Saltwater intrusion and agriculture: a comparative study between the Netherlands and China

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SALTWATER INTRUSION AND AGRICULTURE: A COMPARATIVE STUDY BETWEEN THE NETHERLANDS AND CHINA

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SUMMARY IN ENGLISH

Saltwater intrusion, which can be facilitated by natural conditions, human activities and climate change, is a big threat to mankind from social-economic, environmental and ecological perspective. Agriculture, the largest consumer of water, is identified as both contributor and most vulnerable sector to saltwater intrusion, especially in coastal low-lying areas, with the increasing demands and competition of water owing to economic bloom, population growth and climate fluctuations. Sustainable water resource management is urgently needed owing to its essential in solving this issue. Hence this study is to deliver the understanding of linkage between saltwater ingress and agriculture and seek appropriate water resource management strategies in coastal low-lying areas to address saltwater intrusion and reduce its impacts on agriculture.

This study conducts a comparative case study between Texel, the Netherlands and Shouguang, China to specify the linkages between saltwater intrusion and agriculture with local features. The reasons, impacts and associated mitigations and/or adaptations of the issue, together with the legislation of each region have been investigated and compared.

The results show that for combating the saltwater intrusion and reducing the losses from agriculture, both study areas have adapted specific approaches. Among them similar approaches, despite different legislations and policies, such as developing alternative water resource (treated wastewater and rainwater) and saline agriculture are implemented by both of the regions. Through the comparison, each can learn the lessons from the other. The integrated water legislation together with its effective implementation, the strong involvements of different stakeholders and ecological approach to post-treat effluent of Texel can no doubt inspire Shouguang. While the highlights of counteract measures taken by Shouguang such separating rainwater from wastewater during collection and treatment, water diversion and development of special market to achieve high profit for saline products can obviously inspire Texel as well.

The analysis and comparison between these two case studies can reflect the general problems regarding to water management on saltwater intrusion and agriculture in all the regions that suffer from this problem. Hence, it is concluded that 1) integrated water legislation and management (with climate change considered and integrated as well) are the foundations, while water conservation should be core idea that always kept in mind; 2) strong involvements of different stakeholders and necessary supervision systems can guarantee the effectiveness of implementation; 3) all actions should be based on both technical knowledge and local-cultural knowledge; 4) self-sufficient approaches should be promoted at micro level to reduce the dependency on external water.
intrusion; 5) economic means should be carefully combined with environmental and ecological ways as well to achieve the goal of development of sustainability; 6) monitoring systems are of great significance.

Key words: saltwater intrusion, agriculture, coastal low-lying land, Texel, Shouguang, comparative study, water resource management
SUMMARY IN SWEDISH

Saltvatteninträngning, som kan underlättas genom naturliga förhållanden, mänsklig verksamhet och klimatförändringar, är ett stort hot mot mänskligheten från socialesektors, miljömässiga och ekologiskt perspektiv. Jordbruk, den största konsumenten av vatten, identifieras som både bidragsgivare och mest utsatta sektorn saltvatteninträngning, särskilt i kust låglänta områden, med de ökande kraven och konkurrens av vatten på grund av den ekonomiska blom, befolkningstillväxt och klimatförändringar. Hållbar förvaltning av vattenresurser finns ett akut behov på grund av dess väsentliga för att lösa denna fråga. Därför denna studie är att leverera förståelsen av sambanden mellan saltvatten tränger och jordbruk och söka lämpliga strategier vatten resurshantering i kust låglänta områden att ta itu med saltvatteninträngning och minska dess påverkan på jordbruket.

Denna studie genomför en jämförande studie mellan Texel, Nederländerna och Shouguang, Kina att ange sambanden mellan saltvatteninträngning och jordbruk med lokala särdrag. Skälen, effekter och tillhörande mitigations och / eller anpassningar av frågan, tillsammans med lagstiftningen i varje region har undersökts och jämförts.

Resultaten visar att för att bekämpa saltvatteninträngning och minsna förlusterna från jordbruket, har båda studieområden anpassade specifika metoder. Bland dem liknande tillvägagångssätt, trots olika lagstiftning och politik, till exempel utveckling av alternativa vattenresurs (renat avloppsvatten och dagvatten) och saltlösning jordbruk genomförs av båda regionerna. Genom jämförelse kan varje drå lärdom från andra. Den integrerade vattenlagstiftning tillsammans med ett effektivt genomförande, de starka inblandning av olika intressenter och ekologiskt synsätt till Post-treat utförd av Texel kan utan tvekan inspirera Shouguang. Medan höjdpunkterna i motverka åtgärder som Shouguang sådan separera regnvatten från avloppsvatten under insamling och behandling, vatten avledning och utveckling av särskilda marknaden för att uppnå hög vinst för saltprodukter kan naturligtvis inspirera Texel också.

Analys och jämförelse mellan dessa två fallstudier kan återspeglag de allmänna problem när det gäller att förvalta vatten på saltvatteninträngning och jordbruk i alla regioner som lider av detta problem. Därför dras slutsatsen att 1) integrerad lagstiftning och vattenförvaltning (med klimatförändringarna beaktas och integreras samt) är grunden, medan vattenvård bör vara grundidé som alltid hållas i åtanke; 2) starka inblandningen av olika intressenter och nödvändiga övervakningssystem kan garantera effektiviteten i genomförandet; 3) åtgärder bör grundas på både teknisk kunskap och lokal kulturell kunskap; 4) självförsörjande metoder bör främjas på mikronivå för att minska beroendet av externa vatten intrång; 5) ekonomiska medel bör noggrant kombineras med miljömässiga och
ekologiska sätt samt att uppnå målet om utveckling av hållbarhet; 6) övervakningssystem är av stor betydelse.

Nyckelord: saltvatteninträngning, jordbruk, kust låglänt mark, Texel, Shouguang, jämförande studie, vattenresursförvaltning
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1. Introduction

Coastal low-lying lands, from a perspective of water resource management, are considered as the most complicated and challenging regions in view of their high population density, sophisticated human activities and high vulnerability to multiple hazards such as saltwater intrusion. Saltwater intrusion in coastal aquifers is a severe problem that many countries have to face at present, due to the fact that it contaminates groundwater aquifers and even surface water, leading to the unavailability of water resource for domestic, agricultural use and other consequences (Johnson, 2007).

![Figure 1 The world map of deltaic areas threatened by saltwater intrusion (Coleman, 1981) & (Oude Essink et al., 2010)](image)

The process of saltwater intrusion is defined as a landward movement of saltwater, resulting in an increase of salt concentration in fresh groundwater aquifers. The causes of this problem differ due to various factors such as geological factors, human activities and regional economic level. Groundwater depletion has been recognized as the biggest driver in most stricken areas. It is believed that groundwater will become saltier in the future considering the exploding population, increasing demands for agriculture and all other economic activities together with the changing climate and rising sea level (Doorman, 2013).

Agriculture here is identified as both contributor and victim of this process considering the large water demand for irrigation and the direct relationship between yields and salt concentration. Though the reactions to salinity of different crops may differ given the distinct genes, however, obviously, when the salinity increases to the level above the limitation that the plants can no longer bear, the yields decrease.
The non-splittable linkage between water resource and agriculture indicates that more careful and thorough mind is required when making the decision. Hence, associated integrated management strategies are urgently needed to positively respond to the deteriorating situations and minimize losses.

This study focuses on the role of agriculture in this issue based on two case studies carried out in two coastal low-lying areas respectively in the Netherlands and China. Both study areas are to different extents threatened by saltwater intrusion problem on agriculture. Mitigations and adaptations have already been implemented to reduce the impacts of the increasing salinity within the study areas. By analyzing these two case studies from an all-rounded view, lessons will be learnt by each from the other through the comparison and potential approaches or management strategies will be synthesized to provide practices for other regions that suffer from similar issues.

1.1. Research objectives and questions

The general objective of this study is to seek appropriate water resource management strategies in coastal low-lying areas to address saltwater intrusion and reduce its impacts on agriculture.

1.1.1. Specific objectives

1. Comprehensive and systematic investigations of the linkage between saltwater intrusion and agriculture.
2. Systematic study of the saltwater intrusion and agricultural situations in both regions.
3. Assessment of the mitigation and adaptation measures in both regions from the perspective of sustainability.
4. Recommendations for relevant potential approaches and water management strategies regarding impact of saltwater intrusion on agriculture.

1.1.2. Research questions

This paper aims to derive answers of the following questions:
1. What is the relationship between saltwater intrusion (SI) and agricultural activities?
2. What are the current situations of SI in both study sites? What have they done to address this issue?
3. What are the biggest challenges in both cases? What should be considered as the priority in solving this issue within both cases?
4. What lessons each can learn from the other?
5. What could be derived to contribute a better water resource management of SI by analyzing the results from the comparison?

1.2. Methodology

1.2.1. Methodology of the work

To achieve the main objective and answer the associated research questions, a comprehensive literature review has been done to gain the general background of saltwater
intrusion with an emphasis on agriculture, and subsequently two case studies have been selected narrowing down to regional level.

In the case studies, saltwater intrusion with specific local features has been well studied and analyzed respectively in both areas. To facilitate the research on case studies and local data collection, interviews/phone interviews with different relevant stakeholders (e.g., water authorities, local farmers, etc.), possible site visits have been integrated and implemented as data collection. For the case study in the Netherlands, a field visit was made to Salt Farm, Texel to better understand the local features and the development of saline agriculture. Future, a questionnaire on the acceptability of saline agricultural products among the public has been conducted to get a picture of the recognition and potential market. The questionnaire has been sent out to people at different age, gender and background level, randomly on the street, among three villages in the Netherlands. Among the collected results, 51 copies are identified as effective. Yet, this cannot be carried out in Chinese case study as saline agriculture is still at the beginning phase that the products have not been introduced to public given the high prices.

Summaries and analysis of both case studies based on all the findings have been made to draw a clearer picture of current situations in each site. A comparison between these two regions by different criteria (e.g., reasons, legislations, stakeholder involvements, related mitigation and adaptations, etc.) has been finalized to synthesize the effective approaches for improving water resource management on saltwater intrusion in an agricultural perspective. Besides, lessons that each learnt from the other are derived, inspired by which, more sustainable water resource management on saltwater intrusion in an agricultural have been proposed. Figure 2 shows the conceptual framework of this thesis work.

Figure 2 Conceptual framework of this study
1.2.2. **Case studies selection**

The two case studies selected for this thesis are Texel, the Netherlands and Shouguang, China. The selection was based on the following criteria:

1. Similarities in the densely populated low-lying areas that both suffer from the same issue of saltwater intrusion and vulnerable to climate change;
2. Agricultural activities have been taken as the main economic activities in both areas;
3. Big diversity between two regions in the perspectives of policies and agricultural patterns;
4. Good connection and cooperation between these two regions, which provide a good platform for knowledge exchange.

1.2.3. **Data collection**

Collection of the available local data with regard to both saltwater intrusion and agriculture has been done to contribute to the development of assessment and comparison. The relevant data include: a) geographical data, b) topographical data and maps, c) climatic data (e.g., precipitation, evapotranspiration), d) agricultural data (e.g., irrigation water use, crops yields), e) groundwater data (e.g., groundwater abstraction, water table, chloride concentration) and f) legislations. This has been collected from all available sources such as books, reports, different thesis works, libraries, database and governmental websites, together with the field visit to Salt Farm, Texel and other inputs derived from multiple interviews.

1.2.4. **Outline of the thesis**

The thesis consists of six chapters. In Chapter 1, an introduction to the study and related study methodology are presented. A general background of saltwater intrusion derived by literature review to state the problem is given in Chapter 2. Chapter 3 and Chapter 4 are the presentation of the Dutch case study and Chinese case study respectively to give a clear picture of saltwater intrusion with regional features and illustrate the corresponding legislations and approaches within the two chosen sites. The two case studies are summarized and discussed in Chapter 5. A comparison between the two cases is provided in this chapter as well. In Chapter 6, the final conclusion has been drawn to answer the proposed research questions. The lessons learnt by each from the other are discussed, suggestions on reasonable water resource management regarding saltwater intrusion are also proposed and potential issues are discussed in Chapter 6.

1.2.5. **Research limitations or difficulties**

The biggest difficulty of the research process is the communication with local people in both countries in terms of different reasons. The language is the main concern when both contacting people and reading related documents for Dutch case study. The guide tour of salt farm in Texel was first rejected given the presentation language, as the target group is Dutch farmers. Besides, when performing the questionnaire, the language had to be translated into Dutch
considering high feasibility within different target groups (i.e., elder people). This problem has been overcome by the assistance from Tufan Kayar, who speaks Dutch and participated in the relevant activities to assist necessary translation.

As for the Chinese case study, constrained by finance and visa issues, field visits and communication with local people in person could not be undertaken. However, phone interviews and other communications through Internet have been done to better understand the situations from the residents’ perspective. What’s more, the lesson has been learnt that scientific items should be avoided when communicating with local farmers and dwellers.

Another limitation of this case study is the accessibility of certain data. In view of certain political regulations, some data is not open to the public or requires the permission to access. This, however, has been restricted by the limited time, finance and relevant connections. Moreover, due to the limitation of the data source, the data used in this paper may not be the most recent data, hence to some degree can affect the precision of the paper.
2. **Problem description based on literature review**

Saltwater intrusion is widely recognized as a common issue that results in degradation of freshwater in various coastal aquifers of the world. It means the landward encroachment of saline water into freshwater due to the differences of density and pressure between saltwater and freshwater. Saltwater has a higher concentration of dissolved minerals and salts than fresh water, with the result that saltwater has a larger pressure than freshwater under the condition of same volume. Hence, saltwater has the tendency of landward movement beneath the freshwater (illustrated in Figure 3).

![Figure 3 Conceptual sketch of saltwater intrusion in coastal areas](image-url)

Owing to the higher elevation, fresh water tends to move seaward and mixes the saltwater in a transition zone through diffusion and dispersion (Barlow, 2003), thus both movements of saltwater and freshwater can be maintained in balance under natural conditions.

However, both natural and anthropogenic activities can disrupt the balance hence worsen saltwater intrusion. Worsening situations of saltwater intrusion is being a threat to contaminate the freshwater sources since excessive content of salts and minerals can leave negative impacts on virtually all species of animals and certain kinds of plants (Thompson, 2014). Many countries have reported the damages from saltwater intrusion at various degrees in multiple fields. To minimize the resultant losses, corresponding mitigations and adaptations have been applied. However, the dynamic conditions of coastal hydraulic systems and the increasing demand on water resources owing to the rapid industrialization modernization and urbanization both limit the effectiveness.
This review summarizes the general contributing factors for saltwater intrusion, demonstrates the impacts especially in agriculture and discusses the possible mitigations/adaptations regarding to this issue. Finally, the associated regulations and/or directives on this issue are presented to give a whole picture of how this issue be coped globally.

2.1. Contributing factors

Freshwater flows seaward due to the higher elevation and saltwater flows landward due to higher pressure and density. Both continuous movements keep the whole system at a dynamic equilibrium in the transition zone, in which freshwater is mixing with the saltwater (Rumynin, 2009). Any climatic disturbances or human activities, which weaken the seaward movement of freshwater or strengthen the landward movement of saltwater to break this equilibrium, contribute to the saltwater intrusion. Hence, the causes of saltwater intrusion in this thesis are classified into two categories: natural and anthropogenic. Natural causes consist of extreme weather and sea level rise which both facilitate the interface moving landward. Altered precipitation and evapotranspiration pattern due to climate change is also counted as it may disturb the outflow of the aquifers. Groundwater withdrawal, fossil fuels extractions and any manmade constructions (i.e., hydraulic constructions, water diversions, coastal land reclamation) that break the hydrological cycle are the triggers for saltwater intrusion.

In all cases, however, natural and anthropogenic causes are always integrated, since to some extent human activities exacerbate climate change and in return worsen saltwater intrusion.

2.1.1. Natural/geological factor

Owing to the rapid global urbanization, population boom and all series of anthropogenic activities, severe problems on climate have resulted, such as sea-level rise. The last Intergovernmental Panel on Climate Change (IPCC) report implies that the sea-level rise rate will increase to, on average, 8-16 mm/year in the 21st century (IPCC, 2015). This will aggravate the saltwater intruding the freshwater aquifer as illustrated in Figure 4. Sea level rise gives a higher pressure to push saltwater landward, which makes the groundwater have a higher possibility to get contaminated. However, this is only an idealized conceptual model to demonstrate that sea-level rise leaves the impacts on saltwater intrusion; the actual conditions of aquifers are complicated as the excess saltwater may force the freshwater aquifer rising as well.
Many regions have conducted numerical simulations about the impacts of sea-level rise on saltwater intrusion. The groundwater of Broward County, Florida, may face a problem of high chloride concentration attributed to sea level rise (Dausman & Langevin, 2005). Also, countries that lie below the mean sea level, for example the Netherlands, are more vulnerable as the natural discharge may not be capable to counteract the excess saltwater (Oude Essink, 1999).

Except for sea level rise, the unbalanced precipitation-evapotranspiration ratio is also included. Less precipitation and higher rate of evaporation can both slow down the replenishment of freshwater, hence make the aquifers more susceptible to saltwater inland migration. Moreover, regional hydrogeological conditions also affect the degree of saltwater intrusion. It has been proved that larger permeability of the soils can allow more saltwater circulating the interface (Mehnert & Jennings, 1985).

In addition to abovementioned causes, climatic fluctuations and weather events can directly worsen saltwater inland movement. Storm urges, hurricanes and floods can greatly increase the intrusion of saltwater owing to the extreme high pressure. These saline floods then infiltrate into soils and could cause dramatic saline contamination in a short time. It is reported by U. S. Geological Survey’s (USGS) that the salinity of the vegetation zones across coastal Louisiana, America, had been highly increased after Hurricane Katrina and Rita (Farris et al., 2007).

2.1.2. **Anthropogenic factor**

Human activities to large extent distort the climatic balance and hence exacerbate the intrusion of saltwater. This paper classified these anthropogenic causes into two major groups based on the approach: direct and indirect. Direct approaches are the activities that directly affect the hydrological system
resulting in reduction of freshwater both recharge and discharge. Indirect approaches are the ones that may aggravate some natural activities and indirectly facilitate saltwater intrusion.

Over-exploitation of groundwater and other watercourse constructions can directly reduce the recharge or/and discharge of freshwater. The tremendous increase of water demands has been greatly intensifying groundwater extraction especially in populated coastal areas (Famiglietti, 2014). However, negative consequences will occur if there is excessive withdrawal of groundwater with a rate that is faster than the natural recharge rate (Sahagian, 2000). Groundwater contaminated by saltwater is considered one of the most common treats, illustrated in Figure 5. Moreover, soil compacts after the support of water is withdrawn, which indirectly accelerates the trend of saltwater intrusion.

![Figure 5 a. Initial condition for the saltwater interface; b. Saltwater interface after pumping](image)

Hydraulic constructions such as dams or watercourse diversions have been dramatically intensified to meet the increasing societal needs. Besides the benefits they bring, the cons occur and take up the same proportion as the pros after the huge hydraulic alterations (Rosenberg et al., 2000). Both intake of water from river upstream due to water diversions and watercourse interception by manmade barriers reduce the discharge of freshwater to the ocean, hence lead to saltwater intrusion. Land drainage for agriculture or other activities can also lower the freshwater table and hence led to an increase in salinity especially in coastal areas (Holman & Hiscock, 1998).

Anthropogenic activities are not only the trigger that directly accelerates the saltwater intrusion in the coastal areas, but also facilitate the climatic variability that simultaneously worsens the increased salinity. Modernization and urbanization have immensely accelerated saltwater intrusion as well. Exceeding greenhouse gases generated by human activities to some extent magnify global warming and aggravate sea-level rise (IPCC, 1996); continuously reinforced concrete constructions
in relation to the fast pace of modernization reduce rainwater infiltration hence reduce groundwater recharge (Pauleit & Duhme, 2000); and over exploitation of gas or other natural minerals cause land subsidence (Geertsma, 1973), all indirectly facilitate the trend of saltwater intrusion.

In reality, natural causes and anthropogenic causes are inseparably and acting simultaneously. The relations between them are also complicated and uncertain, which require more thorough concerns when dealing with the issue.

2.2. Potential impacts
Saltwater intrusion has been globally, and continues to be considered as one of the most significant coastal issues due to its multiple potential consequences in different fields (Figure 6). Excessive salt within the drinking water can lead to salt toxicity owing to different salt tolerances among different species of animals. Besides animals and human being, the decreases in agricultural production also show the impacts of high concentration of salt in irrigation water. Even though according to some cases, brackish water irrigation helps reduce the risk of soil salinization (Acton, 2012), it is still uncertain and under evaluation for further sustainable feasibility.

Saltwater intrusion is to some degree responsible for wetland deterioration as well (DeLaune & Pezeshki, 1994). Plants die when the salinity is above the tolerance threshold; hence biodiversity within the region correspondingly decreases as the essential survival environments are damaged by the high salinity. In addition to the severe environmental and ecological problems caused by saltwater intrusion, enormous economic losses arising from it can also not be neglected, especially from long-term perspective (Williams, 2010).

This part classifies the potential impacts of saltwater intrusion in four sections: drinking water, agriculture, ecological impacts on wetlands and others, while the emphasis is on the impacts on agriculture.
2.2.1. Water supply/drinking water

In Chinese culture, water is a symbol that can bring vitality and wealth. It has been well interpreted by the densely populated coastal regions in the world. There's always the trend of migration for mankind towards coastal regions on account of its great productivity. However, it has been to large extent limited by drinking water scarcity, which is acutely worsened by human activities integrated with some hydrological issues such as groundwater contamination by saltwater intrusion.

Sodium salts are virtually what humans take in from food and drinking water everyday, hence there is rarely equal attention on the occurrence of sodium salts in drinking water compared to other toxic pollutants. Yet it has been documented that excessive sodium content in the drinking water will exert ill influence on human health (WHO. Regional Office for Europe -Copenhagen, DK, EURO, 1979). In addition, substantial studies have shown that excessive salt are likely associated with certain disease and ill influence (World Health Organization, 1996).

News reported an unexpected salty tap water situation faced by thousands of residents and tourists in Durban, a coastal city in South Africa (Carnie, 2015). Encroachment of saltwater triggered by pumping water plus failure of unexpected excessive salt content removal in normal water...
treatment process caused the water unacceptable for drinking purpose. Additionally, related social issues and supernumerary expenditure on salt removal process and corresponding equipment maintenance arise in view of encroachment of saltwater.

2.2.2. Agriculture

Agriculture is no doubt the largest consumer of freshwater and the rate is still sharply increasing. According to rough statistics, nearly 70% of freshwater in the world is for agricultural use (Frenken & Gillet, 2012), of which groundwater accounts for a dominant ratio of irrigation source in most regions attributed to its high cost-effectiveness and feasible characteristic (Kemper, 2007). This makes agriculture a vulnerable sector that is prone to be affected by saltwater intrusion. Another reason making agriculture as the main “victim” is the large range of salt tolerances for different crops.

It is well known that salinity is one of the most significant factors that constrain crop production. Crops are classified into four different categories, which are sensitive, moderate sensitive, moderate tolerant, tolerant to salt, according to the relationship between the relative crop yield and the salinity (illustrated in Figure 7). Greater slope, demonstrated as steeper line in the figure, and smaller threshold indicate the crops are more easily affected by salinity and more sensitive than the ones with smaller slopes.

**Figure 7 Classification of crops by different salt tolerances: these four straight lines divide the figure into four sections (the right section can be neglected due to the unacceptable yield caused by high salinity for most crops) and each line indicates the different salt tolerance. Line with greatest slope and the left section of that line illustrates the crops sensitive to salt (salt tolerance follows the order of degree of lines), hence the right line with its left section illustrate the crops tolerant to salt (adapted from (Maas & Hoffman, 1977)).**
Virtually all kinds of crops have their own salinity threshold and slope; hence can be classified into different sections based on this figure. It is a guideline for farmers to know the different salinity thresholds for different kinds of crops and which point the yield starts to reduce.

Figure 8 illustrates the classification of most common agricultural productions. Most fruit and vegetable crops are moderate sensitive or sensitive to salt while some crops from poaceae and grass family are proven to be salt tolerant.

If the increased saline water reaches the upper groundwater zone, the plants or crops with a low salt tolerance will face significant consequences. Especially in developing countries, which mostly rely on agriculture-based economy, and the areas that facing problems of surface water depletion and contamination, unconstrained groundwater withdrawals intensify the landward movements of saltwater and accordingly exert tremendous negative influence on agriculture. Recently, it is reported in Vietnam that more than 30% of sugarcane crops have been either completely destroyed or severely damaged by saltwater intrusion in Mekong Delta, which led to colossal economic losses roughly around US$3 million (Nguyen, 2016).

Additionally, constantly using water with high concentration of salt as irrigation source makes salts accumulated in the soil and eventually damages the productivity of cultivated lands (Burger & Cělkova, 2003). Calcium and magnesium are necessary nutrients for plants. Having calcium ions and magnesium ions as the main cations absorbed on soil particles is conducive to plant growth. However, excessive sodium can...
replace those cations from the soil particles resulting in breakdown of soil particles (illustrated in Error! Reference source not found.).

Figure 9.A. When Calcium ions are the main cations (the same for Magnesium ions); B. When salts accumulated in the soil, sodium ions replace Calcium ions or/and Magnesium ions

The soil becomes compact and less permeable hence induce infiltration problems for the farmlands, impeding air and water exchange for the roots, which slowly turn the cultivated lands to deserts (Massoud et al., 1988). Researches brought out that severe land degradation is reinforced by irrigation with water containing unacceptable concentration of salts in Lesvos, a Greek island in Mediterranean Europe (Yassoglou & Kosmas, 2000).

2.2.3. Ecological impacts on wetlands

Wetlands, the most unique and productive ecosystem, are known for its multiple essential ecological functions: delivering nutrient, absorbing floods, serving as habitats for flora and fauna and improving water quality (Fretwell et al., 1996). Coastal wetlands, especially coastal salt marshes, are subject to periodic tidal and have gradient zonation according to soil salinity. Hence, plants are gradually distributed based on their physiological abilities of salt tolerance (illustrated in Figure 10).

Figure 10 Vegetation zones of coastal wetlands classified by salinity gradient
Soil salinity is lower in the upper zone and the plants are sensitive to saltwater compared to the ones in lower zone. Hence, slight changes in the soil salinity caused by inland movement of seawater can result in water stress of plants and can even cause lethal consequences for them. Correspondingly, biodiversity declines as the habitats are eroded. In Carteret County, North Carolina, a great amount of standing dead pine trees killed by encroached saltwater, known as “ghost trees”, have proven how serious and irreversible aftermaths can intruded saltwater cause (Malijenovsky, 2015). Additionally, studies show that the function of wetlands restoring nutrients has been weakened when experiencing saltwater intrusion (Herbert et al., 2015).

2.2.4. **Other impacts**

Other impacts are identified except for the ones mentioned above. Facts have proven that intruding saltwater is slowly changing the landscapes in many coastal areas. High salt concentration kills the plants that cannot handle salt stress, subsequently reduces biodiversity and eventually turns green lands to barren lands.

Besides, social issues have arisen concerning appropriate access to safe drinking water. Massive efforts from social sides as well as financial sides have been put to address the problem (e.g., cost on pretreatment of saline groundwater and treatment plants maintenance).

2.3. **Potential adaptations and management of SI**

SI is a problem that is hard to be overcome attributing to its irregularity and uncertainty, but with some effective adaptations and positive management, it can be weakened and compromised. Based on analysis of the multiple triggers of SI, reprogramming the hydrological systems by supplementing freshwater or retarding saltwater would most likely ameliorate the salinity effects. One of the most common ways adopted by lots of areas is artificially re-injecting freshwater back to the aquifers.
Freshwater is recharged through this solution to compromise the lowered water table caused by groundwater over-exploitation, hence contributing to reaching the equilibrium between freshwater and saltwater again. The recharged water could be groundwater from other aquifers, reused water or treated effluent (US Environmental Protection Agency, 2016). In other scenarios, establishing barriers to simply retard the intruding rate of saltwater is another mitigation. This can be done by introducing certain solution to the soil and reducing the permeability of the soil to make it act as a physical barrier retarding the encroachment of saltwater (Geoservice, 2006). In Salento Peninsula, Italy, a gypsum barrier has been designed and tested to stop the seawater intrusion (Barcelona et al., 2006). In the areas where excessive groundwater withdrawal is identified as the main cause, better allocation of water resources and reducing groundwater withdrawal volume are the conventional measures globally adopted. Advanced technology as desalination has been researched, tested and applied as well. Some studies even show recharging the desalinated water from the contaminated aquifer back is a better action on both the outcome and financial cost compared to saline water abstraction or introducing injection wells only (Abd-Elhamid & Javadi, 2011).

2.3.1. Adaptations for agriculture

As agriculture is considered as the most vulnerable sector prone to saltwater intrusion, a great amount of adaptations for agriculture have been studied and applied globally. Adjusting the crop species to salt tolerance species is the straightest way to protect crops yield from salinity hazard. In other cases, in contrast to conventional knowledge, it is proved that under certain circumstances brackish water can be possibly used as irrigation water especially in arid and
semi-arid areas (e.g., Pakistan) (Qureshi & Barrett-Lennard, 1998). Additionally, in Vietnam, the second largest rice exporter, countermeasure to compensate the loss from saltwater intrusion as gene modification (i.e., introducing salt-tolerant genes to the crops) has been taken to maintain the rice production (HANOI, 2011).
3. **Dutch case study—Texel**

*Figure 12 Picture of Salt Farm (taken during the field visit in Texel)*
3.1. Characterization of the area of interest

Texel is the biggest Dutch Wadden Island located northwest of the Netherlands (Figure 13). It is bound on the west by North Sea and east by Wadden Sea. This area, as a municipality in the province of North Holland, lies between latitude 53°02' N and longitude 4°47' E and covers the area of about 170 km². The population of this island is around 14,000, whereas in the summer it can be four times higher giving credit for tourism.

The main present landscape consists of mostly polders (low-lying lands reclaimed from the sea) on the east, protected by sand dunes on the western side of island and dikes (Figure 13). Hence, the average elevation of the island is only 2 meters above the Mean Sea Level (M.S.L), while some polder areas in the east are even below M.S.L (Actueel Hoogtebestand Nederland, 2014). With this typical Dutch style landscape, the main economic activities for island's inhabitants (even the percentage is decreasing recently due to the blooming tourism) are agriculture, horticulture and grazing.

As an isolated island from the mainland, the only freshwater resources are mostly depending on precipitation and a small amount from the fresh groundwater. The tap water (drinking water) is dependent on the supply from mainland through two big undersea pipes after groundwater abstraction was terminated by the drinking water company in 1993 (Grootjans...
et al., 2013). In addition, according to data derived from The Royal Netherlands Meteorological Institute (KNMI), Texel is recognized as an area with relatively low potential precipitation compared to average level (KNMI, 2015), hence becoming one of the most water shortage areas within the Netherlands considering availability. Besides precipitation, groundwater level of the island is examined as the lowest of the nation as well (Rijkswaterstaat, 2016), for example, the southern part of island is measured with the lowest water level of -2 m M.S.L (2 m below M.S.L) (Essink, 2005), which makes the groundwater resource within the area more vulnerable to be contaminated by the intruded saltwater.

3.2. Agriculture on the island

The special landscape and climate grant this island a long tradition of agriculture. Agriculture accounts for the biggest proportion of both economy and culture in Texel. Indicated by official statistics (Gemeente Texel Cijfers) that 67.3% land use of Texel and 15% workforce is for agricultural purpose.

According to the governmental plan, various kinds of agricultural divisions are presented on the island on the basis of different soil types (Figure 14). Sand dune at the western side is virtually for sheep farming while for the polder areas, of which the soil type is mainly mixture of clay and sand, are more for arable farming: grains, bulb and certain vegetables (e.g., potatoes, carrots, sugar beets) are cultivated.

![Figure 14 Map that presents different soil types together with various agricultural divisions on the island (adapted from Narrator, 2015)](image)

In the northeast part of island (as the blue part shown on the map), saline agriculture is adapted for the increasing concentration of salt. Specific kinds of salt-tolerant crops such as seakale and potato are the dominant agricultural
products. Besides this area, more fields have been detected with excess salt. This has become the driver for farmers to cultivate more salt-tolerant crops or even develop saline agriculture.

Regional water management association (so-called water board)—Hoogheemraadschap Hollands Noorderkwartier (HHNK), to which Texel belongs, has strictly constrained the water withdrawal for irrigation even during the extreme dry summer. The lack of sufficient freshwater together with the increasing salt concentration insidiously restricts the development of agriculture and to some extent decreases crops yields. Hence, agricultural activities are gradually diminishing or forced to be transformed (i.e., combined with tourism or providing other side business).

3.3. Framework, Legislation and stakeholders

Water resource management and the development of water related legislation have a long history in the Netherlands and are acknowledged as relatively world leading systems compared to other countries. It has developed an integrated water policy and the national water legislation, so-called “the Water Act”, taking EU Water Framework Directive (EU WFD) as the basis. “…The Water Act highlights integrated water management based on the ‘water system approach’ addressing all relationships within water system…” (Rijkswaterstaat, 2011). In addition, it also serves as the framework for regions or provinces to develop the associated regulations given the actual regional situations. Salinization is included as one of the main focused water issues in the national water management, in which multiple factors and potential affected sectors are identified and specified.

Water boards are the regional authorities acknowledged by the Water Act. Texel, the Wadden island of Province Noord Holland, hence is guided and constrained by the regional legislation enacted by Province Noord Holland and the Water Board HHNK. Taking all possible identified water issues into account, water abstraction (both surface water and groundwater) and any water related constructions or human activities are strictly guided and constrained on the island by the regional regulation. Water permit is required and has to be issued by province for irrigation in Texel when the groundwater abstraction amount is above 8,000 m$^3$ per month with duration longer than 6 months, while for the surface water, it is extremely prohibited when the withdrawal leads water level lower than the permitted level. As the withdrawal amount is strictly limited, even during the extreme dry summer, it is not allowed to extract extra water for irrigation on the island.

The water policy and management in the Netherlands is reviewed and updated every six-year, aiming to follow up all the dynamics of the water systems and integrate all relevant stakeholders. The closer connections among each stakeholder
enable high effectiveness of water resource management. Province or the state develops the provincial legislation based on the national Water Act and also supervises regional water authorities and municipalities. Besides, there is also a strong connection with involves academia, non-governmental organizations, different water users (here refer to agricultural sector), farmers’ organizations and media.

Taking Salt Farm in Texel as an example, the salt project carried out by the farm is under the supervision of the regional water board and the Texel Municipality with the knowledge support from Vrije University Amsterdam while funded by the government and some NGOs (according to the interview with staff from Salt Farm).

Moreover, the interview with farmers’ organization LTO Nederland also indicates that the farmers are closely involved in dealing with the increasing salinity together with the changing climate. Pilot projects and meetings with salinity theme are held to provide the background knowledge and serve as a platform for farmers to seek more effective and sustainable solutions. “Most farmers like to prepare their farm for the future and are interested in these topics and discussions about solutions”, said Dorine Kea, the advisor of LTO Nederland.

![Diagram of relations among each sector](image)

**Figure 15 The conceptual diagram of relations among each sector**

3.4. **Reasons leading to saltwater intrusion**

Researches have already clearly shown that Texel at present is salty and is going to be saltier under the influence of both natural and anthropogenic activities (Oude Essink, 2001). In 2000, numerical models had been designed to simulate the
groundwater salinization of Texel. The results revealed the chloride concentration of some southeastern areas reached 12,500-15,000 mg/L (while the chloride concentration of seawater is around 19,500 mg/L) (Pauw et al., 2012). Many factors have been detected to have great influence on facilitating saltwater landward process.

3.4.1. **Geological factor**
As mentioned previously, the average elevation of Texel is only 2 m above M.S.L. Large parts of low-lying polder areas are below the sea level or just above and groundwater levels are mostly below sea level as well. This situation makes this island more prone to salinity encroachment.

3.4.2. **Seepage**
In coastal areas, when the tide subsides, some seawater remains in the underground causing the increase of salinity in the groundwater. The research shows that the deep saline groundwater is at stable status with little mobilizing (De Louw, 2013). However, the seepage due to the great vertical hydraulic gradients takes place, particularly in the polder areas, leading to an increase of salt loads.

3.4.3. **Climate change**
Being a low-lying island, the vulnerability of Texel to the intruding saltwater will to a large extent be worsened by climate change. Sea-level rise, consequences of the increasing temperature caused by massive emission of “greenhouse gases”, is the biggest fear of coastal low-lying lands. According to Intergovernmental Panel on Climate Change (IPCC): “over the period 1901-2010, the global mean sea level rose by 0.19 [0.17-0.21] m…” (IPCC, 2015). Besides sea-level rise, the disturbed precipitation – evapotranspiration pattern and more frequent extreme weather have both intensified the intrusion process.

3.4.4. **Human activities**
Inhabitants have shaped half of the present form of Texel. Construction of dikes and drainage systems, land reclamation and all other hydraulic engineering constructions have altered the natural water system and upset the equilibrium. In coastal aquifers, virtually deep groundwater has a higher salinity (Post, 2004). This is the leftover seawater after ebb. However, large-scale land relemations together with the drainage systems for agricultural purpose distort the stabilized system and brought the consequence as upward seepage (demonstrated in Figure 16) and land subsidence. All these alternatives will only speed up the rate of groundwater salinity.
3.5. Ongoing mitigations and/or adaptations

Due to the fact that the salinization process is taking place at a greater pace in Texel, the availability and accessibility of freshwater is decreasing and threatened by sea-level rise, together with the pressure from economic activities and the increasing loads of tourists. Counter measures to saltwater intrusion are of great importance. Multiple mitigations and adaptations have been implemented on the island and large amounts of researches have been carried out to seek the most effective and sustainable solutions to this process.

3.5.1. *Flush the land with freshwater*

The most common and cheapest way used to mitigate the increasing salinity is flushing the lands with freshwater. External freshwater is pumped from groundwater or surface water to flush the lands aiming to compensate the salinity.

3.5.2. *Developing other water resources*

The limited water resources and large demands by agricultural sector stimulated Texel to search for all possibilities of new water resources. Wastewater, to which the attention was paid, hence has been exploited to play important roles in water system of Texel.

Waterharmonica, the concept that bridges the gap between effluent and surface water, hence serves as a new approach to solve various water issues including water shortage for agriculture with regard to increasing salinization (Kleiman, 2006).

The Everstekoog wastewater treatment plant (WWTP), the biggest one located in the center of the island, connects the
other 4 WWTPs to treat the wastewater from households together with rainwater of Texel. Instead of directly discharging the treated wastewater northward into the nature, a diversion for treated effluent has been made to the southern fields first for agricultural use since 1994 (Van Den Boomen & Kampf, 2012). This can be done by introducing a constructed wetland as a post-treatment system following after the WWTP. The wetland consists of mainly three parts: pre-settling, reacting ditch and discharge ditch. Besides the function of nitrogen removal, the biological effects can also improve the oxygen level; hence turn the “dead” treated effluent to clean water with nutrients (Van Loosdrecht, 2005). The “live” water then flow down to the polder areas for agricultural purpose.

Some projects carried out on the island also show that farmers use the tile drainage and rooftop to retain the rainwater and store it for irrigation use (Dynamic Water Systems, n.d.). The rainwater can be collected through the whole year given the climatic condition. Hence, some farmers take it as an alternative sustainable and also cheap irrigation source. However, the information on whether this approach is widely adopted on the island is lack. It is only known that the rainwater storage has not been adopted by the municipality yet and there is no separation between rainwater and wastewater, as mentioned above, when entering the treatment plants.

3.5.3. Saline agriculture

It is saline agriculture that makes this Dutch island well known in the world. The successful harvest of crops irrigated by saltwater is not only regionally seen as the key solution to tackle SI problem but also worldwide. Restricted by limited freshwater resources on the island, salt farm initiated to execute the “salty” experiments with the help of universities and funded by municipality and related water management associations.

To avoid the contact between salt irrigation water and fresh groundwater, a membrane is placed 50 cm below the ground surface before the crops are cultivated (De Vos et al., 2010). Each kind of vegetable is divided into different groups drip irrigated by saltwater (mixture of freshwater and seawater) with different salt concentrations controlled by a monitoring system (shown in Figure 17 a & b). The plants, which eventually survived high salt concentration, are selected for breeding as high salt-tolerant agricultural products.
At present, the dominant saline agricultural products are potato, seakale, strawberry and some types of seaweed (shown in Figure 17 c, d & e). The highest salt concentration that the improved potato can tolerate is 20 dS/m (*the salt concentration of seawater is 40 dS/m*). Salt tolerances of other vegetables have all to different extents been improved compared to the reference provided by Food and Agriculture Organization of United Nation (FAO) (De Vos et al., 2015). In addition, tested by professional association (Wageningen UR Glastuinbouw), the tastes have been sweetened as well. Owing to the high tolerance of salt, salt spray can be implemented as herbicide or pesticide for salty crops (De Vos et al., 2010).

A questionnaire about the acceptability of the saline agricultural products was developed and administered among Dutch citizens with different ages and various backgrounds to study the feasibility and potential market of saline agricultural products, as the taste distinction from the conventional crops and vegetables. It reflects the concerns from public about the “salty crops” as well. The results show that 77.1% respondents are not aware of these kinds of agricultural products and 82.8% express the negative attitude of it considering the unknown taste, change of nutrients or maybe even “too salty”.

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**Figure 17 a. Various crops irrigated by saltwater with different controlled concentrations; b. The computer system in front of the field which monitors and controls the salt concentration; c/d/e. Strawberries, *ijskruid* (*Mesembryanthemum crystallinum*) and cucumber irrigated by saltwater**
4. CHINESE CASE STUDY – SOUTHERN AREAS OF LAIZHOU BAY

Laizhou Bay is located in the south of Bohai Sea, North China, between Liaodong Peninsula to the north and Shandong Peninsula to the south. This area has been recognized as one that suffers the most serious saltwater intrusion problem owing to its special geological location, climatic conditions, together coupling with unrestrained anthropogenic activities. In this case, to narrow down the geographic scoping, Shouguang City (a county-level city in Weifang City, Shandong Province, south coast of Laizhou Bay) is selected as the main study area. Other neighbor counties may auxiliarily assist to illustrate.

4.1. Characterization of the area of interest

Shouguang, located northwest of Weifang City, Shandong Province, is in the south coast of Laizhou Bay (shown in Figure 18). This county-level city lies between 36°41’-37°19’ N and 118°32’-119°10’ E and covers an area of 2072 km². The population within the area is about 1,140,000 (NBS China, 2014).

Figure 18 Location of Shouguang in Weifang City, Shandong Province, China and zones of different towns within Shouguang (adapted from (D-Maps, 2007))

On the whole, the elevation of Shouguang gradually decreases from south to north. The highest point of the city is 49.5 m M.S.L in the southwest, while the lowest point is only 1 m M.S.L in the north. Except for the south highland and north beach land, most lands of Shouguang are low-lying lands. In terms of this special landscape, agriculture is also one of the most important economic activities in Shouguang.
Shouguang is a coastal city that has extreme water scarcity issue (Shen, 2016). The groundwater (depth to the ground) drops from 5.92 m in 1981 to 23.48 m in 2014 (WCB Shouguang, 2014). One reason is that the local climatic condition decides the precipitation (yearly average 595.3 mm and mostly concentrated in summer) is way lower than the evapotranspiration (yearly average 1265.5 mm) (Shouguang Government, 2014). The other reason is the uncontrollable groundwater withdrawal for the increasing needs of both agriculture and industry within the city. Especially in 1980s, large amounts of unregulated well drillings in rural areas for agricultural purpose together with droughts resulted in groundwater depletion.

According to the water resources statistics report of Shouguang in 2007, groundwater is the main water resource (i.e., accounting almost 90% (Figure 19 Left)) to sustain the city, while the biggest water consumer is agriculture that accounts 84% of the whole water consumption (Figure 19 Right).

With regard to the geographic location, the brine deposits along the coastline make Shouguang a major salt producer in North China. An east-west salt-fresh water boundary divides the whole city into northern (salty zone: concentration of Cl higher than 250 mg/L) and southern parts (freshwater zone: concentration of Cl lower than 250 mg/L). However, both natural and anthropogenic factors have been detected to force the boundary southward (Ma et al., 1997).

4.2. Agriculture in Shouguang

Shouguang, also known as the significant national vegetable producer, or so-called “home of vegetables”, has a long history of agriculture and agriculture-related activities remain to be the essential economic activities of the city. The total arable land within the area is about 172,000 ha by year 2011,
of which grain, vegetable, cotton, fruit and others take up respectively 54%, 30.5%, 4%, 11% and 0.5% (Wei & Zhang, 2013).

Distinguished with other urbanized areas within Bohai Economic Rim that are developing through manufacturing and/or services, the development and prosperity of Shouguang are virtually impelled by agriculture. Construction and improvement of big scale wholesale market for vegetables together with the increasing implementation of greenhouse becomes the driving force for the blossom of vegetable cultivation in Shouguang (Yao, 2008). Not only this city serves as a vegetable supplier nationally but also a big vegetable exporter globally.

The irrigation source in the south of the salt-fresh boundary is groundwater, while in the north, more surface water has been chosen to irrigate farmlands due to high salinity in the groundwater. In some areas, traditional irrigation method – flood irrigation is still being used, which results in extreme low water efficiency of irrigation. Constructions of well drillings and pumping systems need to be undertaken by farmers after the water withdrawal permission authorized by the local government. The main cost for groundwater irrigation is the construction and the energy required to pump water.

Farmers have noticed that the well water is becoming less and saltier. More wells have been drilled and drilled deeper to obtain the fresh groundwater. Several phone interviews and communications with local residents have been conducted to better understand the present consequences of saltwater intrusion on agriculture. One farmer from Tianliu Town described that he had to deepen the wall to 100 m underground to get fresh groundwater for drinking and irrigation. Another farmer Mr. Wang from Yingli Town stated that the production of his wheat farm decreased 50% because of the salty irrigation water. “Other cornfields in the village experienced the total crop failure, the leaves of seeding turned red and stopped growing after using the pumped salty groundwater”, he said.

Besides production decrease, farmers also reflected that the taste of certain vegetable also negatively changed. All these together can lead to enormous economic loss in both national and global markets.
4.3. Framework, legislation and stakeholder involvements

Water Law is the main national water legislation legislated by the Standing Committee of the National People’s Congress (NPCSC) in 1988. However, previously, under the State Council, water resource management is separated into water quality management and water quantity management administrated by Ministry of Environmental Protection (MEP) and Ministry of Water Resources (MWR) respectively. Until 2002, the amended Water Law somehow aimed to provide a framework for integrated water management (Liu & Speed, 2009). Besides, other water related legislations such as Water Pollution Control Law and Environmental Protection Law all include the responsibilities regarding water issues. Based on the main water legislation enacted by the central government, the associated ministries and departments introduce the specific regulations within their scope (i.e., MWR introduced Water Abstraction Management Method). The centralized political system determines a vertical administrative relation from the central agencies (i.e., MWR) to the province, prefecture and county (i.e., Water Conservancy Bureau (WCB)).

The Water Law states that water abstraction should strictly follow the regulations, especially in the coastal areas, in case of saltwater intrusion. It clearly states that groundwater abstraction should be forbidden in the excessively exploited aquifers and should be investigated on-site in coastal areas to prevent land subsidence and saltwater intrusion. Subsequently, Water Abstraction Permission and Collection of Water Resource Charges Regulation was enacted by the State
Council, which stated that water withdrawal for irrigation must be declared to the local administrative departments of water and only can be operated after the permission being issued. The quantity of abstraction should strictly refer to the Irrigation Norm Standard of Main Crops in Shandong Province. In addition, water resources fees should be collected from agricultural units to constrain water resource waste.

Figure 21 The conceptual diagram of relations among the related sector and stakeholder

Given the highly centralized administrative system, the participation of public and non-governmental organizations is relatively weak. Farmers are more dependent on the government coping with hazards. The rapid development of technology in China boosts large amounts of researches and projects on studying the mechanism of saltwater intrusion and salinization. In addition, the government also conducts training courses or meetings to promote the sustainable irrigation patterns and the awareness of water conservation among farmers.

4.4. Reasons leading to saltwater intrusion

It is not surprising that the demand for freshwater is greatly increasing when considering the large population within this coastal plain and the dominant agricultural land use. The exploding demands for freshwater, resulting dramatic depletion of both surface water and groundwater, together with the concerned climate fluctuations, have worsened and are still worsening contamination of salinity.
Figure 22 (Left) The salt-fresh water boundary is moving southward in Shouguang (adapted from (Yang, 2014)); (Right) Guangce Lee, the resident of Wanggao town of Shouguang City, is pointing the well they used for irrigating vegetables, however the water turns saltier and deeper (adapted from (China Weather, 2013)).

Figure 22 (Left) illustrates that the salt-fresh water boundary is moving southward and the rate in the eastern part is faster than the west. Multiple reasons leading to this salinity ingress process have been identified and summarized, of which the geographic and climatic conditions are the background while anthropogenic activities are the dominant factors aggravating this process.

4.4.1. Natural factors and climate change
The climate has decided high evapotranspiration ascribed to plentiful sunshine and concentrated rainfall within the study area, which makes Shouguang more sensitive and vulnerable to droughts. The observed data in last 56 years shows a decreasing trend of precipitation and the frequent droughts in 80s and 90s in Shouguang (Gao & Wang, 2015). Driven by which, not only the discharge of freshwater to ocean was sharply decreasing, more exploitation of groundwater for mitigating surface water dry-up was also intensified. Moreover, the main soil type along the coastline is virtually sand and gravel with relatively high hydraulic conductivity (Shouguang Government, 2014). These situations provide favorable conditions for salt ingress.

In addition, Sea-level Gazette of 2012 shows the sea-level in Bohai Sea raised 31 mm compared to 2011 while 110 mm compared to average historical value (State Oceanic Administration PRC, 2013). The increased pressure difference
between seawater and fresh groundwater exerted a major influence on seawater encroachment.

4.4.2. **Anthropogenic factors**

Reduced freshwater discharge, brought about by large amounts of hydraulic constructions in Shouguang such as water diversion, dam and weir construction and drainage system for agriculture, has been identified as one direct major reason for saltwater intrusion. Large-scale impoundments for satisfying the increasing population directly, especially in dry seasons, lower the runoff that is considered as the main groundwater recharge and disrupt the balance of water cycle. Downstream of the main river, Mi River, has been frequently reported dried-up and parts of it even been reclaimed as farmlands (QiLu, 2015).

Excessive groundwater exploitation in coastal areas has been recognized as the most essential and common anthropogenic factor that facilitating seawater landward movement. Shouguang is a typical example that suffering groundwater deficit due to uncontrolled abstraction.

To solve water scarcity, groundwater resource is seen as the foremost water resource to feed the city. From 1970s, the number of registered groundwater withdrawal wells had exceptionally increased to about 30,000 by 2007 with an annual average withdrawal of 230 Mm$^3$, 22% overdraft compared to the allowable limit however still barely fulfilling the increasing demand, resulting an annual average decrease of water table up to 0.5 m (Shen, 2016) & (Yang, 2008). Figure 23 shows the annual groundwater withdrawal amount in Shouguang.

![Groundwater Extraction Data in Shouguang](data absence in 2001 & 2002) (data gained from Shouguang WCB: wishouguang.sdwr.gov.cn)
Relatively late establishment of sound legislation for reasonable exploitation and absence of water conservation awareness indirectly facilitate indiscriminate groundwater production. Even after the establishment of related regulations, due to the complex procedure and avoidance of duration for obtaining the permission, and the high cost for hiring the professional construction team, large amounts of unregulated wells still emerged without being declared. It has been told by the residents in Shouguang that some bath centers and other carwashes all use groundwater well without declaring to avoid related water resource fees. The greatly depleted water table hence breaks the equilibrium between fresh groundwater and saltwater enabling more saline water in the northern zone and seawater rushing landward.

In addition to those main reasons mentioned above, other human activities such as brine mining for salt production, which virtually depends on seawater recharge, and other mining activities within the area that lower the underground deposits have been considered as the potential trigger. The south coast of Laizhou Bay is well known for its salt production. Flat terrain and dry weather provide favorable natural condition for salt mining. Shouguang, as one of the most important salt producer, possesses 3,095 salt wells with an annual average exploitation of brine up to 122 Mm$^3$ (Lin, 2015).

4.5. Ongoing mitigations or/and adaptations

Being identified as the most vulnerable area to saltwater intrusion, the emphasis is no doubt on the mitigation and future prevention measures. Agriculture in Shouguang, being both the most vital victim and contributor of saltwater ingress, has the biggest potential for implementation of improvements and mitigations.

4.5.1. Water conservation and diversion

Improving the efficiency of water resource utilization right now has been taken as the priority of all activities in water-starved Shouguang, particularly of agriculture. Instead of
flood irrigation, sprinkler irrigation and micro-irrigation have been extensively promoted and practiced. Significant effect has already been noted in Sunjiaji District etc., in which modern irrigation system has been implemented, that water consumption for irrigation purpose has decreased 40% (Wang & Zhang, 2016).

Introducing water from southern water-rich areas to satisfy the demands in water-starved areas of North China is the primary approach of water allocation. Being part of South-North Water Transfer Project, 69 million dollars has been invested to re-allocate the water from Yellow River and Yangtze River to alleviate water scarcity in Shouguang (Shen, 2016).

4.5.2. **Crops selection, breeding and adjustment**

More drought-resistant and salt-resistant crops are selected to replace the vulnerable species. Fruit trees are the new choices for farmers. It has been investigated that lots of farmers in Yingli Town switched to plant trees as the irrigation is only once per year for trees. Moreover, greenhouse vegetable farming, which yields more profit per unit of irrigation water, is being largely adopted. “…Irrigation water was reduced by 15.7% and the production value per unit of irrigation water rose from 5.0 to 25.2 Yuan m\(^{-3}\)” in Shouguang (Qi, 1998). Besides, some certain crop species (e.g., Qingmeihuang soybeans, Lude wheat, Fuzao peanut) have replaced the others due to their higher yields even in salt-intruded lands.

4.5.3. **Developing other water resources**

Development of alternative water resources is the key solution for Shouguang at present to alleviate the rapid depletion of groundwater and meet the huge demands for all water users. Taking Yingli Town as an example, the rainwater and domestic wastewater are collected through different pipelines and treated with different processes. The treated wastewater and rainwater hence can directly transport to the farmlands as irrigation water. The renovation on the separation of pipelines for rainwater and domestic wastewater for the whole city is still in progress. Furthermore, guided by the concept of “sponge city”\(^1\), the urban rainwater collection and storage infrastructure is being implemented aiming to improve the efficiency of rainwater utilization.

4.5.4. **Seawater Farming**

Seawater farming has been developed in Shouguang as well.

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\(^1\) Sponge City refers to the cities as sponge – collecting and soaking the excess rainfall and floodwater. This concept can be seen not only as a flood control approach, but also the effective method to reuse the rainwater as an alternative water resource.
In Yangkou Town, north part of Shouguang, seawater farming has been implemented as an adaptation to salinization. The crops are directly cultivated in salinized soils and irrigated completely by seawater (Shouguang Vegetable, 2011). However, seawater farming in China is still at the beginning and testing stage that only one or two certain species (e.g., Salicornia Europaea) has been introduced. Given the small scale and high price due to high labor cost on manual harvesting, the products have only been supplied to certain upscale restaurants and hotels.
5. DISCUSSION AND COMPARISON

In this section, two case studies are summarized and discussed based on all the findings providing the background for future comparison and proposals of effective counteract measures and management strategies. Subsequently, the comparison on drivers of saltwater intrusion, legislations, counteract measures between two regions is made.

5.1. Discussions of case studies

5.1.1. Case study of Texel

Forced by the special geographical and topographical situations, the Netherlands has a long history and ample experience combating with water related issues. The advanced technology and well-developed legal system assist the Netherlands achieve remarkable results on fighting with the intruding saltwater. The integrated water resource management brings all involved stakeholders in a closer loop to develop more sustainable solutions.

Agriculture and horticulture as the dominant economic activities decide the high demand for water. The famous low-lying polders enable a perfect condition for agricultural activities; however, they pose the problem of saltwater intrusion caused by upwards-saline seepage attributed to human activities and accelerated by the rising sea level. By protecting the vulnerable water system of the island, water abstraction and water use are strictly constrained by the legislation. Furthermore, termination of groundwater abstraction for drinking water brings Texel a high dependency on the mainland for water resources.

To mitigate the influence of increased salinity, the most common way applied in Texel, also in the whole nation, is flushing the lands with freshwater. This, however, has been questioned with low efficiency of water use and decrease of freshwater discharge. To adapt to the saltier water and the changing climate, Texel has increased the development of wastewater or other alternatives and initiated saline agriculture. The wastewater treatment through a constructed wetland is seen as a low-cost ecologically friendly approach that to great extent solves the large water demands particularly for agriculture. Continuous monitoring is of great vital due to the possible instability and uncertainty of ecological process. Besides, given the old water collection pipeline, rainwater and wastewater enter the same treatment process. The drawbacks include 1) energy and resource waste on integrated treatment considering the good quality of rainwater compared to wastewater, 2) when during the extensive rain season, the capacity of the wastewater treatment system cannot handle excess rainfall.

The success of saline agriculture has drawn great attentions worldwide and is seen as the key solution to salinization. In addition, it can also be seen as a good example of close
connections among different stakeholders. The breeding of salt-tolerant crops has been adopted by other arid countries with salinized farmlands like Pakistan. However, attention should be paid that irrigation with saline water on the non-salinized lands, from a long-term perspective, the soil structure will be destroyed and hence serious salinization occurs.

Furthermore, both the questionnaire conducted among public and interview with the advisor from farmers’ organization have indicated that the acceptability of saline agriculture products is quite low given the lack of understanding. Yet, the results from questionnaire also show a higher acceptability after the introduction of saline agriculture. The advisor from LTO Nederland stated in the interview that attributed to the high investment and low profit, saline agriculture has not been accepted nationally. Farmers prefer to choose a cheaper way – flushing the polders with freshwater to reduce the salinity instead of developing saline agriculture.

5.1.2. Case study of Shouguang

Identified to have the most severe saltwater intrusion problem in China, the south coast of Laizhou Bay has drawn a lot of attention both nationally and worldwide. Series of actions have been implemented by the government to address this problem. However, the water related legislation was designed with separate responsibilities, though the Water Law is the main water legislation, it lacks thorough consideration of water systems and is more designed for an administrative system. The poor implementation of legislation and lack of related supervision to guarantee effective implementation have been identified as the main problems at present.

Moreover, centralized administrative system also to some degree limits the participation of relevant stakeholders. Though the mechanism and background of saltwater intrusion have been widely and deeply investigated, the gap between the knowledge and the practice still needs to be bridged and public or farmers need knowledge support. Constrained by certain policies, some data and information is not open to public, non-government organizations or foreign associations. All these drawbacks of water resource management have limited the effectiveness of actions.

It is obviously that the main reason leading to saltwater intrusion and increasing salinity in Shouguang is the uncontrolled groundwater and saline water abstraction. Known as the main vegetable supplier, the main economic activity is agriculture as well. However, lack of awareness of water conservation together with the weak enforcement of regulations, farmers arbitrarily drill the wells close to their lands and flood their farmlands for irrigation. The massive hydraulic constructions and large-scale salt mining activities all disrupt the natural water cycle and worsen the process of landward saltwater movement. In conclusion, human
activities are the main drivers of the increasing salinity, while climate change and sea level rising also facilitate.

The serious crops failure enable farmers to know the severity of this issue and force them cultivate more salt-tolerant and drought-tolerant species. To avoid the low efficiency of water utilization, the government promotes sprinkler and drip irrigation instead of the conventional flooding irrigation and achieves remarkable results. However, the high investment at the beginning of facilities is the biggest concern of farmers. Seawater farming is at beginning phase that only one or two certain species is cultivated and limited to certain market instead of public.

New water resources, such as treated wastewater, rainwater and surface water from other areas, have also been developed to cope with the high demands. The large-scale implementation of rainwater-wastewater separation during the collection and treatment has been proven to be a sustainable approach to water scarcity. What’s more, diverting surface water elsewhere to address water scarcity is recognized as the main approach in Northern China. The case study of Shouguang has proven the effectiveness; yet, the ecological influence still needs to be investigated.

5.2. **Comparison**

The comparison in all aspects has been made (Table 1) between the two case studies aiming to facilitate each learn the lessons from the other.
## Table 1 The comparison between two case studies

<table>
<thead>
<tr>
<th>Reasons</th>
<th>Texel, NL</th>
<th>Shouguang, CN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographic</td>
<td>Low-lying lands: At or even below sea level</td>
<td>Low-lying lands with average elevation at 24m M.S.L., however the lowest part is only 1m M.S.L.</td>
</tr>
<tr>
<td>Climatic</td>
<td>Precipitation distributes throughout the year but also with a focus during the summer</td>
<td>Precipitation only focus during the summer and with high evapotranspiration</td>
</tr>
<tr>
<td>Sea-level rise</td>
<td>All threatened by sea-level rise</td>
<td></td>
</tr>
<tr>
<td>Anthropogenic</td>
<td>Polder drainage and other human activities leading to an increase of saline seepage</td>
<td>Massive groundwater and saline water abstraction; massive hydraulic constructions</td>
</tr>
<tr>
<td>Impact on agriculture</td>
<td>Yields of crops decrease, however without large damages</td>
<td>Huge crop failure within the whole city and soil salinization</td>
</tr>
<tr>
<td>Agricultural pattern</td>
<td>Modernized agriculture with mainly high profit crops such as bulb, dairy</td>
<td>Grains, vegetables and fruits are the main products; in process of transforming to modernized agriculture</td>
</tr>
<tr>
<td>Irrigation pattern</td>
<td>Drip irrigation or sprinkler irrigation</td>
<td>Flood irrigation is still being used; drip irrigation and other modern irrigation methods are promoted</td>
</tr>
<tr>
<td>Accessibility to associated agencies/ Data</td>
<td>Easy: official database open to the public with the most recent data</td>
<td>Relatively hard: parts of the data can be found from the state, however not timely updated; certain data is not open to the public</td>
</tr>
</tbody>
</table>

### Legislation

<table>
<thead>
<tr>
<th>Institutional framework</th>
<th>Integrated</th>
<th>Separated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main focus/objectives</td>
<td>To provide healthy water status</td>
<td>More focus on water pollution and conservation</td>
</tr>
<tr>
<td>Decision making</td>
<td>Top-down and bottom-up; decentralized and centralized</td>
<td>Top-down; centralized</td>
</tr>
<tr>
<td>Enforcement</td>
<td>Relatively high</td>
<td>Relatively low</td>
</tr>
<tr>
<td>Public participation</td>
<td>Different stakeholders are involved</td>
<td>Limited to centralized administrative system public participation is quite low</td>
</tr>
</tbody>
</table>

### Stakeholders

<table>
<thead>
<tr>
<th>Government</th>
<th>Support</th>
<th>Centralized administrative system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academia</td>
<td>Provide knowledge support both to the government and the public</td>
<td>Knowledge support, however lack the support to the public</td>
</tr>
<tr>
<td>NGOs</td>
<td>Support and participate</td>
<td>Constrained/weak</td>
</tr>
<tr>
<td>Farmers</td>
<td>Organized by related farmers’ organization to ensure the involvement</td>
<td>More dependent on government</td>
</tr>
<tr>
<td>Others</td>
<td>Media has been largely used to promote related knowledge</td>
<td></td>
</tr>
</tbody>
</table>

### Technical level

<table>
<thead>
<tr>
<th>Technical level</th>
<th>Well developed</th>
<th>Rapidly developing</th>
</tr>
</thead>
</table>

### Financial support

| Financial support | Cooperation with government and other NGOs and universities | Mainly from government |

### Mitigations/Adaptations

<table>
<thead>
<tr>
<th>Responses to the threats of saltwater intrusion</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Well understanding of the mechanism and background;</td>
<td>1) Well understanding of the mechanism and background;</td>
</tr>
<tr>
<td>2) Researches, from a point of view of future perspective, on simulations of the dynamic behavior of saline groundwater;</td>
<td>2) Promoting the awareness of water conservation and water-saving irrigation;</td>
</tr>
<tr>
<td>3) Wastewater reuse with a post-treatment through constructed wetland</td>
<td>3) Wastewater reuse and rainwater reuse with separated collection and treatment;</td>
</tr>
<tr>
<td>4) Rainwater reuse, however without separation from wastewater;</td>
<td>4) Crops change to more salt-tolerant or drought-tolerant;</td>
</tr>
<tr>
<td>5) Develop saline agriculture that select crops can be irrigated with saltwater;</td>
<td>5) Develop seawater farming</td>
</tr>
</tbody>
</table>
Wastewater reuse and saline agriculture have both been adapted as adaptations by Texel and Shouguang, yet in different modes, hence a comparison of both approaches with specific highlights and drawbacks, aiming to facilitate the future analysis, is presented in Table 2:

| Table 2 Comparison of mitigations adapted by two case studies with specific highlights and drawbacks of each measure |
|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
|                    | Highlights                                      | Drawbacks                                      |
| Wastewater reuse   | ✔ Using ecological process to post-treat effluent; ✔ Low cost; ✔ The treated water is rich in nutrient | ✗ Potential uncertainty and instability of ecological process, Continuous monitoring is needed ✗ Old system that could not separate rainwater and wastewater |
| Shouguang, CN      | ✗ The separation of rainwater and wastewater in both collection and treatment systems ✔ For the conventional treatment system, the quality of effluent can be well controlled and easily monitored | ✗ The high cost and inconvenience of constructing two collection systems for separating rainwater and wastewater |
| Saline agriculture/Seawater farming | ✔ The potential market of saline products towards public is big given the common species and relatively low price ✔ More common species have been improved to salt-tolerant | ✗ Relatively high investment and low profit that cannot be accepted by most farmers ✗ The potential damage to healthy soils by irrigating with salty water even with “cleanup” |
| Shouguang, CN      | ✔ Fully use the salinized soils ✔ Irrigation with complete seawater | ✗ High price for the products that still cannot be accepted by the public, hence the market is only limited to certain upscale restaurants or hotels ✗ Only one or two species is developed ✗ Manual harvesting and high labor cost |
6. CONCLUSION AND RECOMMENDATION

Saltwater intrusion, as a complicated process, threatens virtually all low-lying coastal areas. More attention has been paid on the strategies that assuage the losses particularly on agriculture in both the Netherlands and Eastern China. Although the general background and mechanism of saltwater intrusion have been widely researched, different regional features and different degrees of impacts still need to be fully understood and analyzed to achieve a better management strategy on addressing this issue.

Despite the different scales, populations, climatic backgrounds and policies, these two study sites are somehow facing the same problems (e.g., increasing salinity in agricultural lands caused by saltwater intrusion, land subsidence, sea-level rise, etc.) and, together with all other low-lying and deltaic areas, aiming to achieve the same goal – establishment of suitable and sound systems and management strategies to well control and mitigate the increasing salinity through saltwater intrusion.

6.1. Lessons learnt

By studying and analyzing two case studies, the main issues and priorities for water management within each region have been distinguished. Netherlands has a long history fighting with the threat of seawater encroachment in line with high population density and its low elevation at or below sea level. Water security and related issues have drawn substantial attentions that both technical solutions and associated legislations are relatively well developed and seen advanced worldwide. To well control and monitor saltwater intrusion and integrate the consideration of climate change into legislation are the priorities of water management in the Netherlands determined by current situations and changing climate. Respectively, efficiently allocating and utilizing water resources to avoid regional imbalance, strengthening the enforcement and improving the implementation of regulations are recognized as the priorities for China.

In comparison to the Netherlands, China is now encountering the stage, through which the Netherlands went before. The comparison of two case studies can no doubt serve the purpose to enable each benefit from the lessons learnt from the other. Foremost, there is no doubt that advanced technology and modernized equipment have assisted to make big progress in learning and predicting the change of saltwater intrusion in both the Netherlands and China. However, the difference is that there still exists a gap between the knowledge and practice in China, which can also been seen as the reflection of low farmers’ involvement. Integrating the expertise from universities and the experience from farmers has been proved to be a more rational and effective pattern to deal with the increasing salinity by the salt farm in Texel.
Secondly, as analyzed above, the separation of responsibilities held by multiple legislations and water authorities may result in gaps or overlaps between each sector and confusion within the public, hence limit the efficiency and feasibility of overall water resource management. Real integrated water legislation is urgently needed to guarantee an efficient network for water resource management. Besides, how to improve the implementation of related regulations and legislations is then the other key issue for China as well.

Furthermore, compared to the Netherlands, involvement of local stakeholders in China has always been neglected or paid less attention, which has been determined by the centralized and top-down water management strategy. It makes sense that combating saltwater intrusion is not only the responsibility of government despite different political backgrounds. Bottom-up approaches should be implemented as well since it takes the local features and situations into account. The Netherlands has provided a good example that a systematic farmers’ organization can serve as a bottom-up approach helping to achieve a closer involvement of farmers.

Comparing the mitigations that each case study has adapted, developing other alternative water resource such as treated wastewater and rainwater, saline agriculture or seawater farming and promoting more salt-tolerant crops have been introduced by both Texel and Shouguang. The lesson that Shouguang can learn from Texel is the ecological way for post-treating the effluent from WWTPs to turn the “dead” water to “live” water. This approach fulfills the definition of sustainability by solving the social problem (i.e., water scarcity) through ecological process with low economic cost. Moreover, the common saline products (i.e., with high salt tolerance) such as potato, cucumber and strawberry instead of uncommon ones (i.e., Salicornia europaea adapted by Shouguang) can have a bigger potential market towards public.

Meanwhile, the highlights of counteract measures adapted by Shouguang can also inspire Texel. Instead of using groundwater, diverting surface water to irrigate the farmlands has achieved considerable results to slow down the pace of landward saltwater in Shouguang (Lin, 2015). Given the vulnerability of groundwater aquifers at Texel, reasonable development of surface water or diversion of water somewhere else can to some degree relieve the pressure of groundwater use.

Secondly, renovation of the old sewage collection system to separate rainwater and domestic wastewater before entering the treatment systems is another point Texel should take action on. Inspired by the buffering system concept “Sponge City” from Shouguang, it is recommended to develop citywide rainwater and floodwater storage facility to increase
the efficiency of rainwater utilization while also prevent urban floods.

By comparing the saline agriculture that both case studies have developed, one inspiration that Texel could get from Shouguang to possibly solve the concern of low profit is that the supply line can not only be connected with public, but also with certain high profit demands such as upscale restaurants and hotels.

6.2. Suggestions for improving water management and potential mitigations and adaptations

Figure 26 shows the proposed conceptual framework for sustainable water resource management based on previous findings and analysis. This can be applied by all the regions that suffer from similar issues.

On the whole, integrated management is the trend and the direction for all countries to deal with similar issues as is proved by both the Dutch and the Chinese case studies. This is especially true since water availability is decreasing globally while the water demand is increasing owing to economic bloom, population growth and climatic fluctuation. Hence, overall planning on the priorities for water use among multiple sectors (e.g., domestic, agricultural, industrial, etc.) to avoid potential conflicts should always be kept in mind as a must-do to reduce the possibility of saltwater intrusion caused by less freshwater discharge. Only fully implementing the
Water related legislation and regulations together with corresponding supervision system can the effectiveness of management be guaranteed. Furthermore, considering the vital and complex connections between climate change and saltwater intrusion, integrating climate change to water management is obviously of great significance.

Saltwater intrusion and all other water related issues require an integrated approach with a multi-stakeholder involvement in which all levels of government are presented but also civil society organizations, academia and the private sector. It is no doubt that enhancing the connections between each player can enable the good operation in both decision-making and actions taking. Hence, cooperation among government, NGOs, universities, farmers and other media is encouraged as it can bridge the gaps between the knowledge and practice. All activities for the purposes of solving similar issues should be encouraged, such as easy accessibility to associated agencies and specific data. Moreover, searching potential opportunities and cooperation nationally and/or internationally to exchange knowledge and experience is considered as the best chance to learn the lessons and a way to achieve intra-generational equity.

The great value of water should always be kept in mind and awareness of water conservation should be promoted worldwide. Hence, instead of conventional irrigation pattern, the new ones such as drip irrigation should be promoted and encouraged worldwide as well. Though the investment at beginning is relatively high to farmers, from a long-term perspective, the value of saved water by replacing conventional ways is way higher.

Both mitigations and adaptations to saltwater intrusion should be paid careful attention and considered from a long-term perspective. At macro level, spatially diverting water elsewhere to relieve huge pressure on groundwater withdrawal (inspired by Shouguang case study) or to flush the farmlands aiming to compensate the salinity (inspired by Texel case study) have no doubt achieved obvious results. However, other corresponding circumstances are linked with these measures as well, such as the high cost and potential influence on ecosystem of water diversion, low efficiency of flushing water resulting in water waste. Apart from this, these external mechanisms can result in high dependency for farmers in counteracting salinity. Hence, it is recommended to combine with more self-sufficient approaches at micro level, such as rainwater retention at individual farm level. Storing the rainwater during intense rainfall periods and utilizing the rainwater in dry period is no doubt a self-sufficient method to deal with unbalanced distribution of water in accordance with time.
Besides the mitigations, innovative adaptations such as development of saline agriculture and other alternative water resources (summarized from the two case studies) are considered as the key solutions. With the goal of sustainability in mind, the adaptations should both achieve social-economic growth and solve related environmental issues. The potential market and possible high profit of saline agriculture is the hot topic discussed worldwide at present, though whether it will solve the salinization problem (by creating the possibility to grow crops in salty lands or with salty water) or worsen it (by damaging the soil and turning it to complete barren lands) is still on debate. Hence, actions should be taken carefully on the potential consequences. It is highly recommended to use natural approach achieving sustainable goals given the low cost and potential ecological values (inspired by constructed wetland from Texel case study). The only drawback, as discussed previously in this paper, could be the instability and uncertainty from the use of ecological process. Yet, this could be fixed with close and continuous monitoring systems to guarantee the quality of effluent is safe enough for reuse.

Other high technical solutions such as genetically modified crops and seawater desalinization are under research as well. However due to the possible environmental damage, health risk and other ethical issues related to genetically modified crops (Sakko, 2002), and the high cost for desalinization, the implementations of those are still limited.

Besides the technical measures, economic approaches should also be integrated to better control water use from an economic point of view. Water pricing can be taken as an economic approach to somehow constrain the waste of water. Taking China as an example, water resource charges are collected from farmers and other residents to limit excessive use of groundwater. This can to some degree conserve the water resource. Yet, strict supervision should be taken in case of counter-consequence (i.e., people drill wells or withdraw water privately without declaring to escape corresponding charges).

Last but not least, strengthening monitoring systems, especially in coastal areas and groundwater over-exploited areas, to note the change of salt concentration for quick response. It is recommended to periodically examine the well water and other irrigation source in case of any potential risks, so that certain losses of farmers can be avoided.
REFERENCES


INTRODUCTION

The Netherlands has been dealing with saltwater intrusion problems since the mid-19th century, when the country's water management systems were first established. In recent years, the Netherlands has made significant progress in managing saltwater intrusion, and the country's agricultural sector has been able to adapt to these challenges. In contrast, China is facing a much larger problem, with saltwater intrusion affecting an area of more than 500,000 square kilometers. The Chinese government has been working hard to address this issue, but progress has been slow.

METHODS

To conduct this study, we conducted a comparative analysis of saltwater intrusion and agriculture in the Netherlands and China. We collected data on various agricultural practices and water management systems in both countries. We also interviewed experts in the field of saltwater intrusion and agriculture to gain a deeper understanding of the challenges faced in each country.

RESULTS

The results of our study show that the Netherlands is able to manage saltwater intrusion through a combination of engineering and management solutions. However, China still faces significant challenges in managing saltwater intrusion, with some areas experiencing severe saltwater intrusion.

DISCUSSION

From our study, we can see that there are significant differences between the Netherlands and China in terms of saltwater intrusion and agriculture. The Netherlands has been able to adapt to saltwater intrusion through a combination of engineering and management solutions, while China is still facing significant challenges in managing this issue. However, there are also some similarities between the two countries, such as the importance of developing new crops that can tolerate saline conditions.

CONCLUSIONS

In conclusion, this study has shown that saltwater intrusion and agriculture are complex issues that require a multi-faceted approach to manage. The Netherlands has been able to adapt to saltwater intrusion through a combination of engineering and management solutions, while China still faces significant challenges in managing this issue. However, there are also some similarities between the two countries, such as the importance of developing new crops that can tolerate saline conditions.
APPENDIX B  SKYPE INTERVIEW WITH DORINE KEA – ADVISOR FROM LTO NEDERLAND

Interviewer: Yuxin Duan
Interviewee: Dorine Kea, the advisor from Dutch farmer's organization – LTO Nederland

Q: The low elevation makes the Netherlands more prone to saltwater intrusion and salinization problem, the impacts of which on agriculture are obvious and known by farmers as well. Could you maybe talk about the general situations? And what are the reactions from farmers to this problem?
A: Nice to hear that you’re interested in this topic! In parts of the west of the Netherlands we have some problems with the intrusion of salt water indeed (from seepage and intrusion from the sea when river discharges are low). It depends on which area, which sector (within the agricultural sector, e.g., flower bulbs, dairy farms or crop cultivation), how low/high the surface lies and other local circumstances to find out what the solutions could be. For highly profitable crops that are often very sensitive for salt, more expensive solutions could be used than for low profitable crops. For example water storage in the lower grounds to store water in periods with high rainfall and use this fresh water in the dryer months has been developed recently and more and more farmers are interested in these kinds of solutions. But in other areas, just the inflow and outflow of fresh water to ‘flush’ the system is the best and cheapest solution. A lot of farmers in the Netherlands who live in the lower parts of NL know about the threats of salinization, however flushing the system is the commonly used solution and the water boards are responsible for the regulation of it, so for now, not a lot of investments in expensive solutions have been made.

Q: The saline agriculture, as I know, has drawn a lot of attentions recently, how do you think about it? And has it been widely known and applied by farmers?
A: Climate change could worsen salinization and its consequences. Therefore we try to motivate farmers to adapt to new circumstances and lower fresh water supplies. Saline agriculture is explored in the north of the Netherlands. Profits are often too low to cultivate these crops against the high costs of production (land prices, labor costs, strict policies etc.) in the Netherlands, though. So, it is not an option yet to cultivate salt tolerant crops.

Q: It is known that the involvement of farmers in the Netherlands is quite close, what is the role of your organization and what have you done to ensure this close involvement?
A: We try to spread news about developments of efficient fresh water use and measures against salinity in our own agricultural newspaper (for all farmers in NL) as much as possible and farmers who are interested can participate in pilot projects, in which we as an organization are involved too (like Spaarwater). In local LTO-departments (they have something in between 100-600 members per department mostly) there are often organized meetings with a certain theme. In the departments where salinization is a topic, we sometimes give presentations about what the future will bring with respect to climate change and water management issues. Most farmers like to prepare their farm for the future and are interested in these topics and discussions about solutions.
APPENDIX C PHONE INTERVIEW WITH LI AND WANG – FARMERS FROM SHOUGUANG

Interviewer: Yuxin Duan
Interviewee: Mr. Li and Mr. Wang, farmers from different Tianliu Town and Yingli Town

**Q:** Thank you so much for having the time to answer my questions. I would love to ask some questions about the salinization problems regarding to your farmlands. Have you already noticed the change in your well water? What have you done to solve the problem?

A (L): Before, the well water is sweet and clean, but these years the water turns to be salty. To have better water for both drinking and irrigating the farms, we have to deepen the well. The well next to our farm is already 100m deep. And now we spend way more money and time on electricity to pump the water up.

A (W): For the drinking water, we already use the water from a 280m deep well! Luckily government has paid for that!

**Q:** Have you noticed any impacts on your farmlands? Have you experienced any losses due to the salty well water? What have you done to address the problems?

A (L): Yes, this has been noticed for a while. Just couple of years ago, I have experienced a huge loss for my farmland. The cornfields of mine were irrigated by the salty well water, thus that year the yield of the corns is not even 50% of the expected one. And the wheat completely failed due to the salty irrigation water.

A (W): I have noticed that the soils already turned a bit white on the surface, that's the salt on the surface already! The leaves of the corns turned to red after using salty water for irrigation and hence stop growing! So what I have to change to plant trees, as they only have to be irrigated once a year.

**Q:** Have you reported this problem to the associated agencies? Did they take any actions on solving this problem?

A (L): Yeah, we have reported this problem to our village since it is not only my own problem; a lot of farmers are experiencing the same issue! And then several media came here to report this issue and tried to find the real reasons. Later the government sealed some private wells to stop people using the water from it. And also helped to deepen the wells for clean water as drinking water.
APPENDIX D QUESTIONNAIRE ON THE ACCEPTABILITY OF SALINE AGRICULTURAL PRODUCTS (ONLY CARRIED OUT IN THE NETHERLANDS)

1. What is your gender?
☐ Female
☐ Male
☐ Complex

2. What is your age?
☐ Under 20
☐ 20-30
☐ 30-40
☐ 40-50
☐ Above 50

3. Do you know some vegetables or fruits (e.g., potato, seakale, salad, strawberry...) that now can grow in salty water (i.e., diluted seawater)?
☐ Yes
☐ No

4. If you first see those "salty vegetables" in the grocery stores or the market, would you like to buy them compared to normal potatoes (normal potato is 1,3 euro/kg, salty potato is 1,75 euro/kg)?
☐ Yes
☐ No
☐ Hard to say

5. What would be your concerns about "salty vegetables"?
☐ Taste could be strange (salty or maybe unknown taste)
☐ Nutrients in the vegetables may be changed
☐ Too salty is not good for health
☐ Others

6. What if I told you the salty vegetables could be more tasty and healthy for your body, would you consider paying extra for it?
☐ Yes
☐ No
☐ Hard to say