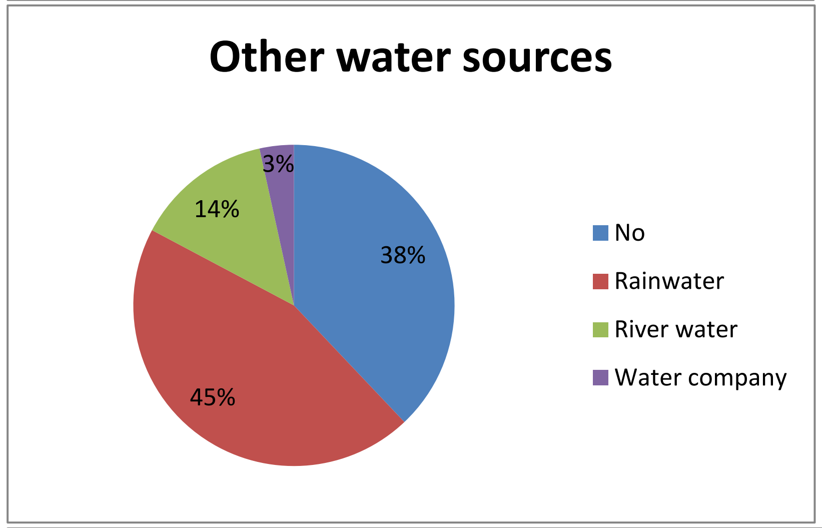
Annex 17: Interview results

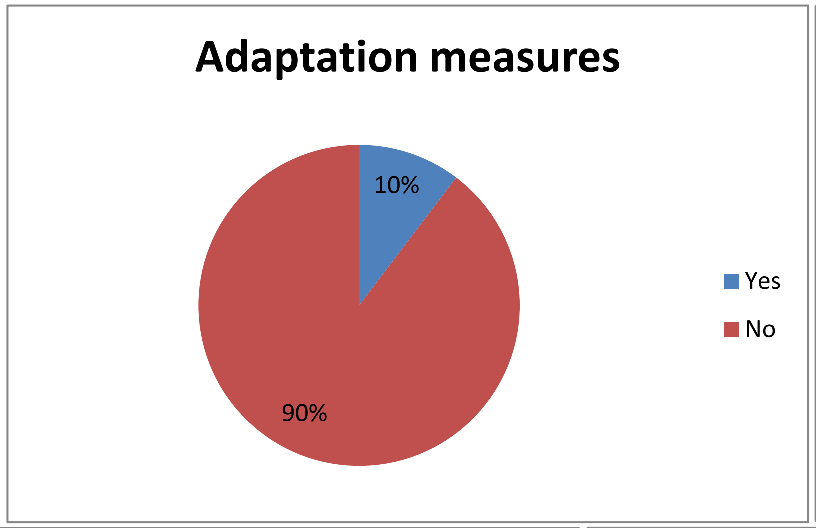
The following charts and graphs are based on the interviews during the field trip in the coastal area of Vĩnh Châu. The percentages are based on 29 interviews and the interviews took place on the 3th till 5th of April 2013.

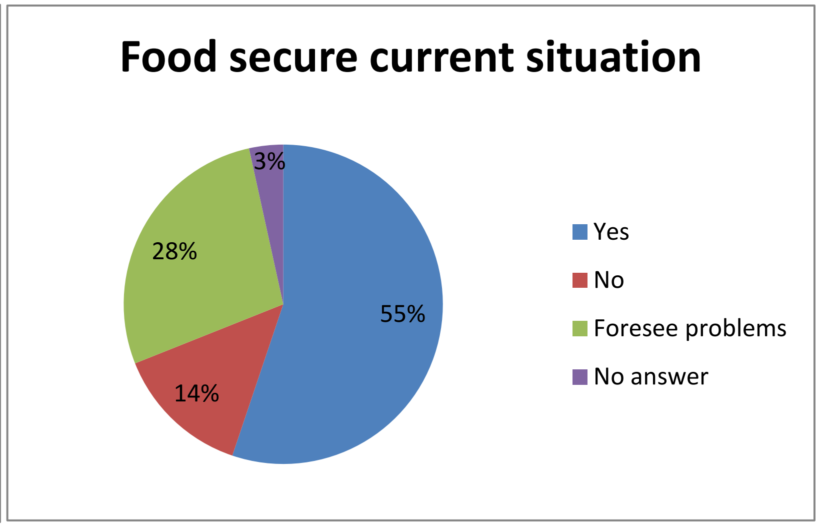


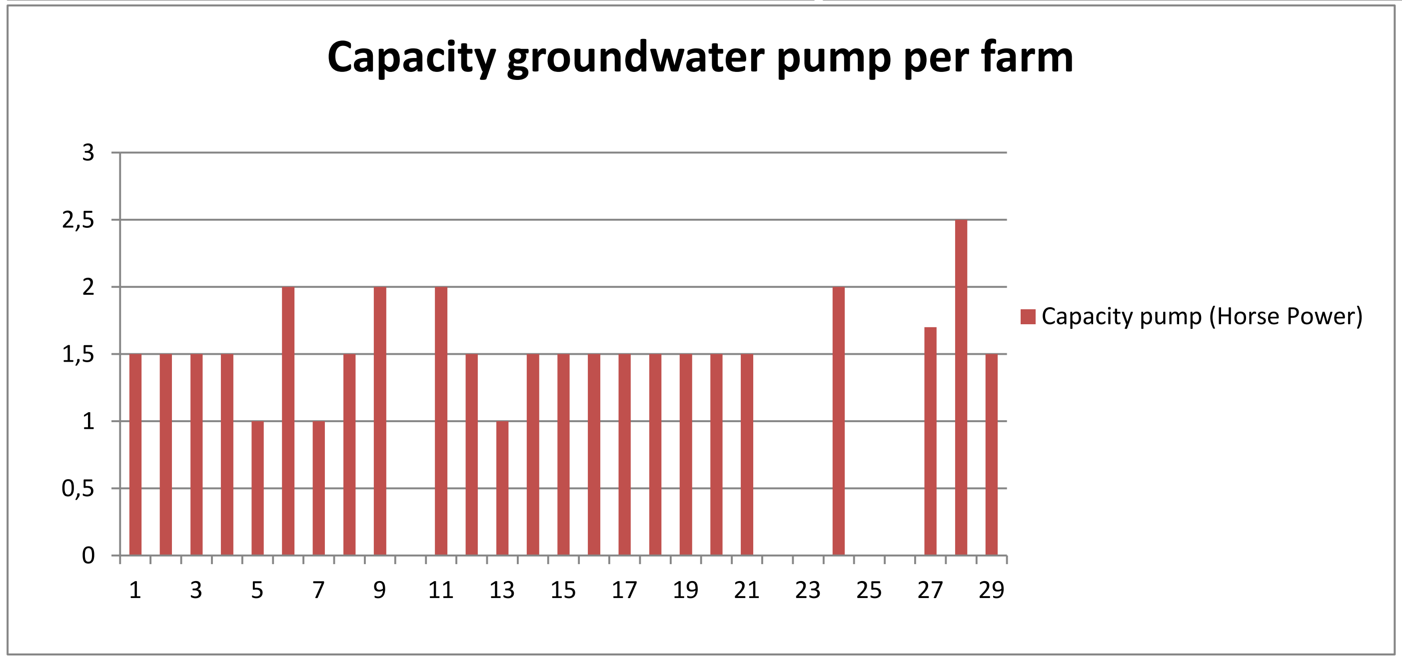


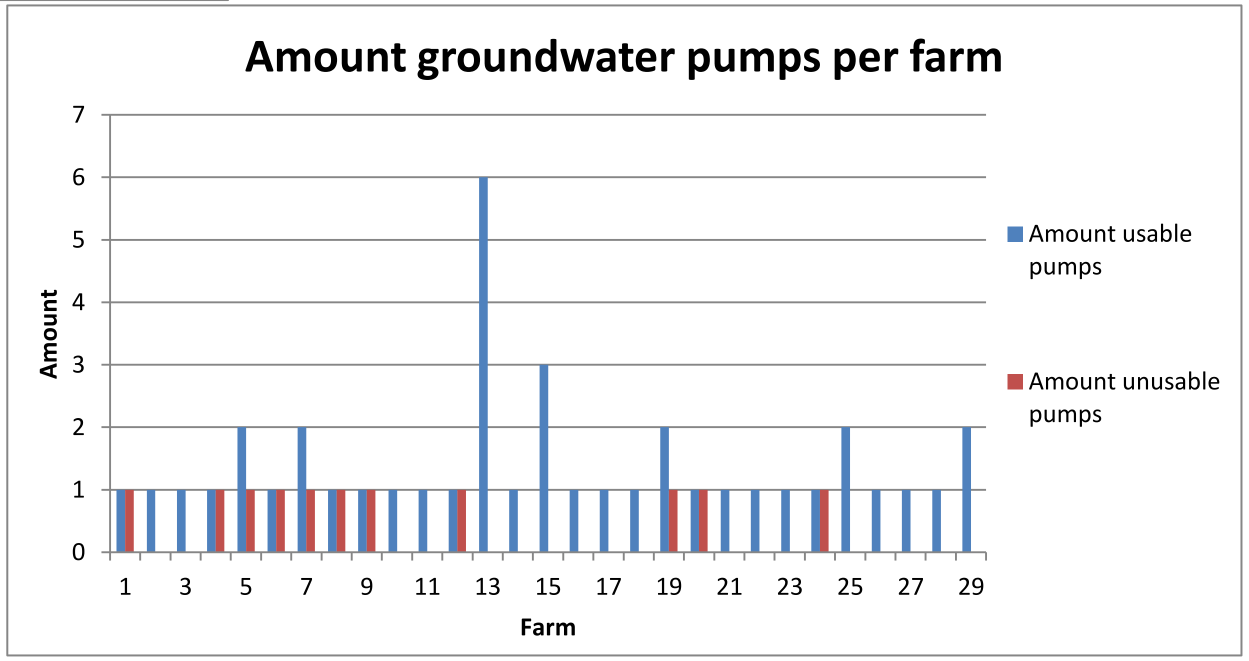








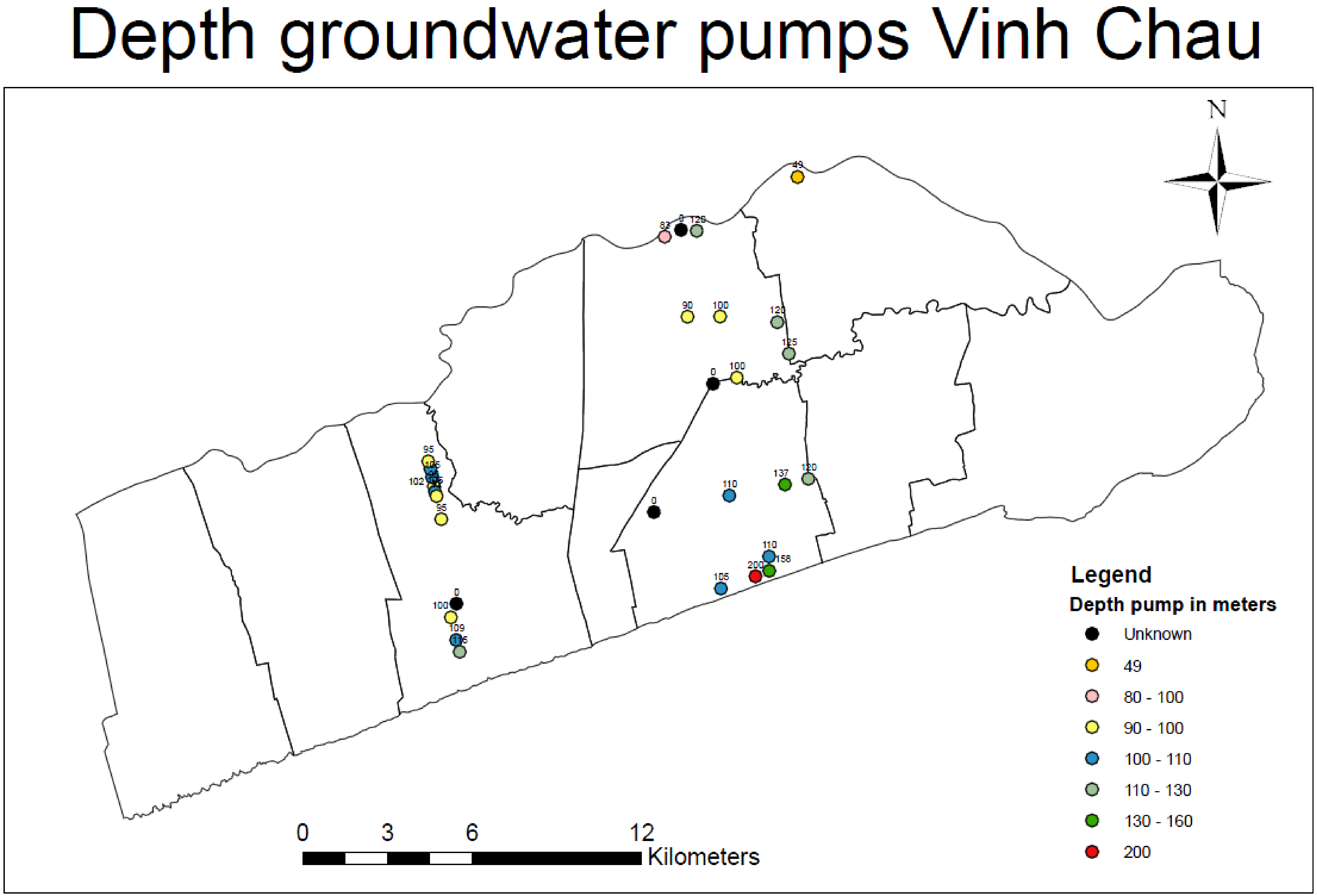




Annex 18: Salinity levels of the groundwater

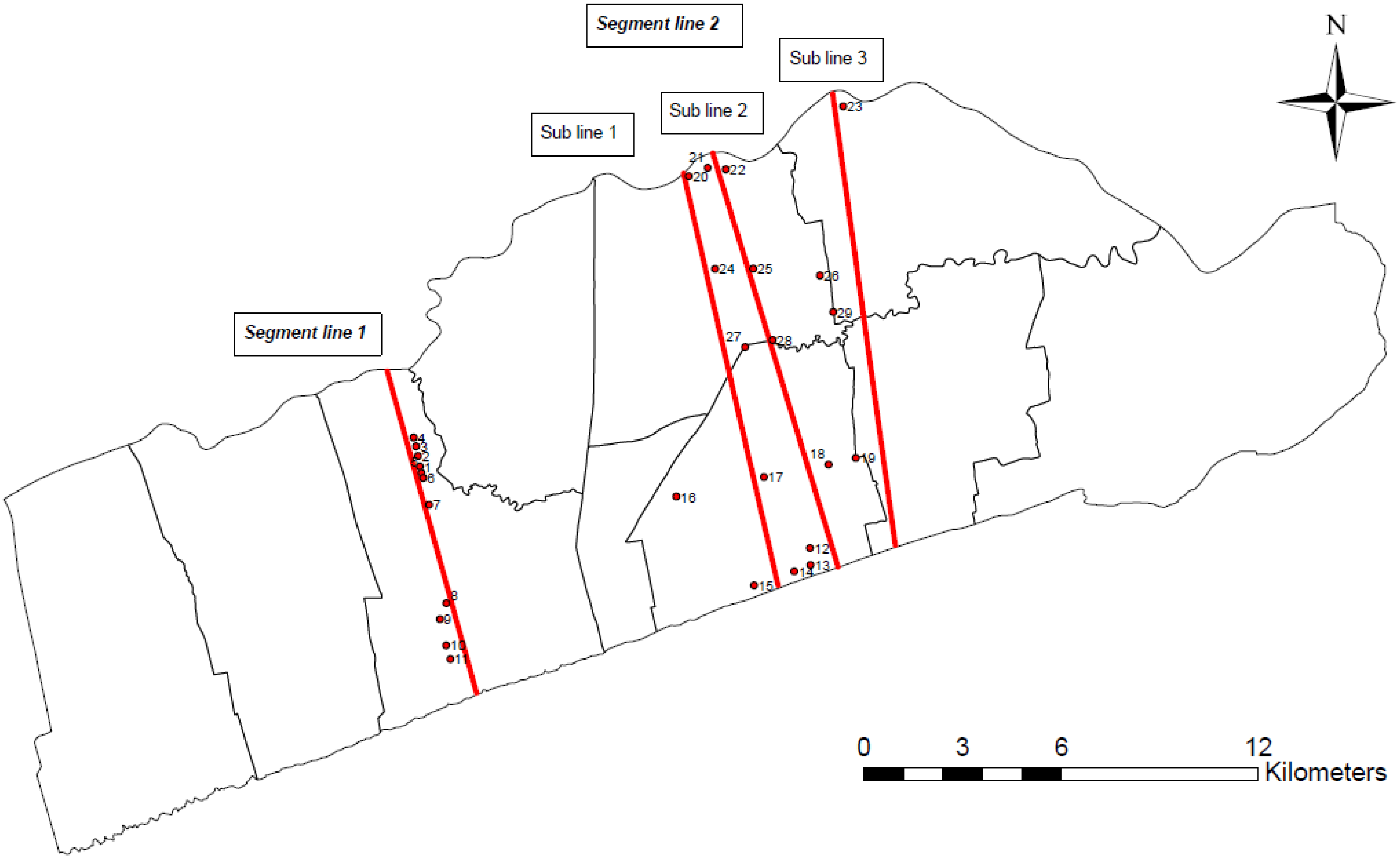
	µS/cm	Temperature (°C)			
Calibrated saline value	1580	31.0			
	Measured value		**Calculated value**		**Depth groundwater pump in meters**
Farm	µS/cm	Temperature (°C)	µS/cm	Temperature (°C)	
1	1381	30.1	1422	31	90
2	1434	31.0	1434	31	105
3	1458	30.6	1477	31	102
4	1528	31.9	1485	31	95
5	1402	30.8	1411	31	105
6	1403	30.6	1421	31	92
7	1345	30.4	1372	31	95
8	1106	30.7	1117	31	0
9	1137	30.5	1156	31	100
10	1090	31.9	1059	31	109
10 (Fish pond)	**10510**	**32.5**	**10025**	**31**	**Fish pond**
11	1088	31.4	1074	31	115
12	1213	32.6	1153	31	110
13	1209	32.8	1143	31	158
14	1163	32.2	1120	31	200
15	1149	33.2	1073	31	105
16	1426	31.6	1399	31	0
17	1297	32.2	1249	31	110
18	1411	33.6	1302	31	137
19	1551	33.8	1423	31	120
20	1122	29.8	1167	31	83
21	1211	32.7	1148	31	0
22	1211	30.5	1231	31	120
23	2070	30.0	2139	31	49
24	1358	33.3	1264	31	90
25	1464	32.7	1388	31	100
26	2190	32.0	2122	31	120
27	1433	31.5	1410	31	0
28	1410	34.9	1252	31	100
29	1619	34.7	1446	31	125

Annex 19: Depth of groundwater pumps



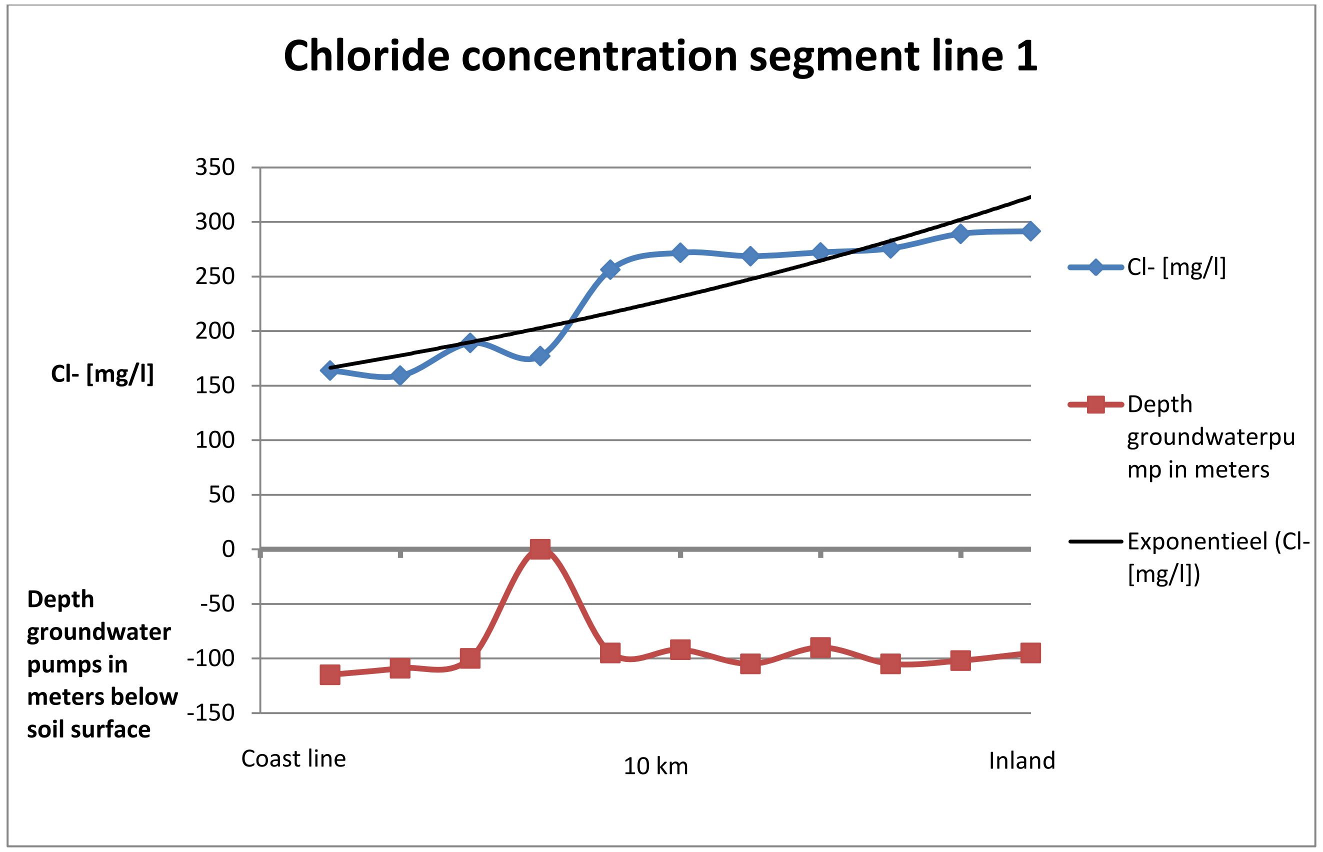
Annex 20: Chloride concentration from coast to inland

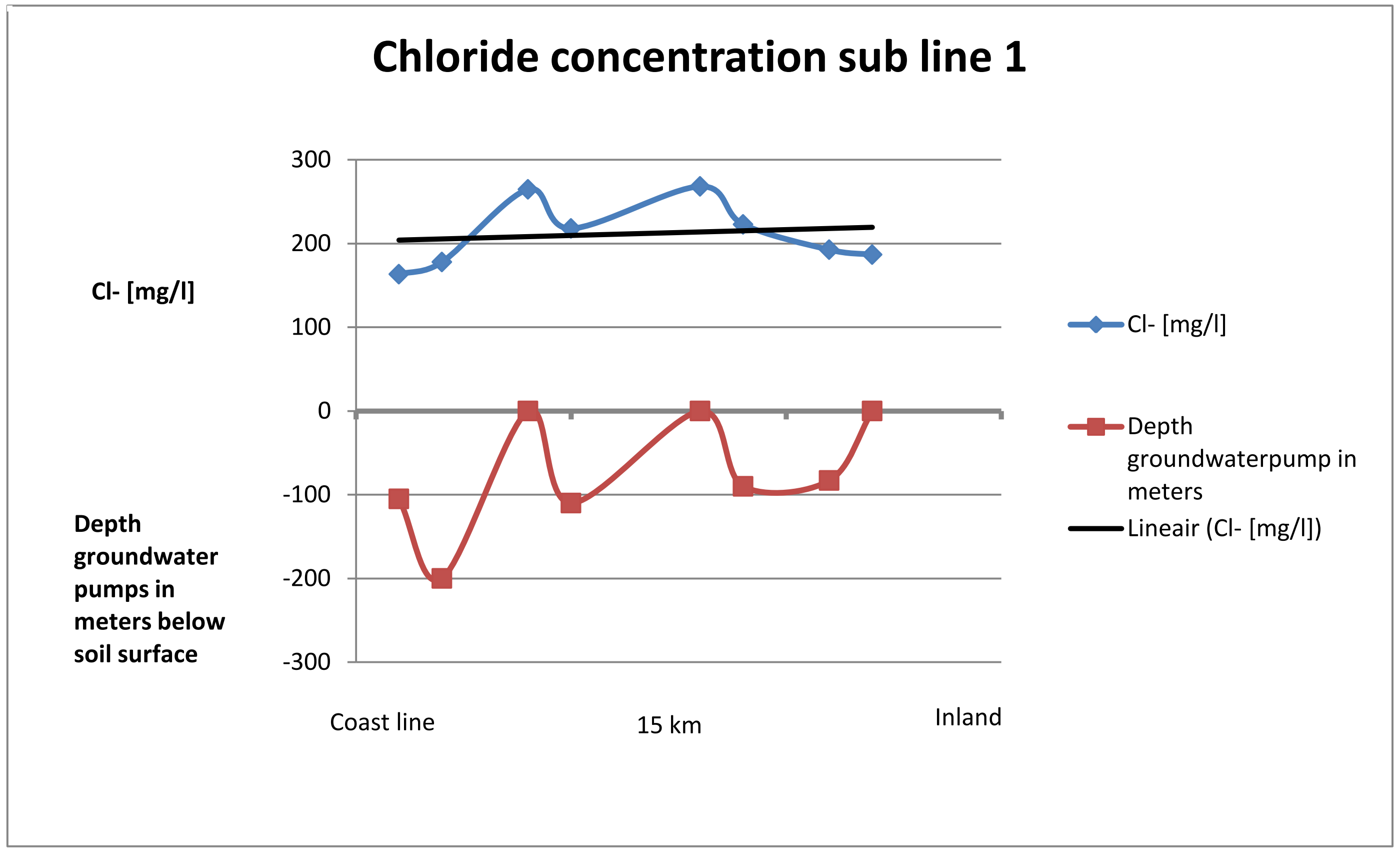
Segment lines salinity measurements Vinh Chau

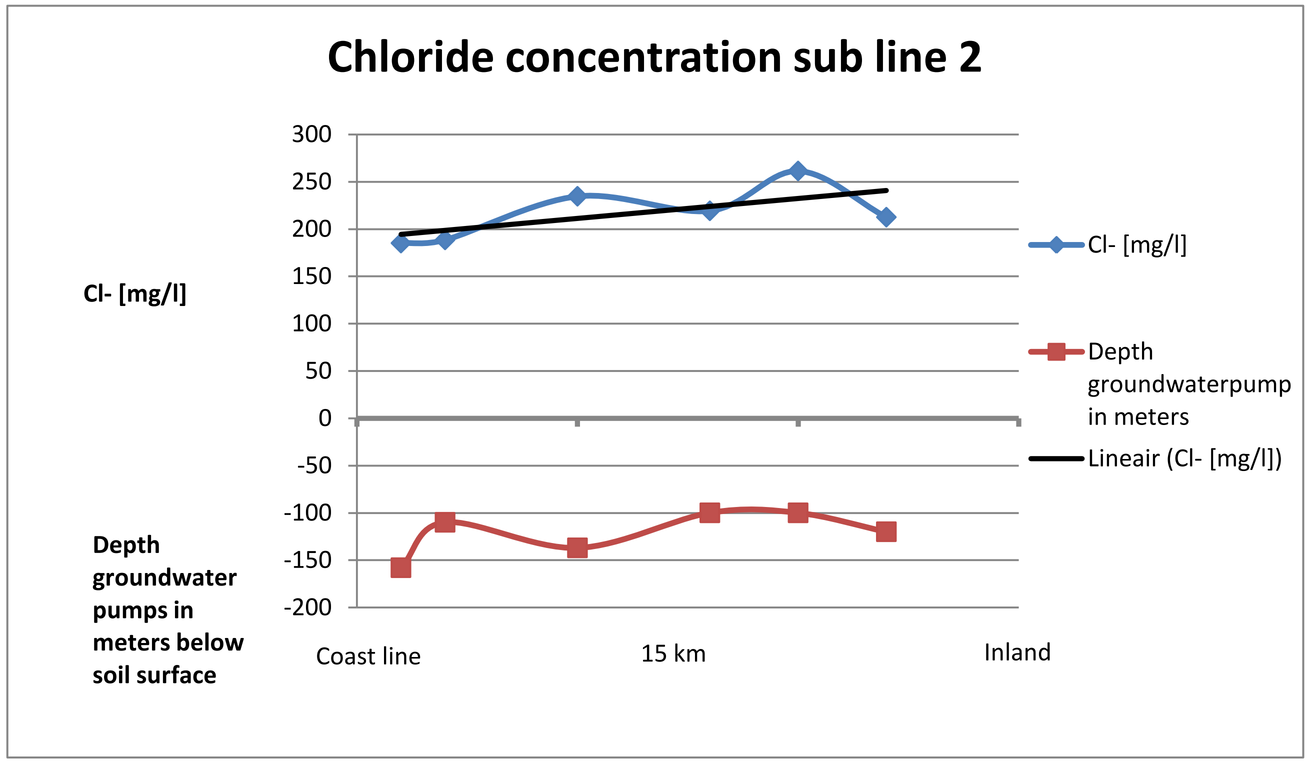


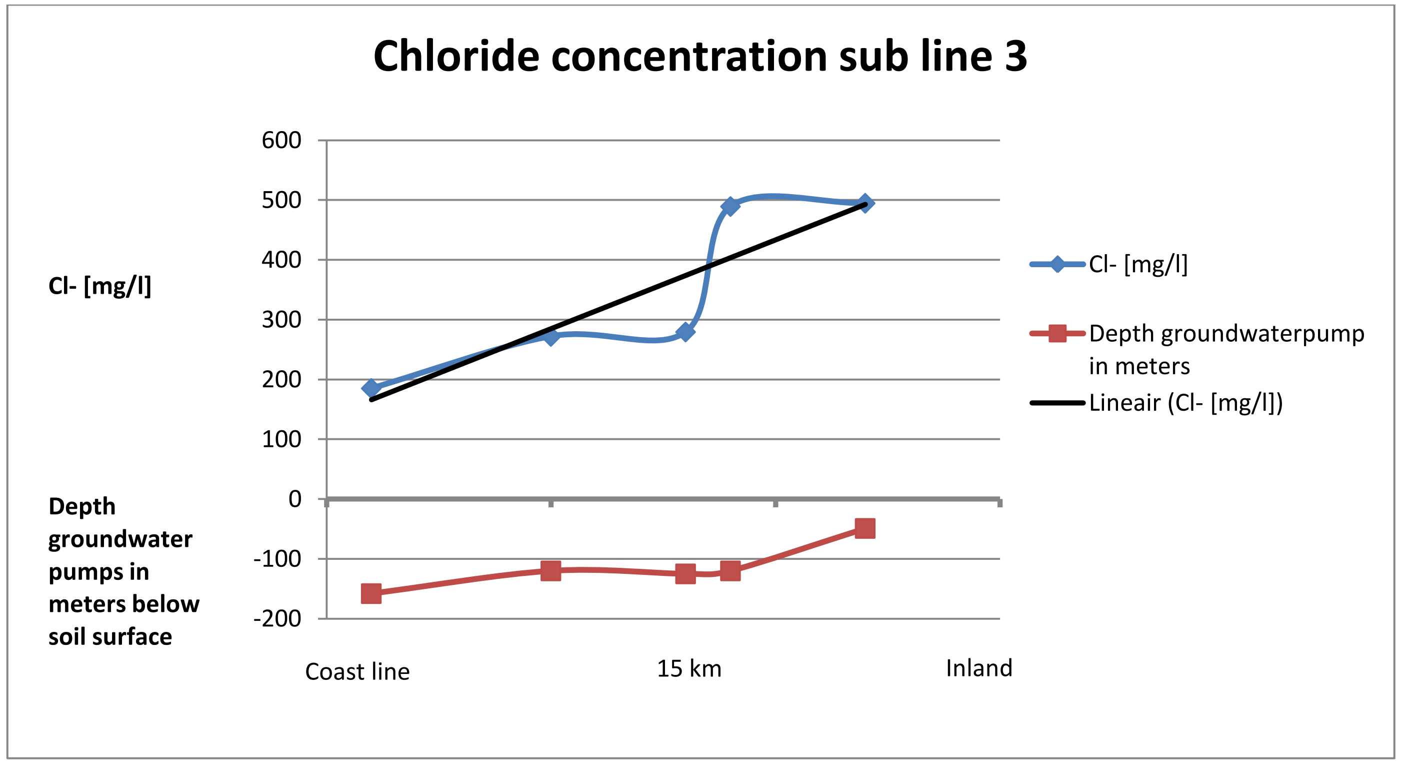
Chloride concentration (mg/l) = 0.3108 EC (µS/cm) – 170.03

Farm	Calculated value 31 °C (µS/cm)	mS/m	Depth groundwaterpump in meters	Cl- [mg/l]
1	1422	142.23	90	272.02
2	1434	143.40	105	275.66
3	1477	147.71	102	289.04
4	1485	148.49	95	291.47
5	1411	141.11	105	268.54
6	1421	142.13	92	271.72
7	1372	137.15	95	256.25
8	1117	111.68	0	177.07
9	1156	115.56	100	189.14
10	1059	105.92	109	159.18
11	1074	107.41	115	163.81
12	1153	115.35	110	188.47
13	1143	114.27	158	185.11
14	1120	111.97	200	177.96
15	1073	107.29	105	163.42
16	1399	139.89	0	264.76
17	1249	124.87	110	218.06
18	1302	130.18	137	234.57
19	1423	142.25	120	272.09
20	1167	116.72	83	192.73
21	1148	114.80	0	186.78
22	1231	123.09	120	212.52
23	2139	213.90	49	494.77
24	1264	126.42	90	222.89
25	1388	138.79	100	261.33
26	2122	212.16	120	489.35
27	1410	141.03	0	268.28
28	1252	125.24	100	219.22
29	1446	144.64	125	279.50



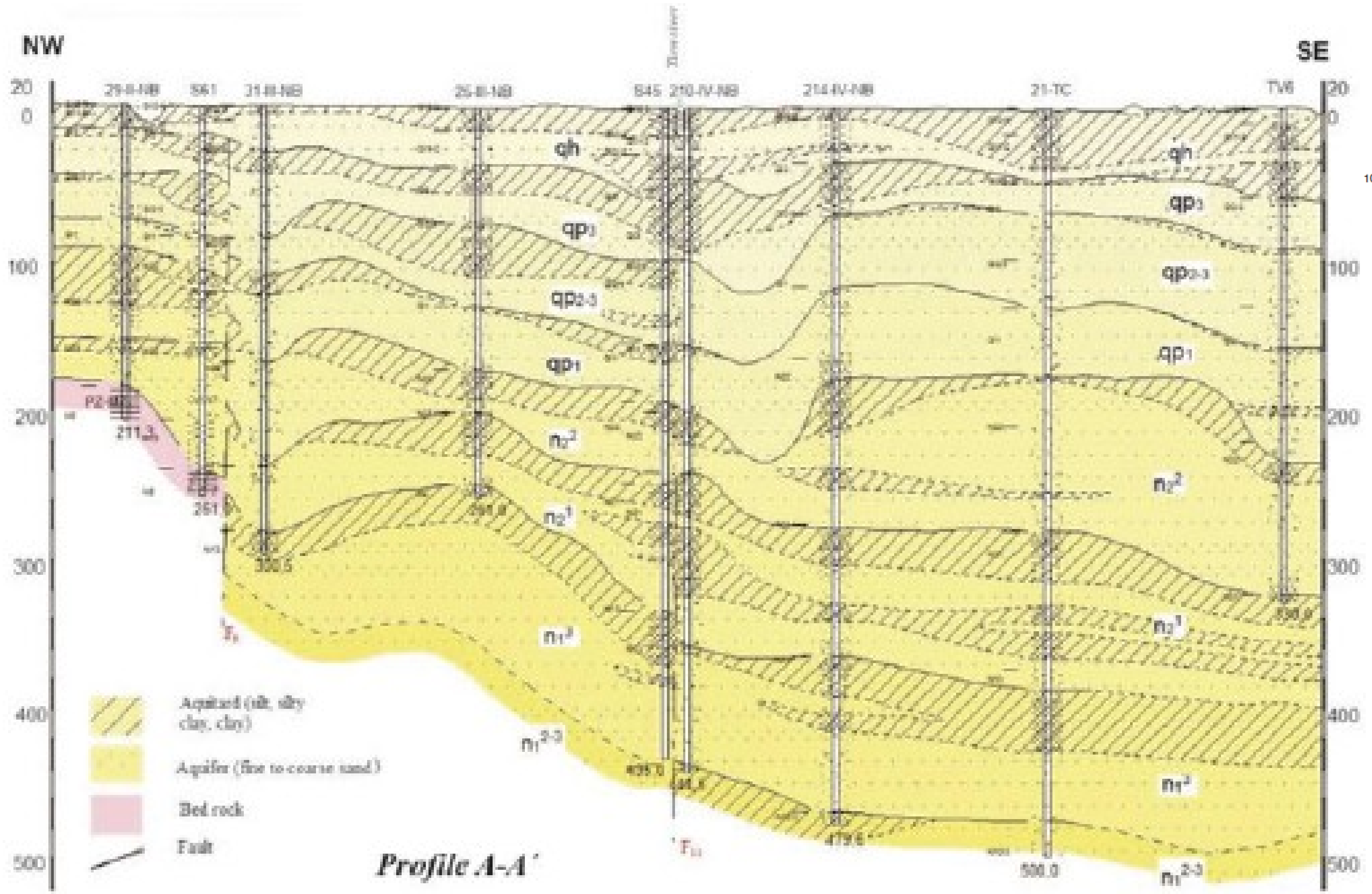


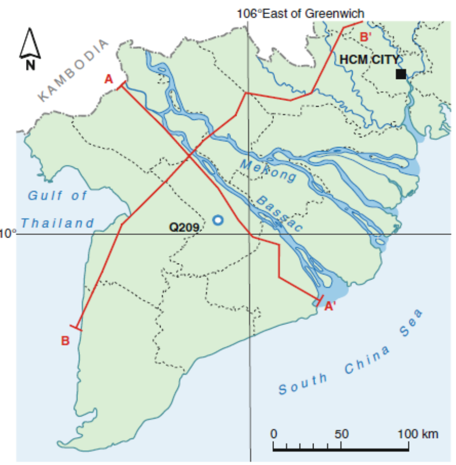




** The value 0 means that there is no data available about the depth of the groundwater pump.*

Annex 21: Hydrogeological profile VMD



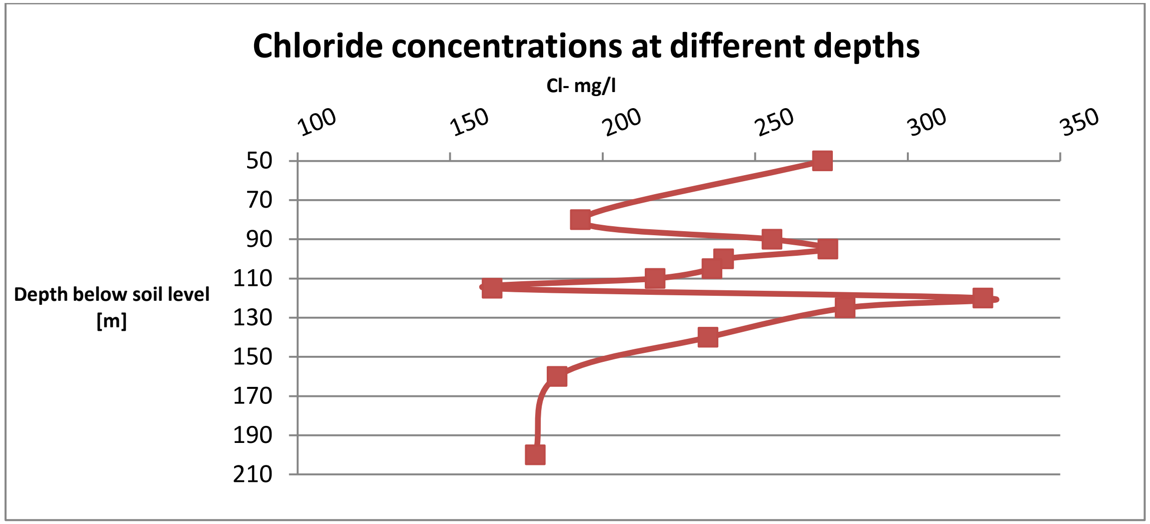


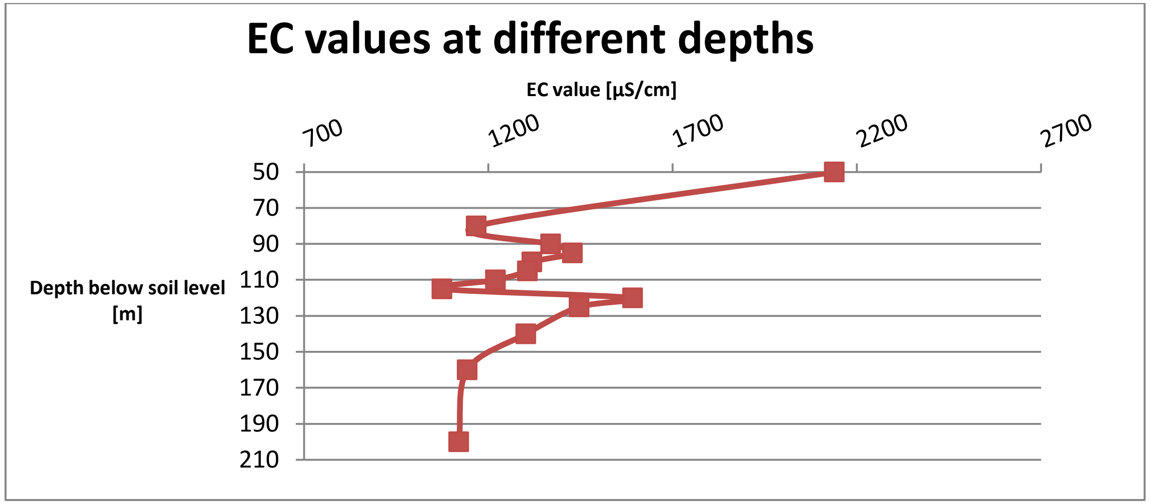
(Wagner, et al., 2012)

Annex 22: EC values and chloride concentration at the different depths

Depth below soil level	Chloride concentrations at different depths*	EC values at different depths*
Meters	Cl- [mg/l]	µS/cm
50	272.09	2139.00
80	192.73	1167.18
90	255.54	1369.28
95	273.86	1428.22
100	239.68	1318.26
105	235.87	1305.99
110	217.24	1219.34
115	163.81	1074.14
120	324.65	1591.64
125	279.50	1446.37
140	234.57	1301.82
160	185.11	1142.65
200	177.96	1119.66

** Average chloride concentrations and EC values per depth groundwater pump*





Annex 23: Salinity tolerance upland crops

Crop			Salt Tolerance Parameters			
Common name	**Botanical name[‡]**	**Tolerance based on**	**Threshold[§] (EC_e)** dS/m	**Slope** % per dS/m	**Rating[¶]**	**References**
		Fibre, grain and special crops				
Onion (bulb)	*Allium cepa* L.	Bulb yield	1.2	16	S	Bernstein & Ayars, 1953b; Bernstein *et al.*, 1974; Hoffman & Rawlins, 1971; Osawa, 1965
Onion (seed)		Seed yield	1.0	8.0	MS	Mangal *et al.*, 1989
Cabbage	*B. oleracea* L. (Capitata Group)	Head FW	1.8	9.7	MS	Bernstein & Ayars, 1949a; Bernstein *et al.*, 1974; Osawa, 1965
Pepper	*Capsicum annuum* L.	Fruit yield	1.5	14	MS	Bernstein, 1954; Osawa, 1965; USSL[††]
Corn, sweet	*Zea mays* L.	Ear FW	1.7	12	MS	Bernstein & Ayars, 1949b

[¶] Ratings are defined by the boundaries in Figure A1.1. Ratings with an * are estimates.

[††] Unpublished U. S. Salinity Laboratory data.

[§] In gypsiferous soils, plants will tolerate an EC_e about 2 dS/m higher than indicated.

[‡] Botanical and common names follow the convention of Hortus Third (Liberty Hyde Bailey Hortorium Staff, 1976) where possible.

(Food and Agriculture Organization, 1999)