The interrelationship of salinity and land use in the Khulna Division, Bangladesh

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Abstract

Bangladesh is a very poor and populous country located in Ganges-Brahmaputra-Meghna (GBM) delta, one of largest deltas of the world. The GBM consists of a low-lying flood plain where the local population mainly cultivates rice, fish and shrimp. However, safe water options for drinking water and agricultural purposes are limited in the GBM delta. In the past a shift from rice cultivation to aquaculture has been made, whereas on the long-term aquaculture could increase salinity, making safe water even scarcer. So, salinization should be kept at a minimum to ensure safe water for the population. Therefore, this study aimed at identifying the relation between land use, agriculture and rice in particular, and salinity.

Remote sensing data was used to make a land use map. 72 soil samples, 73 water samples from boreholes and 115 water samples from the aquifers were taken. In addition, 106 surveys were held to obtain data on farming practices and for validating the land use map. These data were analyzed using a set of T-tests.

Firstly, it was found that aquaculture is increasing over the past decades. Secondly, it was found that salinity is decreasing with respect to latitude. Thirdly, it was found that soil salinity, groundwater salinity at the water table and surface water salinity is related to certain land use types. Here aquaculture is mostly located in areas of high salinity and rice is located in areas of low salinity. No relation was found for land use with respect to shallow groundwater. Fourthly, it was found that land use correlates with elevation which can be explained by the fact that higher laying terrain floods less often with saline water. Therefore, aquaculture is more suitable to be cultivated in the low laying terrain. Lastly, no relation was found between the age of a certain land use type and salinity.

This study confirmed that there is an interrelationship between land use and salinity. However, the direction of the relationship cannot be proven. More research is needed to identify if salinity is a driver for land use change, if land use change is a driver for a changing salinity or if the effects of both land use and salinity are amplifying each other.

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1. Introduction

1.1 Background

The Ganges-Brahmaputra-Meghna (GBM) river delta hosts 170 million people, making it the largest and most densely populated delta in the world (Auerbach et al, 2015; Worland, Hornberger & Goodbred, 2015). The GBM delta consists of a low lying coastal floodplain due to sea level rise and land subsidence. On these flood plains rice and shrimp farming constitute the main activities of the local population, which all need water (Worland et al, 2015). However, safe water options for drinking water and agricultural purposes are limited in the GBM delta, due to pathogens, arsenic and salinity. People traditionally used surface waters contaminated with pathogens. To reduce pathogen related diseases in the area, millions of tube wells were drilled as to supply the local population with a new water source. Yet, these new water sources were largely contaminated with arsenic, where arsenic concentrations as large as 200 times higher than the WHO guideline of 10 µg/L for drinking water have been reported (Harvey et al, 2002; Worland et al, 2015).

Next to Arsenic, salinity poses a threat to the Bangladeshi inhabitants as saline water as a source for drinking water is related to health risks and saline water as a source for irrigation of rice field is related to a decrease in crop yield (Hoque et al, 2016; Swapan & Gavin, 2011). In Bangladesh saline water is estimated to affect 20 million coastal inhabitants and groundwater salinity of more than 2 mS/cm, the Bangladeshi guideline, have been reported in Southwestern Bangladesh (Ayers et al, 2016; Khan et al, 2011).

Furthermore, aquaculture has been emerging over the past decades (Hasan et al, 2013). Water used for aquaculture is of high salinity, which leads to a possible increase in salinity due an increase in the area under aquaculture. Therefore, this thesis will focus on salinity and land use in the Khulna Division, Southwestern Bangladesh as a large part of this area is affected by salinity.

1.2 Problem description

Bangladesh is a very poor country with 47 million of its inhabitant living below the poverty line of which nearly 26 million lived in extreme poverty in 2010 (Jolliffe et al, 2013). The local inhabitants need safe water, but safe and cheap water availability is limited. Highly saline water makes rice cultivation not worthwhile, due to limited fresh water for irrigation (Haque, 2006; Rabbani, Rahman & Mainuddin, 2013). A shift from rice cultivation to aquaculture has been made, where on the long-term aquaculture could increase salinity, making safe water even scarcer (Ali, 2006; Salam, Ross & Beveridge, 2003). This shift in land use made aquaculture the second largest export sector after the garments sector (Sohel & Ullah, 2012). So, salinization should be kept at a minimum to ensure safe water options for the population. It is of importance to know how groundwater salinity and land use interact with each other to minimalize salinization in Southwestern Bangladesh. If a relation is identified, bottlenecks for mitigating the increasing salinity in the Khulna Division can be identified and, hence, a solution for high salinity can be found.

1.3 Literature review

1.3.1 Salinity

Groundwater salinity is affected by natural and anthropogenic processes in Southwestern Bangladesh such as; saltwater intrusion from rising sea levels, cyclones and storm surges, upstream withdrawal of fresh water and aquaculture (Ali, 2006; Khan et al, 2011). It is estimated that the effects of both natural and anthropogenic processes on salinity will increase due to climate and land use change (Ali, 2006; Islam 2006; Rabbani et al 2013).

In the natural situation, groundwater is mostly saline with pockets of fresh or less saline water. Salinity in the deeper groundwater is explained by seawater intrusion, however in shallower groundwater salinity is better explained by connate waters, whereas salinity is spatially variable both regionally and locally. It is estimated that salinity increases from north to south on a regional scale and salinity varies on a local scale due to heterogeneity in thickness of the clay layer above aquifer (Ayers et al, 2016; Worland et al, 2015).

Besides natural processes, anthropogenic processes play a role in increasing salinity. Ali (2006) and Tho et al (2008) found that shrimp farming increased salinity to such an extent that rice yields reduced, and that crop cultivation can become impossible if salinity is increased even more. Aquaculture can limit rice cultivation through saline water intrusion into the rice fields and through seepage of saline water to deeper aquifers, making deeper aquifers not suitable for irrigation (Ahmed & Diana 2015). However, shrimp farming generates more profit than rice cultivation and is, therefore, an alternative for rice cultivation for the poor Bangladeshi inhabitants (Ali, 2006). So, salinity is, amongst others, affected by land use. Here the most important land use to affect salinity is aquaculture (Ali, 2006; Rahman, Lund & Bryceson, 2011).

1.3.2 Land use

Hasan et al (2013) used remote sensing to perform a spatial analysis of land use change for Bangladesh over the period 1976-2010 to get an understanding of land use change. Hasan et al (2013) found that for the Khulna division, located in Southwestern Bangladesh, cropland reduced over time. The area of both mangrove forests and settlements increased until 2000 and then decreased, leading to a slight overall increase in mangrove forest between 1976 and 2010. Lastly, urban & industrial land cover increased more than threefold between 1976 and 2010.

On a national scale, it was found that before 2000 agricultural lands and forests were mainly converted into settlements. After 2000, agricultural lands were converted to forest (excluding mangrove forests), rivers, aquaculture, settlements and accreted land. Next, Worland et al (2015) found that, for an area characterized by a mixed rice and aquaculture community, local farmers cannot use groundwater for irrigation due to salinity. Lastly, Karim (2006) found that the average distance between different land use types decreased over time. So, several studies suggest that there is an increase in aquaculture in the Khulna Division due to limited fresh water availability for other land uses than aquaculture (Ali, 2006; Hasan et al, 2013; Rahman et al, 2011; Worland et al, 2015).

Other studies showed that urban land use change is driven by elevation difference and that low-lying terrain is suitable for aquaculture, whereas rice is cultivated in more elevated areas and villages are located at the highest elevation, due to different floodability levels (Ali, 2006; Dewan & Yamaguchi, 2009). One explanation for aquaculture on low lying terrain might be given by Dasgupta (2014), who concluded that for a 1-meter increase in elevation salinity decreased on average by 0.665 dS/m. So, these studies suggest that a high flooding probability leads to salinization. Hence aquaculture will be located at lower elevations then rice and homestead area (Ali, 2006; Dasgupta et al, 2014; Dewan & Yamaguchi, 2009).

1.4 Knowledge gaps

Much is known about salinity and land use change. Several studies in Southwestern Bangladesh showed that groundwater salinity is an issue for safe water supply and spatially variable (Ayers et al, 2016; Rabbani et al, 2013; Worland et al, 2015). The Soil Research Development Institute (Hasan et al, 2013) did an extensive study concerning land use change, where they found that urbanization was the main driver of land use change. However, they did not study the effects of salinity on land use and they only took cropland, forests, rivers, rural settlements and urban & industrial land use into account for the regional changes in land use, so aquaculture was only incorporated in the national land use change figures.

Also, limited research on land use with respect to elevation has been done. It is known that salinity is inversely related to elevation, but it is not known on what scale this might affect land use or if this is also the case in the Khulna Division (Dasgupta et al, 2014).

In summary, several studies have been performed on salinity and land use. However, these studies did not relate changes in land use to salinity on a regional scale. Secondly, there are no studies that aimed at identifying the direction of the relation. So, the studies that were performed did not research if land use is a driver for increasing salinity or if salinity is a driver for land use change.

1.5 Aim and research questions

This thesis aims at identifying how salinity and land use are linked with each other on a regional scale.

The aim of the thesis can be translated into the following research question:

How do agriculture and aquaculture spatially interrelate to groundwater and soil salinity patterns within the Khulna division, Bangladesh?

To answer the above research question, the following sub questions were drafted:

1. What are the regional land use patterns and how did they change over time?
2. How is shallow groundwater and soil salinity varying in space?
3. How do regional land use and salinity patterns correlate?
4. Is elevation a reason for strong correlation with land use?

The above 4 sub-questions are drafted to answer the main research question. The first sub-question is needed to relate land use to salinity in a later stadium. The second sub-question is needed to relate salinity to land use in a latter stadium. In the third sub-question, sub-question 1 and 2 were combined to find a relation between salinity and land use. The fourth sub-question gives insight in how elevation is related to land use as it is hypothesized that salinity is a function of elevation (Dasgupta et al, 2014).

2. Theory

Land use and groundwater salinity in Southwestern Bangladesh have changed over time, whereas this chapter tries to identify theories on how salinity and land use relate to each other. From the literature it is evident that there are two main groups of processes in place that affect salinity or are affected by salinity. These two groups of processes consist of climate and land use processes. This thesis focused on identifying a relation between salinity and land use.

2.1 Climate

The Natural processes are related to climate in the Khulna Division. There are 4 seasons acting on a yearly timescale in Bangladesh: winter (December-February), pre-monsoon (March-May), monsoon (June-early October) and post monsoon (late October-November) (Shaw, Mallick & Islam, 2013). In general, salinity is highest in winter. In winter, river water becomes more saline due to a decrease in precipitation, which intensifies the effect of seawater. Salinity of the soil increases due to flooding and seepage from rivers. Next, evaporation leads to an intensification of the salt concentration in soils and groundwater (Haque, 2006). On a larger timescale, Khan et al (2015) depicted another mechanism that can lead to salinization. They found that salinity intrusion increases with the occurrence of natural disasters, such as cyclones. So, climate affects salinity both through seasonality and through the occurrence of natural disasters.

2.2 Land use

Land use in the Khulna Division has changed over time. There is competition between land uses, because amount of land is limited. There are roughly 4 land use types: settlements, agriculture (mainly rice fields), aquaculture and forests (Hasan et al, 2013). Typical for food production in Bangladesh is the use of enclosed areas characterized by an encirclement of land along banks by tidal rivers, where water flow is controlled by sluices (Karim, 2006).

It is hypothesized that land use affects salinity. Shrimp farms and, thus, aquaculture is associated with an increase in salinity through 2 mechanisms. Firstly, there is an increase of soil salinity due to inundation with saline water. Shrimp farms require a change of pond water every 1 to 6 days, depending on the farming practices. Pond water is recharged and discharged by river water (Paul & Vogl, 2011). The water used for shrimps is saline as shrimps are often farmed at salt concentrations of 10-35 parts per thousand (ppt). These salinity levels are needed as otherwise freshwater algae growth is not inhibited and, hence, shrimp development is slowed down (Deb, 1998; Flaherty, Vandergeest & Miller, 1999). So, as pond water is saline, shrimp farms are hypothesized to increase soil salinity due to prolonged trapping of saline river water (Ali, 2006). Next to controlled flooding, soil salinity is also affected through uncontrolled flooding causing inundation with saline water (Ahmed, Allison & Muir, 2010; Kartiki, 2011; Salam et al, 2003). Secondly, there is an effect due to an increase in groundwater use. This increase in groundwater use leads to a drop of the water table, which in turn leads to a salinity flux into the aquifer (Islam, 2003; Paul & Vogl, 2011).

No effects of rice farms on salinity were found other than rice being reclamative for sodic soils (Tho et al, 2008). However, salinity is found to negatively affect tradition rice species yield with values above 4 ppt, but salt tolerant crops can cope with higher salinity levels of 8-9 ppt (Ali, 2006; Boland, Ziehrl & Beaumont, 2002; Islam & Gregorio, 2013). If salinity levels are high, rice yield is affected by reduced growth of seedlings, reduced seed yield, increased susceptibility to insect pests and stress in growth, biomass and chemical composition of rice plants (Flaherty et al, 1999).

2.3 Other effects

There are some other effects next to the climatic and land use effects on and from salinity. Geology and clay layer thickness influences groundwater flow and, hence, salinity and how salinity differs spatially (Ayers et al, 2016). The Farakka Barrage in India influences the discharge through the Ganges and, therefore, it also influences salinity (Islam & Guchhait, 2017). A conceptual model of what affects salinity and land use is given in figure 1.

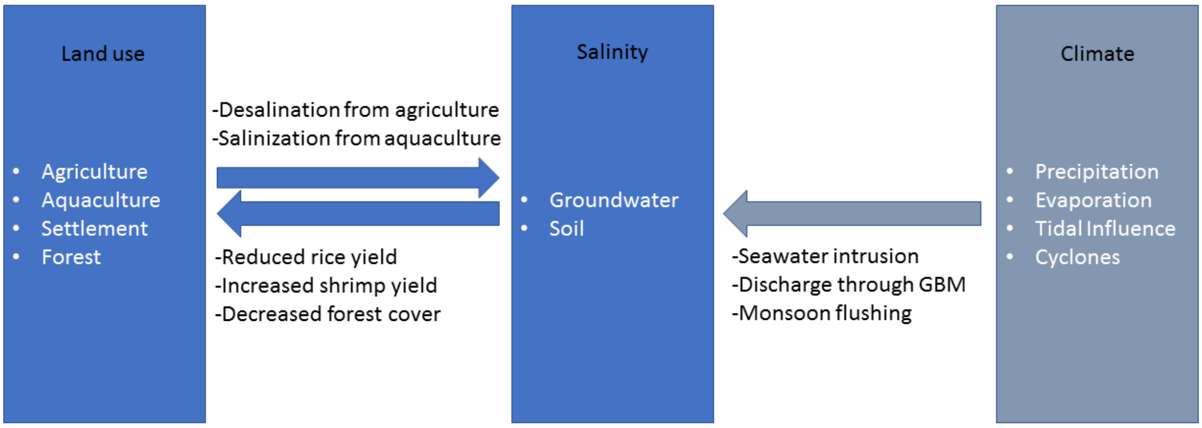


Figure 1 A conceptual model of the factors affecting land use and salinity in the Khulna Division, with in dark blue the factors of interest for this study.

2.4 Spatial scale

It is shown in figure 1 that salinity and land use are likely to be interacting with each other, but it is not clear on what spatial scale this happens. Karim (2006) found that aquaculture affected vegetation, whereas for example trees on dykes disappeared over time due to salinity. He found that aquaculture was located closer to homestead areas in 1999 than in 1975 and 1995. In 1999, 46% of aquaculture was within 10 m of a homestead area, 24% was within 10-24m and 16% was within 25-50m of homestead area. So, in 1999 85% of aquaculture was located within 50m of homestead area and caused problems with decreased vegetative cover. Also, more regional effects are in place, which are driven by a drop in the water table due to increased groundwater pumping, but also by inundation and seepage (Paul & Vogl, 2011; Rahman et al, 2011). However, this last process will be slow as there is a clay layer of 3-25m in the subsurface confining the aquifer (Ayers et al, 2016).

2.5 Hypotheses

From the theory the following hypotheses were drafted, where point 1 correspondents with sub-question 1, point 2 with sub-question 2, point 3 and 4 with sub-question 3 and point 5 with sub-question 4:

1. If aquaculture is an emerging sector then aquaculture will have a lower age than rice.
2. If the seawater drives salinity then salinity will increase with latitude.
3. If rice farms do not affect groundwater and soil salinity, then groundwater and soil near rice farms is generally fresh or less saline then under aquaculture.
4. If aquaculture causes salinization due to salinity input of at aquaculture areas being larger than the monsoon flushing capacity, then at aquaculture areas salinity would increase with the age of aquaculture.
5. If aquaculture needs higher salinity levels than rice farms, then aquaculture is located at lower elevations than rice farms.

3. Methods

3.1 Study area

The Research area is located in Southwestern Bangladesh in the districts of Khulna, Sathkira and Bagerhat; North of the Sundarbans and south of Khulna City (see figure 2). Elevation in the research area is less than 10m, whereas most places in Khulna Division have an elevation of around 1m above sea level (Awal, 2014).

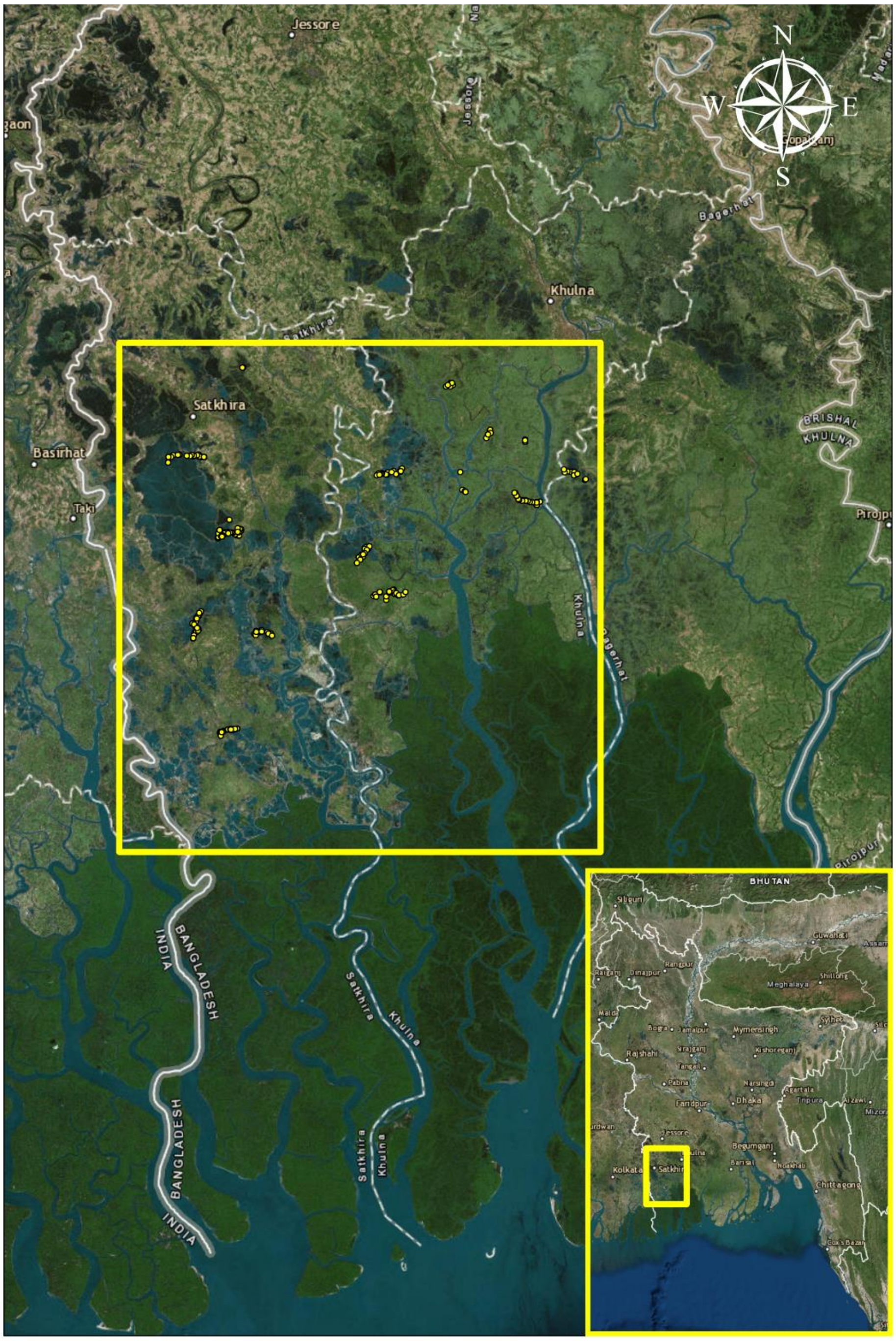


Figure 2 Study area with the sampling locations in yellow.

3.2 Data collection

Data was collected both in the field and from the United States Geological Survey (USGS) for remote sensing.

3.2.1 On-site collection

Data was collected on salinity, management practices and history of a parcel of land. Data on salinity was retrieved in the topsoil, in the surface water, at the water table and in the shallow aquifers or aquifers which are being used for irrigation. The samples were collected at different sites, whereas sites were chosen based on the following criteria:

- Both rice and aquaculture should be present in the area. 3 types of areas are to be visited: mainly rice, mainly aquaculture and combined rice and aquaculture areas.
- There should be difference in elevation.
- The whole research area should be addressed.

From the above criteria, 8 Sampling locations where found in Sathkira district, 5 sampling locations in Khulna district and 1 sampling location at the western border of Bagerhat district, whereas the samples preferably were taken at the border between rice and aquaculture (see appendix 1 - sampling locations, see figure 2).

72 soil samples were taken from the topsoil, 73 water samples from boreholes and 115 samples were taken from the aquifers. The EC has been measured for all the above sample types, however different methods have been used. The surface water, borehole water and the aquifer sample were all measured with an EC-meter. The borehole water and the surface water were directly measured after collecting the water, whereas this was not the case for water from the aquifer. The wells, which were used to retrieve water from the aquifer, were used by the local population. Therefore, the method proposed by Appelo & Postma (2004), which required pumping for some time, was not deemed necessary as the local inhabitants already pumped water from the aquifer before. Alternatively, the well water was pumped until the temperature resembled the temperature of the aquifer. Next, the EC was measured. The EC of the soil was taken, by dissolving a core sample of the topsoil with demineralized water in a 1:4, weight based, solution. The mixture was shaken for a minute and afterwards EC has been measured with an EC-meter, giving a relative EC (FAO, 2005; Rhoades, Chanduvi & Lesch, 1999).

Next to the EC, water samples have been taken from the borehole and the aquifer to obtain chloride values using ion chromatography. The chloride concentrations were taken, because EC is not solely dependent on the chloride concentration, but depends also on temperature, mobility, valences and relative concentrations of the individual ions comprising the solution. Furthermore, the EC can be misleading, because not all ions will be existing as a charged –species due to ions bonding (Appello & Postma, 2004; Peinado-Gueveira et al, 2012; Rhoades et al, 1999).

Lastly, 106 surveys have been taken to get insights in the management processes and history of a parcel of land. This survey included questions on land use practice, historic land use, reasons to switch between land uses, dyke failure and water sources (See Appendix 2 - Survey).

3.2.2 Remote sensing

Next to the on-site data collection, data was also retrieved using satellite imagery. Data is obtained in December 2016 and February 2017. Data from Landsat 8, which has a 30m resolution, has been retrieved from the USGS website, whereas data was selected if the following requirements were satisfied (Barsi et al, 2014; Roy et al, 2014; USGS, nd; Zanter, 2016):

- Image is of tier 1 quality (RMSE<12 m), making it suitable for time-series progressing.
- Image has less than 10% cloud cover.
- Image should have as little disturbance as possible, according to the quality assessment band.

Lastly, data on elevation was retrieved using the Shuttle Radar Topography mission (SRTM) images from NASA. The SRTM uses synthetic aperture radar interferometry to measure digital topography with a 30m pixel size and has an accuracy of 16m absolute and 11m relative (Van Zyl, 2001).

3.3 Data analysis

3.3.1 Land use patterns

A land use/land cover (LULC) map was drafted in order to confirm or reject the following hypotheses:

- If aquaculture is an emerging sector then aquaculture will have a lower age than rice.
- If aquaculture needs higher salinity levels than rice farms, then aquaculture is located at lower elevations than rice farms.

Remote sensing was used to make the land use/land cover (LULC) maps. Here remote sensing can be defined as the practice of deriving information about the Earth's surface using electromagnetic radiation reflected or emitted by the earth (Campbell & Wynne, 2011). Landsat 8 was used for remote sensing, which has 11 spectral bands (see table 1). Data was retrieved for bands 2 to 7 as these proved to be most efficient for land use classification. The data was not converted from digital numbers to physical units as the research area is small and located within one Landsat image (row: 138, Path: 44). The conversion to physical units is not necessary as this is a linear relation and the slope and intercept of the conversion formula will be the same for each pixel as only one Landsat image was used for one LULC (Mishra et al, 2014; Roy et al, 2014).

Band	Description	Wavelength (µm)
1	Blue	0,43-0,45
2	Blue	0,45-0,51
3	Green	0,53-0,59
4	Red	0,64-0,67
5	Near infrared	0,85-0,88
6	Shortwave infrared	1,57-1,65
7	Shortwave infrared	2,11-2,29
8	Panchromatic	0,50-0,68
9	Cirrus	1,36-1,38
10	Thermal infrared	10,60-11,19
11	Thermal infrared	11,50-12,51

Table 1 An overview of the spectral bands of Landsat 8. Adapted from Roy et al (2014).

Several methods for processing remote sensing data into land use maps are proposed in literature (Khan et al, 2015; Mundia & Aniya, 2005; Salam et al, 2003; Rozenstein & Karnielli, 2011). Jia et al (2014) found that a supervised classification scheme obtains sufficient results. Images are trained when performing a supervised classification method in contrary to an unsupervised classification method. Supervised classification methods use these training samples to create threshold values for specific land cover types. However, supervised methods require prior knowledge on land use before classification (Mohammady et al, 2015; Phiri & Morgenroth, 2017). The most likelihood classification (MLC) algorithm is often used when performing a supervised classification. The MLC method depends on the probability of a cell belonging to a certain class based on the researchers input classes and the values depicted in each spectral band (Rawat & Kumar, 2015). However, there are also drawbacks, where this method relies on a Gaussian distribution of the bands and signatures with relatively large values in the covariance matrix tend to be over-classified (Dewan & Yamaguchi, 2009; Rawat & Kumar, 2015). The MLC method is still used for this study, due to its ease of use, its accuracy and the fact that it proved to be efficient in Bangladesh when Dewan & Yamaguchi (2009) acquired an accuracy of 85 to 90% for Landsat-derived land use maps in greater Dhaka, whilst using this method.

LULC maps were drafted based on Landsat data from December 2016 and February 2017 for the data analysis and an initial LULC map was made based on data from February 2017 to identify study areas. Here land use is defined as: The different human practices on a parcel of land. I.e.: rice farms, shrimp farms and urban land (Fisher, Comber & Wadsworth, 2005). Where land cover is determined by direct observations and does not necessarily relate to human activities. I.e.: grassland, wetland, rivers and forests (Fisher et al, 2005).

LULC categories had to be drafted before starting with the MLC. Several land use types were used by other authors conducting a remote sensing project in the research area and these categories were used to obtain the initial LULC map (see table 2). Survey and on-site observations were used to obtain the different LULC classes to make the LULC map for analyzation (see table 2). For the latter map, the start of December 2016 was taken as a proxy for land use in the monsoon time as it was not possible to retrieve any good Landsat data during the monsoon time. It was assumed that the Landsat images were still a good proxy for monsoon type rice as these were taken at the end of the harvesting season. Furthermore, the data on February 2017 was used to make a LULC map for the dry season (Abedin, Feldmann & Meharg, 2002).

LULC classes for initial mapping	LULC mapping for data analysis	Description
Homestead	Homestead	Settlements and forests
Aquaculture	Aquaculture	Year round fisheries
Rice	Rice	Year round rice fields (1 or 2 cycle)
River	River	River
Mangrove	Mangrove	Sundarbans
	Combined rice & aquaculture	Areas where rice is cultivated in one season and fisheries are present in another season

Table 2 An overview of the different LULC classes.

Data from surveys held in the field were used to locate the different land use types during the year. The output of these surveys was used for the signature file of the MLC and for validating the land use maps. However, if a survey was used for the signature file then it was not used for the validation. This resulted in 2 LULC maps. The accuracy of both maps was calculated by comparing the survey data with the land use map, whereas the land use map was considered good for a point if it reflects the actual land use or if the actual land use is reflected within 2 pixels of the survey as there will be a bias in the location of the survey. Next, a kappa coefficient was calculated, and the land use map with the highest accuracy and kappa coefficient was taken as the basemap (Giri, 2012). Lastly, another land use type was identified from the surveys being the combined rice & aquaculture land use type, where different land uses are practiced during the year. For this reason, the land use map of December 2016 and February 2017, were compared and a location was marked as combined rice & aquaculture if rice was found in one map and aquaculture in the other. The locations of this land use, was incorporated in the basemap to yield a land use map of the research area. Lastly, small parcels were removed for smoothing purposes. This basemap was used to give an overview of the locations of land use in the region and it was used as input for identifying the relation between land use and elevation. Furthermore, the survey data was used to identify how land use changed over time.

3.3.2 Salinity & land use

For sub question 2 & 3 similar methods have been used and, therefore, these two sub-questions are taken together in the methods. The following hypotheses were tested to answer sub-question 2 & 3:

- If the seawater drives salinity then salinity will increase with latitude.
- If rice farms do not affect groundwater and soil salinity, then groundwater and soil near rice farms is generally fresh or less saline then under aquaculture.
- If aquaculture cause salinization due to salinity input of the aquaculture being larger than the monsoon flushing capacity, then at aquaculture areas salinity would increase with the age of aquaculture.

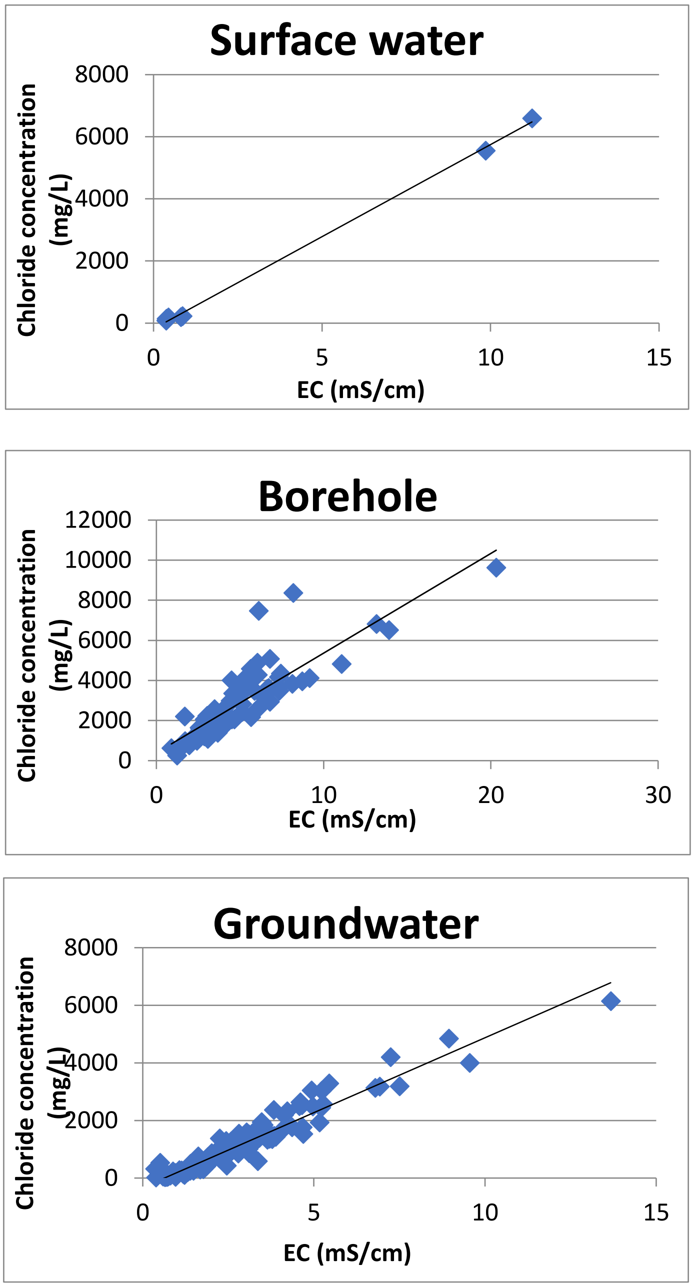
This section will first explain the statistical methodology and afterwards it will show the variables which have been used for analysis. A t-test was used to test the hypotheses and determine if average values between the salinity at different location of different land uses differed statistically. When running the T-test 2 assumptions had to be made (De Winter, 2013):

1. The sampling population is normally distributed.
2. Two populations should have the equal variances.

Before the T-test was run an F-test was performed to find out if the second assumption holds. For the F-test it is assumed that there is independence of observations, normality of the population and homogeneity of the population variances (Lix, Keselman & Keselman, 1996). If the second assumption did not hold then an alternative version of the T-test was performed (Ruxton, 2006). Lastly, for the T-test a 95% confidence interval (CI) was considered.

3.3.2.1 Electrical conductivity & Chloride concentrations

In the preliminary analysis the EC was used as a proxy for salinity. Next, the chloride concentrations were analyzed. The EC was compared to the chloride concentration for each type of sample to validate using EC as a proxy for salinity. A trend line was fitted through the data and the R-squared value was computed. The significance levels were calculated. From this it was believed that the EC of the borehole had a low R-squared value of 0,74, whilst for the surface water and groundwater higher R-squared values were present (See figure 3). The chloride data of the surface water was not used furthermore as there was little data available and the chloride data related linearly with the EC. No chloride values were available for the topsoil solution, so also for this variable the EC data was used for analysis. The chloride concentrations were used for the borehole data as this data had the worst fit with the EC. Lastly the chloride values from the groundwater wells were also analyzed.



	Surface water	Borehole	Groundwater
Trendline	592,9x - 180,48	497,42x + 389,62	520,24x - 329,7
R-squared	0,9986	0,7361	0,9298

	Surface water	Borehole	Groundwater
Trendline	592,9x - 180,48	494,8x + 410,1	520,24x - 329,7
R-squared	0,9986	0,7310	0,9298
P-value (slope)	<0,01	<0,01	<0,01
P-value (Intercept)	<0,07	0,07	<0,01

Figure 3 Linear regression for EC and Chloride concentrations in different water sources. Some more details of the data and the statistics are given in the tables at the right

This process of performing T-tests was repeated numerical times, whereas for each T-test different variables where chosen. The variables that were used for each hypothesis are summarized in table 3.

Hypothesis	Variables
If the seawater drives salinity then salinity will increase with latitude.	Longitude, latitude, EC of the surface water, EC of the topsoil solution, EC and chloride concentrations of the borehole and EC and chloride concentrations of the aquifer.
If rice farms do not affect groundwater and soil salinity, then groundwater and soil near rice farms is generally fresh or less saline then under aquaculture.	Longitude, latitude, EC of the topsoil solution, EC and chloride concentrations of the borehole, EC and chloride concentrations of the aquifer and land use.
If aquaculture causes salinization due to salinity input of at aquaculture areas being larger than the monsoon flushing capacity, then at aquaculture_areas salinity would increase with the age of aquaculture.	Farming duration and the chloride concentration of the borehole, the groundwater well and EC of the topsoil solution.

Table 3 The hypotheses for sub-question 2 & 3 and the variables which are being used for each hypothesis.

3.3.3 Land use & elevation

To identify the relation between land use and elevation the following hypothesis was drafted in the theory chapter: If aquaculture needs higher salinity levels than rice farms, then aquaculture is located at lower elevations than rice farms. Data on elevation should be linked to land use in order to confirm or reject this hypothesis. The SRTM image was used to obtain data on elevation (Van Zyl, 2011). The land use map was split in three new maps; the first map showed the locations of aquaculture by reflecting aquaculture with the value 1 and all other land uses with the value 0, the second map did the same for combined rice & aquaculture, whilst the third considered rice. These maps were multiplied with the SRTM image, resulting in an image with the elevations of each land use for food production. The average, median, lowest and highest 25% percentiles were calculated and from this a view was formed on the relationship between land use & elevation. Lastly, a set of T-tests was carried out to test for significance of the results.

4. Results

4.1 Land use

Regional land use can be divided into 4 land use classes: homestead, aquaculture, rice and combined rice and aquaculture. A LULC map was made with Landsat data retrieved from December 2016 and February 2017 with 30m resolution.

The land use map of December 2016 was drafted using 50 different areas, including river, homestead and mangrove areas, in the signature file and the validation of the map was calculated using the 87 surveys which were not used for making the basemap, of which 44 samples belonged to the aquaculture type, 8 belonged to the combined rice & aquaculture type and 35 belonged to the rice type. With this data an accuracy of 81% and a kappa coefficient of 0,66 were calculated. The land use map based on February 2017 was drafted using 55 different areas, including river, homestead and mangrove areas, in the signature file and the accuracy and kappa coefficient was calculated using the 91 surveys not used for the signature file. 48 samples were of the aquaculture type, 5 were of the combined rice & aquaculture type and 38 were of the rice type. The basemap for the dry season had an accuracy of 77% and a kappa coefficient of 0,58.

The map of December 2016 was taken as the basemap as both the accuracy and kappa coefficient were higher compared to the map of February 2017. However, the combined rice & aquaculture land use class was still not incorporated in the map. So, both maps were combined to map land cover changes over between two seasons and to identify the locations of the combined rice & aquaculture class. This class was incorporated in the basemap of December 2016 to retrieve the final land use map (see figure 4). From this map it was calculated that aquaculture covered 47% of the lands for food production, rice covered 33% and combined rice and aquaculture covered 20%.

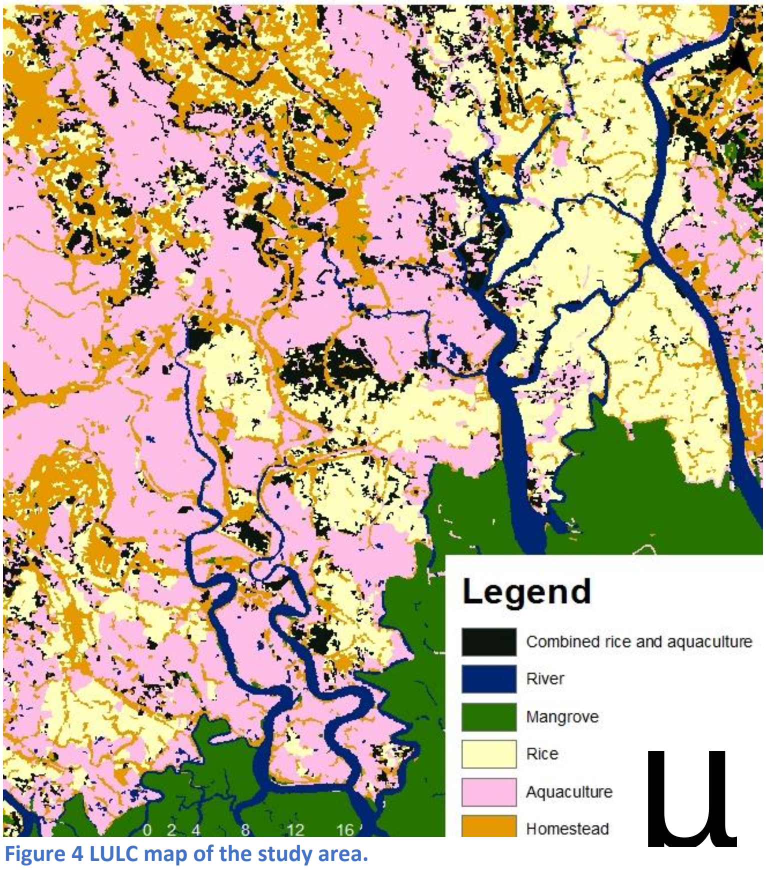


Figure 4 LULC map of the study area.

From the survey it was found that the combined aquaculture and rice land use is on average practiced north to aquaculture and the combined rice & aquaculture land use is practiced in between aquaculture and rice. Also, on average combined rice & aquaculture is practiced east to rice and aquaculture. However, for both the latitude and longitude there was no significant difference to be found (see table 4).

Latitude	Mean	Standard deviation	Observations	Categories T-test	P-value
Rice	22,60	0,12	43	Rice against aquaculture	0,15
Aquaculture	22,57	0,09	57	Rice against combined rice & aquaculture	0,30
Combined rice & aquaculture	22,58	0,09	32	Combined rice & aquaculture against aquaculture	0,74

Longitude	Mean	Standard deviation	Observations	Categories T-test	P-value
Rice	89,27	0,19	43	Rice against aquaculture	0,87
Aquaculture	89,27	0,18	57	Rice against combined rice & aquaculture	0,78
Combined rice & aquaculture	89,28	0,15	32	Combined rice & aquaculture against aquaculture	0,90

Table 4 An overview of the T-tests results for the relation between land use and location with at the top the results for latitude and at the bottom the results for longitude.

Lastly, from the surveys it is evident that in the past aquaculture was not an important land use. There were 38 parcels of land which made a change of land use. 68% of those parcels switched from rice to aquaculture or combined aquaculture and rice. 18% switched from 1-cycle rice farming to 2 cycle rice farming. 8% changed from aquaculture to rice or combined aquaculture and rice. Lastly, 5% switched from any other type of land use than the defined land uses categories to aquaculture. This has been a gradual change, whereas the first parcel changed 50 years ago and the last parcel changed last year. When applying linear regression, it was found that for both aquaculture and combined rice & aquaculture age increased with latitude, age decreased with latitude for rice. However, the slope of the different curves did not fall within the 95% CI. The slope was only significantly different from 0 for rice farms, whereas an age of more than 60 years was neglected (see table 5).

Land use	Slope (year/degree)	P-value
Rice	-123	0,10
Rice (age < 60 years)	-104	0,01
Aquaculture	40,2	0,26
Combined rice & aquaculture	87,9	0,15

Table 5 the relation between age of a land use type and latitude.

4.2 Groundwater and soil salinity

On average EC of the borehole was 5,4 mS/cm with a standard deviation of 3,3 mS/cm. The deeper groundwater had a mean of 3,0 mS/cm with a standard deviation of 2,63mS/cm. Whereas, the water in the borehole has a significantly higher EC than the deeper groundwater. Next, if all 4 sample types are compared to each other, then it is seen that only for the topsoil there is no significant trend with latitude when linear regression is performed. The same regression was performed for the chloride concentrations and with this data the slope of the salinity of the borehole was no longer significant (see table 6).

Latitude	Slope EC	P-value EC	Slope Cl	P-value Cl
Surface water	-8,07852	<0,01	N.A.	N.A.
Topsoil	-0,04481	0,85	N.A.	N.A.
Borehole	-19,9575	<0,01	-1394	0,44
Groundwater well	-8,7979	<0,01	-2834	<0,01

Table 6 An overview of the results from linear regression with its calculated slope and p-value of the slope for the different sample types.

4.3 Salinity & land use

4.3.1 Salinity and land use

4.3.1.2 Electrical conductivity

Firstly, the EC is compared with the land uses, whereas the water in the pond itself will be most important with respect to fish or crop growth, hence surface water was compared for the land uses. The EC of different ponds were compared and it was found that salinity in the ponds used for aquaculture was highest and differed significantly from the other two land use types in which the EC of water in the rice fields was lowest. However, there is overlap in the EC value between different land uses and the difference between rice and combined rice & aquaculture did not prove to be significant.

Secondly, the topsoil was considered and from the relative EC of the topsoil aquaculture was the most saline and rice the least saline land use. However, the difference between aquaculture and combined rice & aquaculture did not fall within the 95% confidence interval.

Thirdly, the borehole data showed that rice had a lower EC than the two other land use classes, whereas the difference between aquaculture and combined rice & aquaculture was to be neglected. Although the difference in mean EC did fell within the 95% confidence interval for rice and aquaculture, if rice was compared to combined rice & aquaculture then it did not fall within the 95% CI.

Fourthly, the groundwater wells were analyzed and it was found that combined rice & aquaculture was the least saline, whereas there was a significant difference found between rice and combined rice & aquaculture. For an overview of the results described above see figure 5 and table 7.

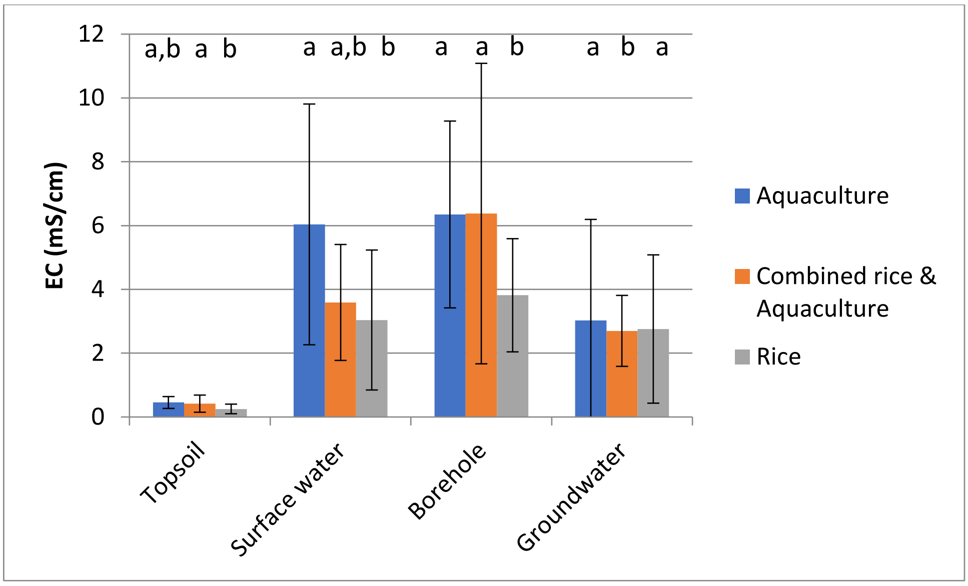


Figure 5 An overview of the differences in EC for each water source per land use type. The standard deviation is used for the error bars, whereas the letters show differences or similarities in standard deviations.

Observations	Topsoil	Surface	Borehole	Groundwater
P-value	**Topsoil**	**Surface**	**Borehole**	**Groundwater**
Rice against aquaculture	<0,01	<0,01	<0,01	0,59
Rice against combined rice & aquaculture	0,36	0,53	0,07	<0,01
Combined rice & aquaculture against aquaculture	0,05	0,02	0,98	0,08

Table 7 Basic statistics following for the differences in EC for each water source per land use.

4.3.2.2 Chloride concentrations

Next, the chloride data was used for analyzation. It is found that on average the rice fields have lower chloride content than the combined aquaculture and rice and the aquaculture land use for the borehole data. This difference also proved to be significant. However, there is no significant difference between aquaculture and combined aquaculture and rice. When using the chloride concentration of the groundwater well, there was no real relation found, except that the range chloride concentrations for the combined rice and aquaculture LU type was lowest (see figure 6 and table 8).

In addition, the chloride content of different rice regimes, i.e. 1 and 2 cycle rice were compared for the borehole. It was found that 2-cycle rice had significant lower chloride levels, which also proved to be significant as a p-value of less than 0,01 was found.

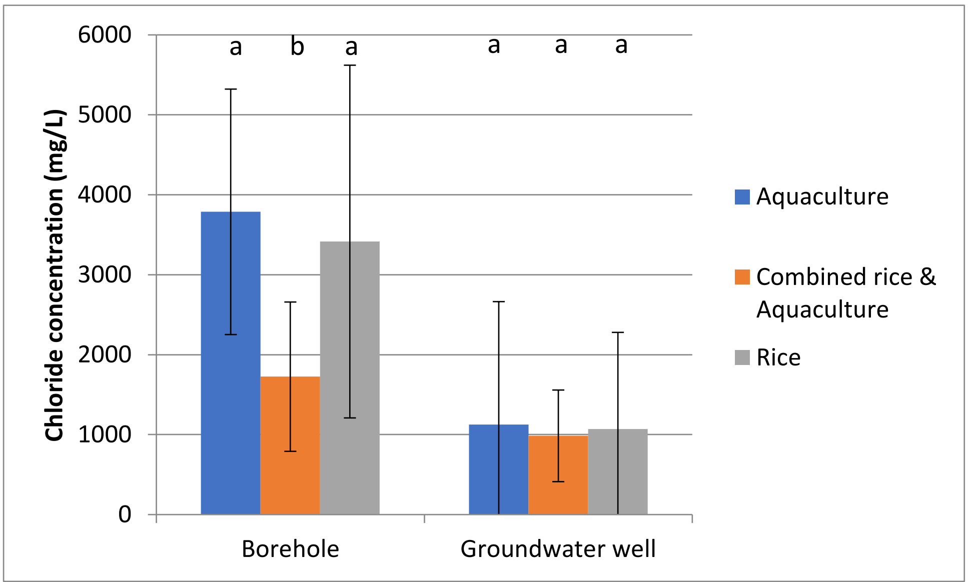


Figure 6 An overview of the differences in chloride concentrations for the groundwater wells and borehole per land use type. The standard deviation is used for the error bars, whereas the letters show differences or similarities in standard deviations.

P-value	Borehole	Groundwater well
Rice against aquaculture	<0,01	0,90
Rice against combined rice & aquaculture	<0,01	0,77
Combined rice & aquaculture against aquaculture	0,53	0,73
Observations	**Borehole**	**Groundwater well**
Rice	25	22
Aquaculture	25	17
Combined rice & aquaculture	20	16

Table 8 Basic statistics for the differences in chloride concentrations for groundwater wells and boreholes per land use.

4.3.2 Farming duration and salinity

The last parameter that was analyzed was the age of a farm. However, for both the EC and the chloride concentration no significant different or trend was found. A linear regression was performed for chloride concentrations of the borehole and the EC of the topsoil solution with age (see table 9). The variables surface water was not taken into account as it was not that this variable is dependent on farming duration and the variable groundwater was not taken into account as no differences in groundwater salinity for the different land uses were found previously.

	Cl borehole		EC topsoil	
	Slope	P-value	Slope	P-value
Rice	6,622611	0,062293	-0,0008	0,77
Aquaculture	-6,70023	0,81418	0,0045	0,14
Combined rice & aquaculture	-14,1774	0,685675	0	0,95

Table 9 An overview of the linear regression for land use and age of a farm.

4.4 Land use & elevation

Elevation is displayed by the SRTM image. It was found that aquaculture had the lowest average elevation and rice had the highest elevation when the SRTM image is compared with the landuse image. In addition a T-test was performed and it was found that the average elevation of all three the land use types differed significantly from the elevations of the other land use types (see table 10).

Land use	Average elevation (m)	Lowest 25% percentile (m)	Median (m)	Highest 25% percentile (m)	Observations	Categories T-test	P-value
Rice	4.0	3	4	5	140693	Rice against combined rice & aquaculture	<0,01
Aquaculture	3.3	2	3	4	198353	Rice against aquaculture	<0,01
Combined rice & aquaculture	3.5	3	3	4	86711	Combined rice & aquaculture against aquaculture	<0,01

Table 10 An overview of the relationship between elevation and land use left and right the p-values of each T-test.

5 Discussion

This research aimed at identifying the relation between spatial land use, in particular aquaculture versus agriculture, and soil salinity. It was found that there has been a shift in land use and that salinity is spatially variable. I found that high salinity corresponds with aquaculture areas and low salinity with agriculture areas. High elevation correspondents with rice fields and low elevation correspondents with aquaculture. No relation was identified with farming duration. This is in line with the hypotheses, although questions remain on the severity of the problem. This discussion will first tackle the different sub-questions with its underlying hypotheses. Secondly, the limitations will be discussed and, lastly, the implications for the future will be discussed.

5.1 Sub-questions

5.1.1 What are the regional land use patterns and how did they change over time?

Regional land use is made up by homestead, rice, aquaculture and mixed rice and aquaculture areas with aquaculture being the most important land use in terms of area covered. No significant relation was found with respect to longitude and latitude. However, it is difficult to conclude that there is no relation between location and land use as the sampling locations were not chosen randomly. Salam et al, (2003) stated that shrimp farms were mostly located at places with high water availability and at places with high influences of neighboring shrimp farmers, indicating that aquaculture is clumped together close to rivers and not necessarily a function of longitude or latitude. Furthermore, a LULC was made which depicts the locations of the different land use classes.

I found that in the past more 1-cycle rice fields were present and that starting 50 years ago a shift was made towards aquaculture and 2-cycle rice farming. This is also in line with Hasan et al (2013) who concluded that shrimp farming emerged from the 1980s. Khan et al (2015) obtained similar results where for the period 1999-2012 aquaculture increased by 30% and agriculture decreased by 48% which is due to both anthropogenic and natural factors. However, Donchyts et al (2016) found that water bodies are being turned into land mass in the study areas. This implicates that either aquaculture is being transformed into rice fields or that new polders have been made in the past 30 years.

When the local farmers were asked why they changed their land use, the most frequently answered question was because of profit followed by too high or too low salinity. This implies that profit is the most important factor in determining if someone is a shrimp or rice farmer. However, salinity effects will influence the profit that a farmer makes. Lastly, other reasons can be decisive in choosing a certain farming activity; such as local agreements, food security, lack of knowledge and tradition. These results are in line with Ali (2006), who concluded that economic reasoning is the most important reason for a shift to shrimp farming as shrimp farming earns up to 9 times more than rice farming. On the other hand, Ali (2006) also concludes that local farmers are not true risk-takers as they are also consumers and need to ensure a certain subsistence, making it not only about profit. Other scholars concluded the high costs associated with aquaculture is a reason, besides profit, to not switch towards aquaculture, since Bangladesh is a poor country (Ahmed et al, 2010; Joliffe, 2013). This indicates that land use is determined by multiple factors.

5.1.2 How is shallow groundwater and soil salinity varying in space?

Borehole water was the most saline water source and the groundwater wells were the least saline. furthermore, I found that for both surface water and groundwater well water salinity decreased with latitude. For the borehole data the decrease in salinity with latitude was not significant for chloride concentrations and, hence, it cannot be proven that borehole salinity varies spatially. From literature it was hypothesized that salinity in the shallow aquifer is best explained by connate waters, whereas eustatic sea-level change plays an important role and that salinization of this groundwater can occur through over pumping for agricultural purposes (Worland et al, 2015). However, soil salinity is better explained by waterlogging during high tide in the polder area and inundation with saline water due to anthropological and natural effects, such as an increased area which is under aquaculture or cyclones (Khan et al, 2015). Literature does not provide with any data on salinity at the water table. However, as Haque (2006) concludes that the monsoon flushing capacity is not enough to flush away all salts, this could be an indicator for a downward flux of saline water.

When only taking the EC into account the slope of the relation between borehole water and latitude was significant, which implicates that the EC is a function of location but the chloride concentrations are not. As the EC shows the effect of all soluble ions, it is likely that another ion than chloride is varying in space. This is supported by the R-squared value of the borehole salinity which was low (~0,7). This difference in results for the EC and the chloride concentrations can possibly be explained by the facts that the boreholes were dug at different depths and in different soil types such as peat, whereas Fraser, Roulet & Lafleur (2001) stated that the concentrations of ions, such as calcium, varies with depth underneath a peat layer. Lastly the effect of rain on chloride concentrations or EC was believed to be negligible as all measurements were carried out in the dry season with average rainfall less then 100mm and no rainfall was present at any time during sampling (Mainuddin et al, 2015).

5.1.3 How do regional land use and salinity patterns correlate?

The third sub-question related land use to salinity. I found no significant relations for the groundwater wells between salinity and land use, but significant results were obtained when comparing the borehole and the topsoil salinity with land use. Rice was the least saline, where aquaculture and combined rice & aquaculture did not differ significantly from each other in the case of the borehole and the topsoil. Aquaculture was the most saline and rice and combined rice & aquaculture did not differ significantly from each other in the case of surface water. Similar results were depicted by others who concluded that shrimp cultivation leads to salinity intrusion and, hence, higher soil salinity for aquaculture (Ali, 2006; Rahman et al, 2011; Khan et al, 2015). This is an indicator for salinity determining land use.

Secondly, I found a difference between 1- and 2-cycle rice. Where 2-cycle rice salinity levels were much lower than for 1-cycle rice. Here only the salinity levels of 1-cycle rice will encounter yield losses in some areas due to high salinity (Hoang et al, 2016). However, as all the measurements were done in the dry season, 1-cycle rice will not be affected by the dry season salinity level, but it will be affected by the monsoon season salinity levels as 1-cycle rice is mainly cultivated during the monsoon in which salinity will diminish tremendously (Rahman, Khalil & Ahmed, 1995). The fact that 2-cycle rice farming has a much lower salinity than 1-cycle rice farming is an indicator that salinity is a main driver for a certain land use type and that 2-cycle rice is possibly not able to persist at locations where there is 1-cycle rice at present.

Thirdly, I did not identify a relationship between age and salinity. This would indicate that there is no effect of land use on salinity, that the research design is insufficient in proving the existence of a relationship or that other factors are more important in determining groundwater salinity at the water table (Bahar & Reza, 2010). Possibly too little samples were taken at farms that are not operating for many years as it will be likely that in the topsoil the effect of salinity due to inundation with saline water will be visible in the first few years after repeated inundation if monsoon flushing capacity proves not be sufficient in washing away salinity (Haque, 2006). However, for the borehole the age of the different farms used for this study should be in the right range if a flow of 1m year^{-1} is assumed for clay soils (Baram, Kurtzman & Dahan, 2012; Hendriks, 2010). This implicates that there is either no relation between age and groundwater salinity at the water table or that too little samples were taken.

Ali (2006) did, in contrary to this study, found that salinity of the soil increased due to shrimp farming with the largest increase in salinity occurring within the first five years after starting to farm, but afterwards an increase in salinity is still occurring implicating that the monsoon flushing capacity is not sufficient to counter salinization. Furthermore, Khan et al (2015) and Salam et al (2003) found an effect of shrimp farming on salinity. However, Salam et al (2003) also concluded that crop agriculture was not substantially affected by shrimp and crab culture, indicating there is no effect of land use on salinity. If age does not correlate with salinity it would implicate that there is no effect of land use on salinity.

Lastly, it is evident that rice yield is threatened due to high chloride concentrations. These chloride concentrations are on average 1,7g/l and for combined rice and aquaculture this value is 3,4 g/l in the borehole, whereas concentrations of 1,5 g/l can diminish rice yields with 10% and values of 3,5 g/l can diminish rice yields with 50% (Hoang et al, 2016). When measuring pond water salinity levels, the average value of a rice field was on average 3 mS/cm and for combined rice & aquaculture it was 3,6 mS/cm indicating that in some instances decreased rice yield can be an issue as an EC of 3.5 mS/cm corresponds with a 10% decrease in yield (Hoang et al, 2016).

5.1.4 Is elevation a reason for strong correlation with land use?

I found that elevation strongly correlates with land use, whereas rice is grown on the higher elevated land and aquaculture is practiced in the low-lying areas. Although it should be noted that the strong correlation might be misleading due to the large number of 425757 samples used for analyzing which can lead to an arbitrarily low P-value (Johnson, 1999). However, it was not believed that in this case an insignificant relation became a significant one solely due to the sample size, as other studies showed a similar correlation and it can be physically explained that rice is located at the higher elevated areas due to rice having a lower salinity tolerance than aquaculture which is exceeded at multiple locations in the study area (Hoang et al, 2016; Salam et al, 2003). This is an indicator for salinity being a determining factor for land use allocation.

5.1.5 Integration

The following hypotheses were drafted at the start of this thesis:

1. Aquaculture will have a lower age than rice
2. Salinity will decrease with latitude
3. If rice farms do not affect groundwater and soil salinity, then groundwater and soil near rice farms is generally fresh or less saline then under aquaculture.
4. If aquaculture causes salinization due to salinity input of at aquaculture areas being larger than the monsoon flushing capacity, then at aquaculture areas salinity would increase with the age of aquaculture.
5. If aquaculture needs higher salinity levels than rice farms, then aquaculture is located at lower elevations than rice farms.

Each hypothesis was discussed in the previous sections and overall it can be stated that hypotheses 1 and 5 can be confirmed, Hypotheses 2 and 3 can be partially confirmed and hypothesis 4 cannot be confirmed.

The question remains how land use interrelates with salinity in the study area. I found that land use and salinity are related to each other with respect to the salinity of the water at the water table, the salinity of the topsoil and the salinity of the surface water. However, no direction of the relation was identified.

Processes

Still uncertainties exist about the processes that are in play and how important these processes are. Hence, it is difficult to find out the direction of the relation. In the introduction and the theory several processes were mentioned:

1. Land use is determined by salinity, because rice and aquaculture have limits of salinity values they can cope with.
2. Salinity is increased, because of inundation with saline water from anthropogenic sources.
3. Salinity is increased, because of inundation with saline water due to climate factors.
4. Salinity is increased due to a salinity influx into the aquifer.
5. Present salinity is explained by historic geological processes rather than land use processes.
6. Salinity is increased, because of the Farakka Barrage.

I cannot conclude that one of these processes is the main driver for salinity from the results that I obtained, but I can only hypothesize that one driver might be more important than another. Land use can be determined partly by salinity, because it can be seen that salinity of rice field is lower than for aquaculture, but as there is overlap in the values this is not expected to be the only explanation for the relation between land use and salinity. The second and third process are similar to each other and it is difficult to conclude these are true as I would have expected to find a relation with the farming duration, however other studies did find a relation as mentioned before (Khan et al, 2015; Salam et al, 2003). I did not find a relation which can confirm the fourth process, but others did show a relation (Worland et al, 2015). The fifth process will hold truth to it as history will have set a certain salinity level as a baseline value (Worland et al, 2015). However, it cannot be concluded which part of salinity is a function of history and which part is explained by other processes. The last process cannot be confirmed or rejected as I did not have data on salinity before the Farakka Barrage and it also fell outside the scope of this research.

When looking at transferability of the knowledge of this thesis, one should keep in mind the site-specific circumstances. For example, combined rice and aquaculture are also practiced in the northern part of Bangladesh. Salinity will be less of an issue in these areas, because salinity levels are lower. However, land use studies can benefit from using a similar approach into making a land use map as similar types of land use are present (Gupta et al, 1998). It is better to transfer the knowledge of this study to other coastal areas within South East Asia which face similar threats, such as the Mekong Delta (Tho et al, 2008).

5.2 Future outlook

I found that land uses which are currently under aquaculture practice are less suitable for rice cultivation. It is expected that a further increase in aquaculture practice might lead to less suitable circumstances for rice cultivation (Haque, 2006). There is research being done in new saline resistant rice crops in Bangladesh to increase yield under saline circumstances which could be part of a solution to mitigate the effects of salinity (Islam & Gregorio, 2013). However, under climate change and if other research regarding the effects of shrimp farming proves to be true then an increase in salinity will enlarge the issues concerning rice yield and introducing more saline resistant rice crops will not be sufficient. Solutions into mitigating these effects could be to have separated areas of shrimp and rice cultivation, such that there is no inundation from shrimp ponds into adjacent fields. However, this would require a functioning market for individuals to acquire subsistence. Another solution could be to promote using less saline water, such as only using high tide water, increasing embankment strength such that inundation with saline water is reduced. Lastly, it can be aimed to let aquaculture take place at other more suitable places as proposed by Salam et al (2003).

For future policy it is of importance to know if land use change from rice to aquaculture can possibly be reversed. As I found that salinity at rice fields are lower than at aquaculture and that salinity levels of aquaculture are of such a high level that rice growth is inhibited (Hoang et al, 2016). It is likely that at least on a short time scale switching back from aquaculture to rice is not possible. The monsoon rain will be able to flush away salts if aquaculture practices are seized in the research area (Haque, 2006). However, question remains on how effective this will be and on how much time this will take.

Furthermore, problems could increase if the water flow from the Brahmaputra is negatively affected due to water management practices of upstream countries. This will have similar consequences as the damming of the Ganges, which led to an increase in salinity (Lovelle, 2016).

5.3 Limitations

Several limitations should be noted. Firstly, whilst processing the land use data into making a LULC map, it was considered good if within two pixels of a survey location the actual land use was shown by the LULC map, because there is a bias in the survey locations. It meant that it was assumed that the actual survey location was within 60m of the measured location as one pixel had 30m resolution. This also seems reasonable; due to the fact that the survey location was not held in the middle of a field and that a GPS receiver in a phone has a median uncertainty of 5 to 8.5m with a maximum uncertainty of 30m (Zandbergen & Barbeau, 2011). This should not prove to be a problem when showing the regional land use practices. However, when using this map for further calculation this bias might hamper the accuracy of the study. As there is a bias on pixel level in the LULC map, multiplying the LULC map with the elevation map gives insecurities at pixel level. Furthermore, an accuracy of the LULC map of ca. 80% was obtained which is good when comparing to other studies. However, an accuracy of 80% also implies that in 20% of the cases the elevation of a pixel was attributed to the wrong land use type for both LULC maps (Rozenstein & Karnieli, 2011).

Secondly, site selection is another variable which could compromise the reliability of the study as site selection was not random. Site selection was based on having an even distribution in land use, however this could mean that certain variables are over- or underrepresented in the dataset for making and validating the LULC map. For example, I found that agriculture was being transformed in aquaculture from the survey, however, Donchyts et al (2016) found that large areas of water were converted to into land. So, the study by Donchyts et al (2016) indicates that aquaculture is also being transformed back to agriculture. This difference in results could be attributed to the fact that I did not sample in any of the areas where water bodies were converted into land according to Donchyts et al (2016).

Thirdly, a note should be made based on the statistics used for this study. A T-test was used to test if variables were statistically different from each other. The T-test assumes normality of the population distribution. However, normality was not tested and was assumed to be the case as in reality non-normality of the population distribution scarcely affects the outcomes of the T-test (Zimmerman, 1987).

Fourthly, there could be a bias in the accuracy of salinity of the topsoil solution. As most of the topsoil is of a clayey soil type there are still some differences in soil type which could give a bias whilst using the EC of the topsoil solution as proxy for salinity. This bias might be present as clay soils are negatively charged and can therefore bind to free ions, whereas this is not the case for sandy soils (Corwin & Lesch, 2003; Theng, 1982). However, differences between soil types at the sampling locations were small and most samples were taken in a clayey soil. So, it is justified to use the relative EC of the solution in the study area of this study (FAO, 2005).

Lastly, as mentioned previously there are multiple variables which possibly explains land use. Water availability is one of these variables that might affect land use. From the surveys there was a variability between sources throughout the seasons and between land uses, however with the limited amount of data no analysis was done and a remote sensing analysis was not within the scope of the research as this would require data on very small spatial scale. Hence, further research is needed to address the relation between land use and water availability.

6. Conclusion

This thesis aimed at identifying the relation between land use and salinity in the Khulna Division, which translated in the following research question:

> *How do agriculture and aquaculture spatially interrelate to groundwater and soil salinity patterns within the Khulna division, Bangladesh?*

It can be concluded that there is a relation between salinity and land use, where aquaculture is located on average in the more saline areas and rice is located on average in the less saline areas. So, if salinity is low then it is more likely that a rice farm is present than aquaculture. However, for the salinity of the groundwater wells no relation was identified with land use. Lastly, it cannot be concluded that land use is affecting salinity or vice versa.

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Appendix 1- Sampling locations

Groundwater wells			Borehole			Topsoil			Surface water		
Name	**Lat**	**Lon**	**Name**	**Lat**	**Lon**	**Name**	**Lat**	**Lon**	**Name**	**Lat**	**Lon**
NA1	22.571	89.136	NAB1	22.57	89.134	NAB4	22.565	89.1124	NA10S	22.568	89.129
NA2	22.572	89.137	NAB2	22.566	89.134	NAB5	22.565	89.111	SA8S	22.453	89.164
NA3	22.574	89.137	NAB3	22.568	89.129	NAB6	22.565	89.1115	SA9S	22.451	89.164
NA4	22.574	89.136	SAB1	22.451	89.164	NAB7	22.567	89.1138	K14S	22.455	89.08
NA5	22.575	89.133	SA8S	22.453	89.164	NAB8	22.57	89.1185	K196	22.449	89.077
NA6	22.57	89.134	SA9S	22.451	89.164	NAB9	22.569	89.1184	Sy8S	22.327	89.11
NA7	22.568	89.129	SAB2	22.451	89.164	NAB10	22.57	89.1196	Ch15S	22.602	89.52
NA8	22.568	89.129	SAB1	22.451	89.164	NAB11	22.569	89.12			
NA9	22.567	89.129	SAB1	22.451	89.164	NAB12	22.568	89.1203			
NA11	22.569	89.127	SAB2	22.451	89.164	NAB13	22.569	89.1274			
NA12	22.569	89.126	StB1	22.661	89.075	StB1	22.661	89.0753			
NA13	22.57	89.124	KB1	22.469	89.082	StB2	22.66	89.0464			
NA14	22.569	89.122	KB2	22.469	89.08	KB3	22.459	89.0769			
NA15	22.57	89.119	KB3	22.459	89.077	KB4	22.46	89.0776			
NA16	22.57	89.117	KB4	22.46	89.078	KB5	22.458	89.0765			
NA17	22.568	89.116	KB5	22.458	89.076	KB6	22.467	89.0793			
NA18	22.566	89.113	KB6	22.467	89.079	SyB4	22.333	89.1235			
NA19	22.57	89.133	SyB1	22.333	89.124	SyB5	22.333	89.1234			
NA20	22.565	89.112	SyB2	22.333	89.124	SyB6	22.333	89.1256			
NA21	22.569	89.12	SyB3	22.332	89.114	SyB7	22.335	89.1269			
SA1	22.446	89.177	SyB4	22.333	89.123	SyB8	22.334	89.128			
SA2	22.447	89.156	SyB5	22.333	89.123	SyB9	22.334	89.1231			
SA3	22.451	89.156	SyB6	22.333	89.126	SyB10	22.334	89.123			
SA4	22.452	89.156	SyB7	22.335	89.127	SyB11	22.332	89.1135			
SA5	22.452	89.157	SyB8	22.334	89.128	PNB1	22.639	89.3258			
SA6	22.451	89.157	SyB9	22.334	89.123	PNB2	22.642	89.3271			
SA7	22.451	89.164	SyB10	22.334	89.123	PNB3	22.64	89.3214			
St1	22.66	89.088	PNB1	22.639	89.326	PNB4	22.639	89.3162			
St2	22.66	89.086	PNB2	22.642	89.327	PNB5	22.643	89.3341			
St3	22.66	89.085	PNB3	22.64	89.321	PNB6	22.639	89.3375			
St4	22.66	89.083	PNB4	22.639	89.316	PB1	22.547	89.2975			
St5	22.662	89.08	PNB5	22.643	89.334	PB2	22.55	89.297			
St6	22.661	89.076	PNB6	22.639	89.338	PB3	22.549	89.2996			
St7	22.662	89.073	PB1	22.547	89.297	PB4	22.544	89.2952			
St8	22.661	89.071	PB2	22.55	89.297	PB5	22.537	89.2912			
St9	22.661	89.067	PB3	22.549	89.3	PB6	22.533	89.287			
St10	22.663	89.057	PB4	22.544	89.295	PB7	22.545	89.297			
St11	22.66	89.089	PB5	22.537	89.291	PB8	22.545	89.2969			
St12	22.66	89.046	PB6	22.533	89.287	PSB1	22.499	89.3294			
St13	22.66	89.043	PB7	22.545	89.297	PSB2	22.499	89.3293			
St14	22.653	89.042	PB8	22.545	89.297	PSB3	22.501	89.3335			

St15	22.662	89.055
K1	22.466	89.079
K2	22.464	89.079
K3	22.464	89.079
K4	22.462	89.078
K5	22.459	89.076
K6	22.458	89.078
K7	22.456	89.079
K8	22.454	89.08
K9	22.448	89.076
K10	22.443	89.075
K11	22.456	89.08
K12	22.455	89.08
K13	22.455	89.08
K15	22.453	89.081
K16	22.452	89.08
K17	22.45	89.079
K20	22.446	89.076
K21	22.443	89.075
K24	22.467	89.079
K25	22.455	89.08
K26	22.455	89.082
K27	22.453	89.082
K28	22.452	89.081
K29	22.467	89.08
K30	22.46	89.076
K31	22.455	89.08
Sy1	22.33	89.11
Sy2	22.331	89.111
Sy5	22.334	89.129
Sy7	22.327	89.11
Sy9	22.326	89.111
Sy10	22.331	89.112
Sy11	22.331	89.113
Sy12	22.334	89.124
Sy13	22.331	89.112
PN1	22.639	89.326
PN2	22.639	89.325
PN3	22.641	89.32
PN4	22.64	89.319
PN5	22.64	89.317
PN6	22.641	89.315
PN7	22.638	89.313
PN8	22.642	89.332
PN9	22.643	89.344
PN10	22.642	89.343

PSB1	22.499	89.329
PSB2	22.499	89.329
PSB3	22.501	89.333
PSB4	22.496	89.337
PSB5	22.494	89.341
CHB1	22.608	89.506
CHB2	22.608	89.501
CHB3	22.609	89.497
CHB4	22.613	89.494
CHB5	22.616	89.493
AUB1	22.691	89.459
AUB2	22.693	89.46
AUB3	22.688	89.46
AUB4	22.682	89.455
P22B1	22.621	89.423
P22B2	22.619	89.427
P22B3	22.618	89.428
BB1	22.681	89.505
BB2	22.678	89.505
MB1	22.642	89.564
MB2	22.642	89.56
MB3	22.643	89.56
MB4	22.642	89.556
MB5	22.645	89.555
MB6	22.642	89.568
MB7	22.642	89.568
MB8	22.638	89.568
MB9	22.64	89.573
MB11	22.633	89.583
NKB1	22.746	89.411
NKB2	22.748	89.408
NKB3	22.744	89.405
NKB4	22.744	89.402
NKB5	22.744	89.408
NKB6	22.748	89.41

PSB4	22.496	89.3368
PSB5	22.494	89.3409
CHB3	22.609	89.4974
CHB4	22.613	89.4941
CHB5	22.616	89.4927
AUB1	22.691	89.4591
AUB2	22.693	89.4596
AUB3	22.688	89.4604
AUB4	22.682	89.4546
P22B1	22.621	89.4234
P22B2	22.619	89.4266
P22B3	22.618	89.4275
BB1	22.681	89.5048
BB2	22.678	89.5049
MB1	22.642	89.5639
MB2	22.642	89.5597
MB3	22.643	89.5597
MB4	22.642	89.5561
MB5	22.645	89.555
MB6	22.642	89.5682
MB7	22.642	89.5682
MB8	22.638	89.5681
MB9	22.64	89.5728
MB10	22.632	89.5823
MB11	22.633	89.5832
NKB1	22.746	89.4111
NKB2	22.748	89.4083
NKB3	22.744	89.4051
NKB4	22.744	89.4023
NKB5	22.744	89.4079
NKB6	22.748	89.4103

PN11	22.643	89.344
PN12	22.639	89.316
P1	22.544	89.295
PS1	22.493	89.309
PS2	22.495	89.31
PS3	22.495	89.31
PS4	22.495	89.311
PS5	22.493	89.312
PS6	22.498	89.317
PS7	22.498	89.316
PS8	22.489	89.325
PS9	22.493	89.325
PS10	22.498	89.328
PS11	22.497	89.329
PS12	22.499	89.329
PS13	22.498	89.335
PS14	22.496	89.336
PS15	22.496	89.338
PS16	22.497	89.338
PS17	22.495	89.341
PS18	22.495	89.347
PS19	22.498	89.35
Ch1	22.603	89.52
Ch2	22.606	89.524
Ch3	22.606	89.52
Ch4	22.606	89.52
Ch5	22.606	89.514
Ch6	22.606	89.511
Ch7	22.607	89.508
Ch8	22.608	89.505
Ch9	22.608	89.501
Ch10	22.609	89.497
Ch11	22.61	89.496
Ch13	22.613	89.494
Ch12	22.614	89.494
Ch14	22.617	89.491
AU1	22.687	89.457
NKGW3	22.746	89.405