ANALYSIS OF SETTLEMENTS

DRIVING FORCES BEHIND THE LOCATION OF SETTLEMENTS IN SYLHET, BANGLADESH

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May and June 2012

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Photo on the front page: A settlement in the district Sylhet (www.commondatastorage.googleapis.com)

Foreword

This thesis is a final work of the Bachelor Earth Science and Economics, VU University Amsterdam. The aim of this learning project is to describe, analyze and explain a certain problem that can be observed from an earth scientific and economic perspective.

My research is carried as part of the development of a current project the Climate Adaptation Atlas Bangladesh, which is powered by various Dutch companies and a Bangladeshi partner. The Climate Adaptation Atlas (CAA) provides information to a wider audience, about adaptations of the impacts of climate change. The CAA project focuses on one of the six districts of Bangladesh: Sylhet.

This thesis analyzes the location of settlements in the district Sylhet. With the changing climate and future population growth in mind, this is important information for land use planners and governmental authorities.

The results of my analysis will hopefully be useful for the CAA project of Bangladesh. The idea is that the insights about settlements in Sylhet will be used as inputs for the Future Land Use Model of Bangladesh.

I have had very useful supervisors assisting me during this research and I would like to take the opportunity to thank them here.

Thanks to Eric Koomen, my first supervisor, who has guided me in the right ways. He introduced me to Arjen Koekoek, my contact person of Geodan. Due to Arjen I had full access to the digital data of Sylhet. Arjen referred me to Martin van der Beek, an employer of Object visions, who converted the data sets for me. I also would like to thank Peter Mulder, my second supervisor, who has given me useful advice.

Abul Kashem Md. Hasan, director of Database & IT Division of CEGIS and Md. Mostafizur Rahman, specialist of Database & IT Division of CEGIS, have provided me of very useful answers to the questions I was honored to ask them, during their stay in Amsterdam.

Summary

This thesis analyzes the locations of settlements in Sylhet, one of the six districts of Bangladesh. The changing climate and expected population growth are a threat, because it is a vulnerable region. Information about the settlements is therefore very useful for land use planners and governmental authorities.

To find the most determining driving forces for the locations of settlements, two types of analyses have been carried out: a spatial analysis and a logistic regression analysis.

According to the results of both analyses, the following conclusions are made:

Earth scientific conclusions:
An increasing flood depth has a <u>*negative*</u> *effect on the locations of settlements. See* Figure 11 *and* Table D.

The increasing distance from settlements to the river has a <u>*positive*</u> *effect on the location of settlements. See Table D.*

The soil types clay and shale both have a <u>*negative*</u> *effect on the presence of settlements. See* Figure 13 *and* Table D.

The soil types alluvium and colluvium have a <u>*positive*</u> *effect on the presence of settlements. See Figure 13 and Table D.*

Socio Economic conclusions:
Safe drinking water is in almost every Thana (sub district) of Sylhet available, so it does not have an impact on the locations of settlements. See Appendix 2J.

The increase of food insecurity has a <u>*negative*</u> *effect on the location of settlements. See Table D.*

An increasing distance from settlements to the road has a <u>*negative*</u> *effect on the location of settlements. See* Figure 18 *and Table D.*

Contents

1 Introduction

1.1 CAA project Bangladesh

This thesis is carried as part of the development of the Climate Adaptation Atlas Bangladesh (CAA). It is powered by several Dutch firms: Alterra, Geodan, Deltares, Geocycli and a Bangladeshi partner CEGIS.

The CAA project is a discussion/decision support tool to raise attention about the planning of climate adaptation. "The main goal of the project is to develop a show-case to demonstrate its applicability for other regions in the world. Another goal is to increase awareness of the Government of Bangladesh for long term effects of climate change" (Alterra, 2011).

The CAA project is focused on one of the six districts of Bangladesh: Sylhet. It is located in the northeast, adjacent to India. See Figure 1.

Bangladesh is a poor and vulnerable country below sea level and climate changes can have a huge impact on the nature, people and activities. Flat, low lying areas, called haors, are vulnerable areas and very common in Sylhet (Alterra, 2011). They might be affected by sea level rise, droughts and floods. Since the population growth is expected to increase in the future, Bangladesh needs to be well organized to adapt to these changes. Dutch companies are setting up a climate atlas so that Bangladeshi firms or authorities can learn and take over (Alterra, 2011).

One part of the CAA project is to set up a Future Land Use model for Bangladesh, to create future land use scenarios. One of the needed inputs is information about the settlements. Because of the expected climate change and -population growth, it is good to know where the people will live. To determine where this will be, we should know where they live now and for what reasons.
This is exactly what will be discovered in this thesis. What driving forces play a role when people choose a place to live?

1.2 General information about Bangladesh and Sylhet

Bangladesh is a sovereign state located in the south of Asia. It is adjacent to India and Myanmar and the Bay of Bengals in the south. The total area is 144,862 km² (Brammer, 2002). Sylhet has a total area of 20,000 km².

Till 1757, Bangladesh was governed by several Indian leaders. Great Britain possessed the country as part of British India, from 1757 till 1949. After these two centuries, it was named East Pakistan and became an independent and sovereign state in 1971 (Hossain et al. 2008).

Most parts of Bangladesh are located in a delta of big rivers, except for some regions that have an elevation level of maximum 1300 meters (Hossain et al. 2008). Large parts of the country get flooded in the monsoon season, which takes place from June till September. This is a period with the highest rainfall, humidity and cloudiness of the year. Due to this heavy rainfall, floods are very likely (Brammer, 2002). Sylhet consists of large basins (haors) that flood during the monsoon season and become parched in the winter period (December to February) (Hossain et al. 2008).

The seasonal flooding restricts the suitability to live on these plains. The people are dependent of the higher parts of the landscape, along the rivers or along abandoned river channels. Where these ridges are absent, people have built artificial platforms on the floodplains, above the normal flood level (Brammer, 2002).

The population in Bangladesh has increased almost four-fold in one century: from 24 million in 1881 to almost 90 million in 1981. To provide the inhabitants of food, the cultivation has increased almost three-fold (Brammer, 2002). The population growth continues with a growth rate of 1,43% a year. The estimation is 177.3 million inhabitants by 2025 and 210.8 million by 2050, according to Hossain et al. (2008). The question arises, where are these people going to live?

A former study showed that the population increase between 1951 and 1974 was solved by building additional houses in the existing settlement area; trees, grasslands and gardens were replaced by houses (Brammer, 2002). They also showed that an increase of settlements tends to take place at safe locations and not in high flood risk areas. In one certain area, the settlements growth was enormous, due to improvements in flood protection (Brammer, 2002).

Agriculture is one of the most important economic activities in Bangladesh, and also in Sylhet. The aim of the government is to meet the nation’s food requirements. Floods and other natural phenomena can disrupt the economic situation, by destroying the harvest/agricultural lands (Hossain et al. 2008). The government of Bangladesh is trying to upgrade the living standard of the citizens by providing the basic needs. According to the director of the Database & IT Division of CEGIS, A.K.M. Hasan, the plan of the government is to create possibilities for the lower areas (that face the deepest floods). Those areas are not very attractive to live, because of the scarcity of facilities as schools and medical services.

The government of Bangladesh does not regulate the land use, except for urban areas and some forest areas. Land owners can decide what they do with their land, there are no rules. It is even possible to leave the land fallow or change it into a non-agricultural use.
Local governments do not have land use regulation powers either. The only thing they can do is help to realize the public interests; demand for roads, flood protection or small scale irrigation (Brammer, 2002).

Bangladesh has a large diversity of soils, often in diffusive- and complex patterns. Soils differ within regions, villages and even between individual fields. This diversity leads to a complex land use planning (Brammer, 2002).
Half of the agricultural land is owned by small farmers (farmers with less than 5 acres), this equates to 77% of all farmers. They are experts in treating their piece of land to the specific circumstances (Brammer, 2002). Before, policy makers and agricultural researchers were not interested in the knowledge of local farmers and never integrated them in the farming systems research (Ali, 2003). However, this integration will be necessary to develop sustainable farming systems that can handle different environmental conditions (Ali, 2003), but it will not be easy to make small farmers change their way of cultivation (Brammer, 2002).

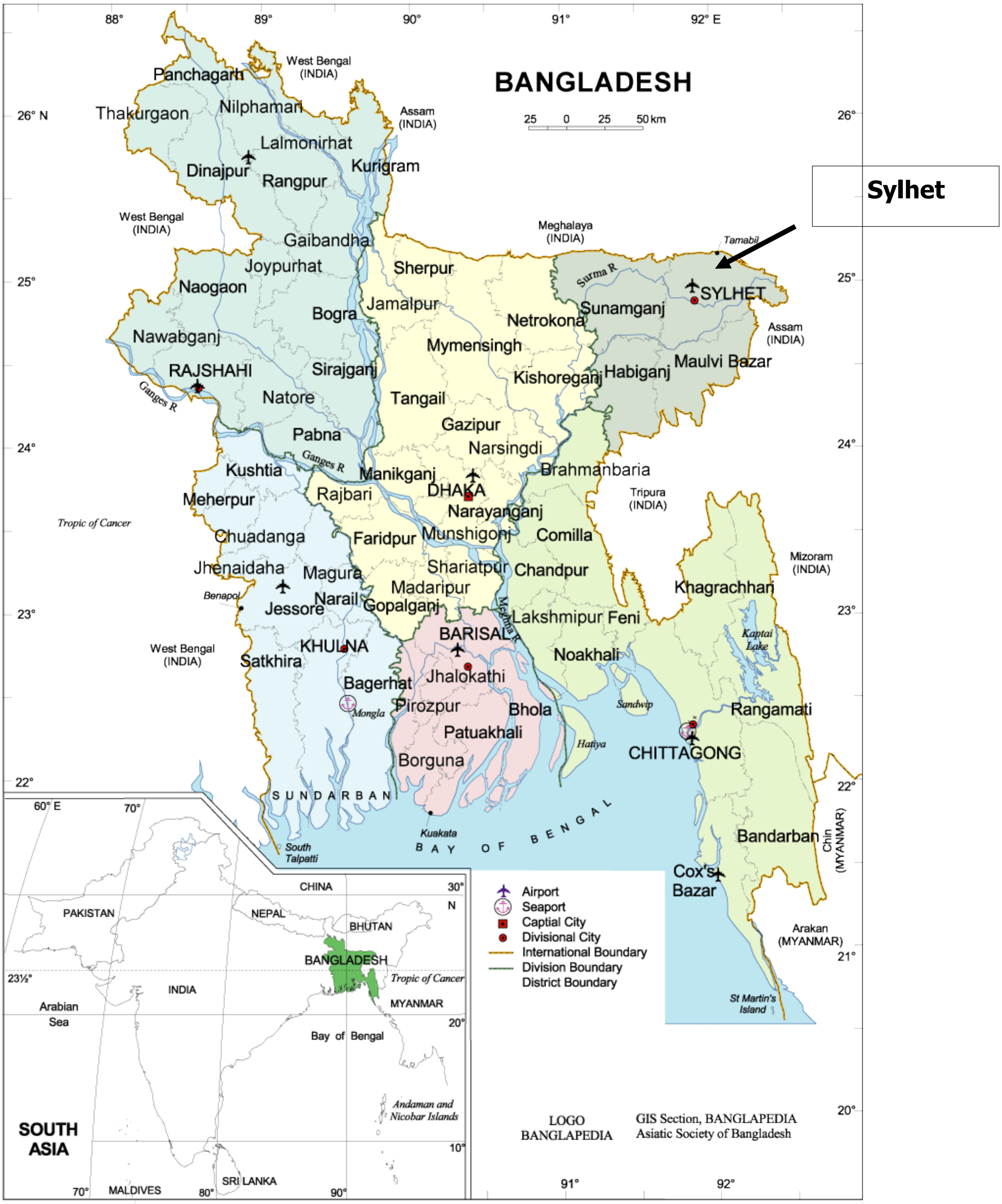

FIGURE 2 DISTRICTS OF BANGLADESH (WWW.BANGLAPEDIA.ORG)

1.3 Main research question and sub questions

Sylhet has to deal with climate- sensative conditions, where seasonal floods play a major role. In combination with the growing population and increasing needs for houses/agricultural lands, future planning is needed. To realize future planning, information about determining variables is required and declarations need to be found for the locations of current settlements. This leads to the main research question of this thesis:

How can the locations of current settlements in the climate-sensitive region Sylhet (Bangladesh) be explained?

The answers to this question will consist of an assessment of the various driving forces that explain the location of current settlements. To let this thesis be representative for an Earth science and Economics Bachelor, the conclusions will be split up in two: earth scientific- and socio economic conclusions. This is why the main question is divided into the three following sub questions:

1. *Where are the settlements located at this moment?*
2. *What are explanations from the perspective of earth sciences?*
3. *What are explanations from the perspective of socio economics?*

2 Methodology

This chapter describes the structure of this thesis and the two methods that will be used.

Structure

The main problem will be viewed from two perspectives; the earth scientific- and socio economic perspective. Both are divided into three driving forces, which will be used to pinpoint a determining force in the conclusion. These driving forces consist of variables that will used as input for the analyses. See Figure 3 below. A motivation for the driving forces, related variables and a description of their characteristics, can be found in chapter 2.1.

Perspec-tive	Earth Scientific				Socio Economic	
Driving Force	Physical elements		Accessibility		Necessity of life	
Variable	Geology	Flood depth	River	Road	Food Insecurity	Water Availability

FIGURE 3 STRUCTURE OF THIS THESIS

Methods

Two analyses will be done. The first one is the Spatial Analysis and will be contributed with ArcMap, a main component of the computer software ArcGIS. The produced maps will lead to initial conclusions and a hypothesis.

The second analysis, a Logistic Regression Analysis, will provide information if this hypothesis is correct or not.
The description of both methods is described in chapter 2.2 and 2.3.

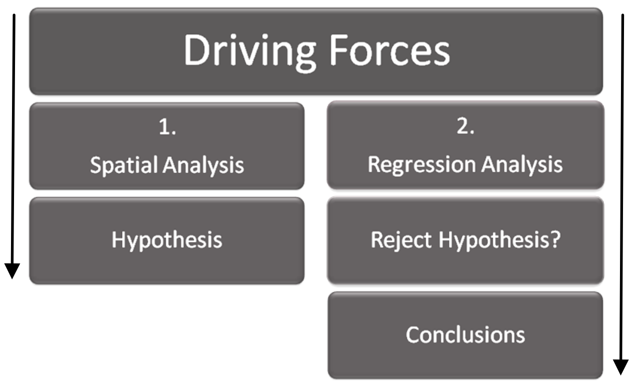

FIGURE 4 METHODS

2.1 Driving forces and variables

A driving force is an element that has a possible effect on the focal issue. This thesis will find an answer to the question which driving forces are important for the locations of settlements in Sylhet. Information about these driving forces is important for decision makers and authorities; for the future planning of the land (Peña et al, 2007).

Studies use to focus on a couple of driving forces, mainly because the statistical methods operate better with a limited number of independent variables (Hersperger and Bürgi, 2007).

A previous study (Hersperger and Bürgi, 2007) did similar research and looked for driving forces that changed the Limmat Valley west of Zurich from a traditional agricultural valley (in 1930) to a suburban region (in 2000). Five major driving forces were chosen to analyze: political-, economic-, cultural-, technological- and natural driving forces.

This thesis chooses three driving forces that are expected to be important in the settlement process in Sylhet: Physical, Accessibility and Necessity of life.

Each driving force represents two underlying variables. The importance of each variable is described below. The chosen variables are based on the driving forces used in other studies and important processes of the study area: delta's, floods, agricultural activities, poverty and population growth. Another study has found that poor (urban/slum) settlements in Bangladesh are often located in low-lying- and flood-prone areas and have minimal access to safe water and sanitation (Rashid, 2009). These aspects are critical for a normal living standard and will be taken into account in this research.
The concept of driving forces and underlying variables is represented in Figure 5.

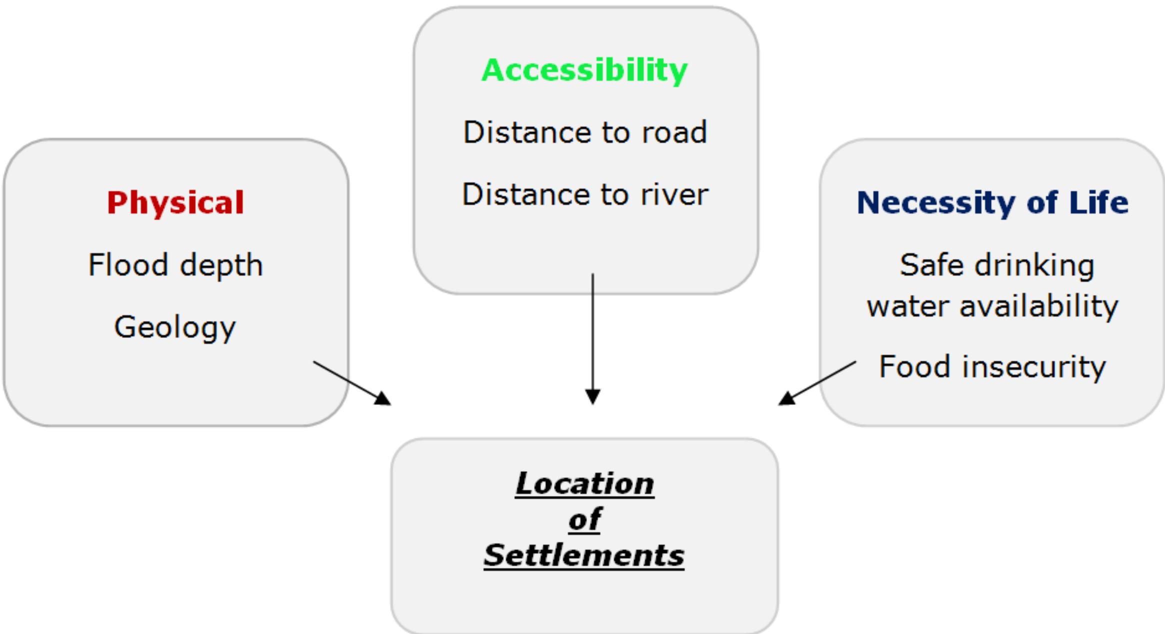

FIGURE 5 POSSIBLE DRIVING FORCES AND VARIABLES

Settlements
The description of a settlement, according to the data description of the CAA Project is as follows: “A settlement is a contiguous area around the house containing trees, a nursery ground, a garden with some vegetation, but separated from agriculture land”. The director of the database & IT Division of CEGIS, A.K.M. Hasan, explained that one settlement consists of a couple of houses and families. The data set contains of the locations of settlements, provided with x- and y coordinates and is displayed on a map of the district Sylhet.

Physical
Sylhet has many rivers. These rivers have a strongly varying discharge, depending on the season. The flood depth is linked to the height of the landscape; the lower the elevation, the higher the flood depth (Brammer, 2002).
In a previous study, residents of floodplains in Bangladesh were interviewed and 96% of them appeared to be exposed to flooding in the raining season every year. In one-third of the cases the water comes waist high (1.5 feet) and one-third even shoulder high (3 feet) (Brouwer et al. 2007). The flooding is the major problem in these regions, followed by bad roads, unemployment and lack of electricity (Brouwer et al. 2007).
Sylhet also consists of deep flood zones, so a (high) flood risk can be an important reason for people to avoid living close to it. This is why the flood depth is considered as an important variable for the locations of settlements.

The flood depth is negatively related to the altitude of the landscape, see Table D in the Appendix. The r is -0.459, which means the deeper the floods, the lower the landscape is. This relation is moderate, but strong enough to leave the altitude of the landscape out of this analysis. Another reason is that the elevation of the land is not a primary reason for people to live; it is not the number of height that is of importance. The inundation (flood) depth on the other hand, can be determining to be sure places are safe enough to live. The data set of Flood depth is displayed on a map of the district Sylhet, see Appendix 2B.

Geology seems a decisive variable for settlements. Settlements in the rural areas are often built on natural levees to protect for floods (Ali, 2003). The levee is made of alluvial material, deposited by the rivers. Silty clay is often used as cropland and settlements are often located on sandy loam (Ali, 2003).
The original geology data set contains data of all different types of soil in Sylhet. To make the analyses easier, it has been reclassified into fewer classes. A detailed description of this process can be found in Appendix 1. The data set Geology is displayed on a map of the district Sylhet, see Appendix 2D.

Accessibility
This driving force describes the accessibility from settlements to other destinations. Roads and rivers are expected to be two important ways of transport that enlarges the scope of the habitants. The presence of railways is scarce in the district Sylhet; the railways have a total length of 1000 kilometers while rivers cover about 4000 kilometers (www.bangla2000.com). The distribution of goods is mostly increased in the water transport sector, from 1986 till 1997, followed by respectively the road-, rail- and air transport (Chowdhury et al. 2001). 76,3% of the total distribution of goods were transported by roads, 18,7% by water and only 4,6% by rail (in 1997) (Chowdhury et al. 2001). Rail does not play a major role (yet) and is therefore not used as a variable in this thesis.

The road seems to be an important transport factor, so it is an assumption that people do not want to live too far from the roads. For trade and transport of products, the cheapest location to live is near a road, because it is time efficient and transport costs are low.

Another reason why it is expected that people live close to the roads is because poor people cannot afford another transport mode. Walking to schools, markets or other villages should be possible on (rural) roads.

The distribution of goods by water transport is another good alternative, according to Chowdhury et al. 2001. The river can therefore be an important factor for the locations of settlements. The rivers, especially in the monsoon season, disturb the connectivity between villages. In these months, roads get flooded and transport by the river seems a good alternative until the river gets parched. Since there are so many rivers, it is assumable that people use it for transport, and want to live as close as possible for this reason (taking the flood risk into account). Living close to distribution points is an advantage, because it saves time, costs and effort. Living close to the rivers might also be of importance for agricultural activities and the fertility of the soil.

The information of both data sets, distance to road and distance to river, are displayed on map of the district Sylhet. See Appendices 2Fand 2H.

Necessity of life
The presence of arsenic in the groundwater is a major health problem for countries in South Asia. It is confirmed that the arsenic release into groundwater of the Bengal Basin is caused by microbial metabolism of organic matter in river floodplain and delta deposits, and not by anthropogenic cause (Ahmed, 2006). Since the introduction of (deep) tube wells by the government, the diarrheal diseases are reduced. Still, the government should continue and expand water testing activities, because people in Bangladesh still drink water containing toxic levels of arsenic (Ahmed, 2006). The district Sylhet is largely provided with safe drinking water as Appendix 2J shows. It is imaginable that people want to live close to safe tube wells, to ensure their health conditions of themselves and their family. Safe drinking water can therefore be a determining factor for the location of settlements.

The availability of food can be seen as another important variable. Bangladesh produces lots of rice and wheat, but the availability of food is not everywhere guaranteed. Income and consumption are dependent of the season. Some seasons do not provide enough food, locally known as the Monga, which sometimes leads to famine (Khandker, 2011).The intensity of Monga depends on local conditions as the size of floods and droughts. Regional differences in poverty are due to the seasonality of income and consumption. Governmental policies can help to mitigate (Khandker, 2011).
Food is a basic need, but unfortunately not guaranteed throughout the year. Several factors have an impact on the availability of food. Agriculture plays an important role, just like the weather and seasonal floods. This is why the food insecurity itself and not agriculture is chosen as a variable for this research.
Two data sets of the CAA provided information about the food availability; Food Insecurity and Nutrition. Since their correlation is pretty strong (r=0.679), only one is used in this analysis (food insecurity), see Table F in the Appendix.

The availability of safe drinking water and food insecurity are chosen as depending variables of this driving force and can be analyzed from the socio economic perspective. Both variables are expected to be important necessities of life, especially in a country like Bangladesh where lots of people live beneath the poverty level. Both data sets provides information per Thana (sub district) of Sylhet, see Appendices 2J and 2K.

2.2 Description of the spatial analysis

The spatial analysis is meant to analyze and describe the current situation. The obtained digital data (from the CAA project Bangladesh) can be imported in ArcMap, a geospatial processing program, which is a main component of ArcGIS. All data files are converted from polygon to raster files; this is easier for all the operations.

The variables described in the previous paragraph play an important role in this analysis. Each variable will be considered separately. The first step is to display the data on a map and explore spatial patterns and potential relations between the settlements and the specific variable.

The second step is carried out with an ArcMap tool; Combinatorial And. It is listed under the Math directory of the Spatial Analyst Tools. *Combinatorial And* combines two layers in one. If Settlements and Flood depth are taken as an example, the settlements will be divided in the flood depth categories. With that result, it is possible to observe in what flood depth category the settlements are located. The ModelBuilder (function of ArcMap) shows this process:

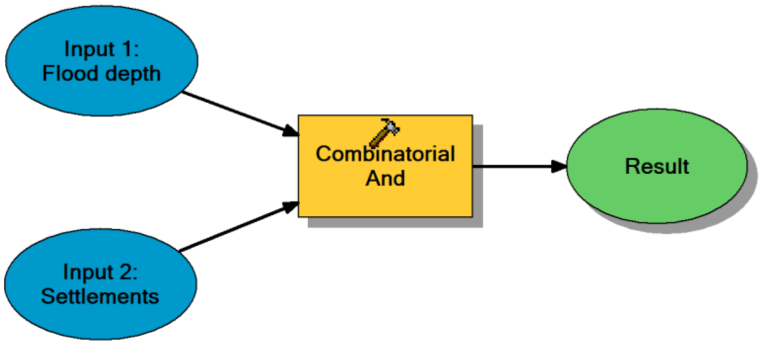

FIGURE 6 MODEL BUILDER OF COMBINATORIAL AND TOOL

The process of the *Combinatorial And* tool:

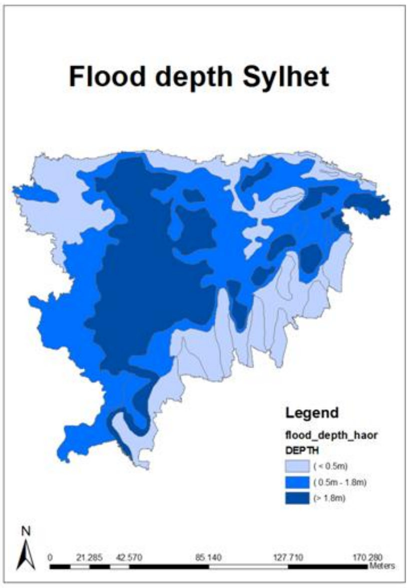

FIGURE 7 INPUT 1 FLOOD DEPTH

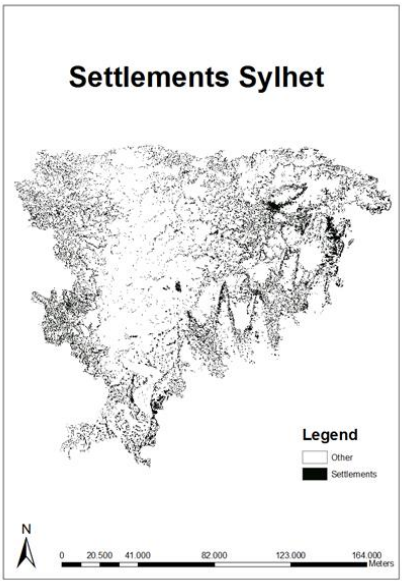

FIGURE 8 INPUT 2 SETTLEMENTS

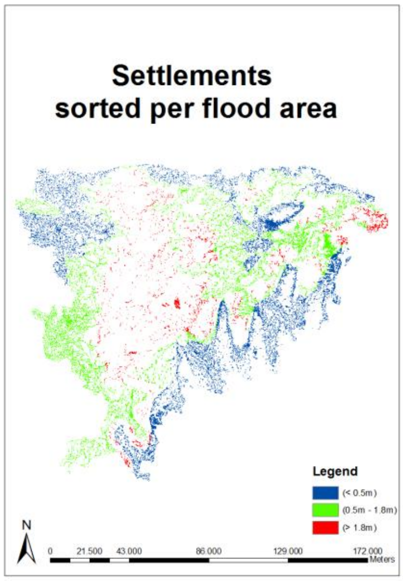

FIGURE 9 OUTPUT

An output map as showed on the previous page will not be showed in the chapter Results, but a graph will be used for this as it provides a clearer overview of the data.

The analyses described in this chapter will be carried out for each variable; flood risk, geology, availability of safe drinking water, food insecurity, distance to roads and distance to rivers. The results can lead to initial conclusions and suggestions, if the variables are related to the locations of settlements.
At the end of this paragraph, a hypothesis will be formulated that consists of an answer to the following question: How do the variables influence the location of settlements?

The second analysis, the regression analysis, will show if the stated hypothesis is correct or not.

2.3 Description of the logistic regression analysis

A logistic regression analysis will be carried out to explain the influence the variables have on the presence or absence of settlements. This analysis will show if the hypothesis, based on the spatial analysis, is correct. A logistic regression estimates the influence of one or more independent variables on a dichotomous (0 or 1) dependent variable.

The first step is preparing the data for SPSS, the program that will be used for this regression analysis. The function *Sample* in ArcMap is a useful tool for this. *Sample* is an extraction tool of the Spatial Analyst Tools. It creates a table with the settlements, its x and y coordinates and all the variables that are wanted to test. The prepared table can be imported in SPSS.

The dependent variable is the settlements data set. It has a dichotomous dataset: 0=no settlement 1=settlement

The independent variables have a different level of measurement. All consist of a continuous scale; the data is ranged in order of importance. Geology has a categorical scale, so it needed to be treated different. Appendix 1 explains this process in more detail. Detailed information of all variables can be found in Table A.

TABLE A DESCRIPTIVE STATISTICS 1

variable	min	max	unit	mean	st. dev
settlements	0	1	0 or 1	0.15	0.356
clay	0	1	0 or 1	0.41	0.492
colluvium	0	1	0 or 1	0.04	0.198
shale	0	1	0 or 1	0.02	0.123
alluvium	0	1	0 or 1	0.42	0.494
sandstone	0	1	0 or 1	0.1	0.306
flood depth	0	3	%	2.01	0.799
distance to road	0	100	hm	6.99	7.603
distance to river	0	72	hm	3.46	4.337
availability of safe drinking water	0	4	%	2.98	1.123
food insecurity	0	3	low-very high	2.88	0.385

As Table A shows, not all variables are standardized. With standardized values it is possible to compare scores with different units. SPSS is able to convert actual scores into standardized z-scores (mean=0, standard deviation=1). Table B shows the new values, calculated with the standardized variables.

TABLE B DESCRIPTIVE STATISTICS 2

variable	min	max	mean	st. dev
settlements	0	1	0.15	0.356
clay	0	1	0.41	0.492
colluvium	0	1	0.04	0.198
shale	0	1	0.02	0.123
alluvium	0	1	0.42	0.494
sandstone	0	1	0.10	0.306
flood depth	-2.513	1.24	0	1
distance to road	-0.798	15.8	0	1
distance to river	-0.920	12.23	0	1
availability of safe drinking water	-7.486	0.314	0	1
food insecurity	-2.649	0.912	0	1

When all data is prepared, the binary regression can be realized. The output is a table with statistical data. The following variables will be used for this analysis:

B is the estimated effect of the independent variable on the dependent variable. A negative number gives a negative effect and a positive number gives a positive effect. The larger the number, the larger the effect.

Exp(B) gives the estimated effect of the independent variable on the dependent variable in percentages for a value of 1. If the factor is 1.033, the expected effect is an increase of 3.3%. ((1.033-1)x100%). If *Exp(B)* is bigger than 1, the effect is positive. If *Exp(B)* is between 0 and 1, the effect is negative.

3 Results

This chapter is divided in results of the spatial- and regression analysis.
The spatial analysis is contributed with ArcMap and the regression analysis is contributed with SPSS, as explained in the chapter Methodology.

3.1 Results of the spatial analysis

In this paragraph, all variables will be displayed on a map and compared to a map with the locations of settlements. A graph (derived from results of the *Combinatorial And* tool) will show the facts and leads to first impressions. The variables are subdivided into Earth Scientific- and Socio Economic variables.

3.1.1 Location of Settlements

Figure 10 shows where the settlements are located; the black spots represent the settlements in the district Sylhet. One settlement is described as a contiguous area around the house containing trees, nursery ground, garden, vegetation and separated from agriculture land. One settlement consists of a couple of houses and families (CAA project, 2011).

A first observation of the figure below is that the distribution appears all around the borders and is highly concentrated in some areas. The emptiest part is in the middle with a north-south direction. Comparing this figure with Figure 1, tells that the region around Sylhet (the capital city of Sylhet) is one of the most densely areas.

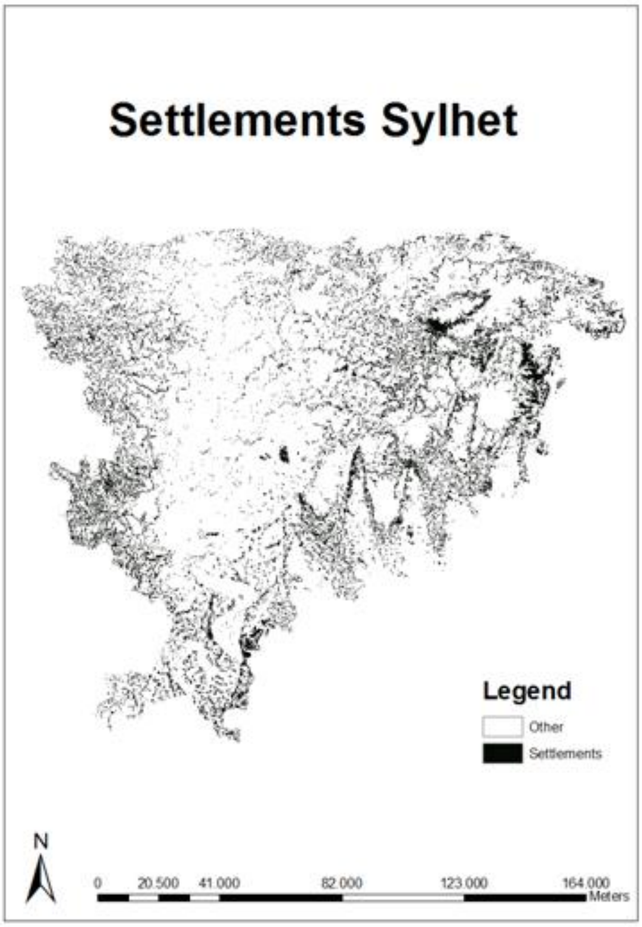

FIGURE 10 LOCATIONS OF SETTLEMENTS

3.1.2 Earth scientific variables:

Altitude/Flood depth

Sylhet has lots of rivers that flood from time to time. Especially in the Monsoon season (June-September) the floods are enormous (Brammer, 2002). The data file of the flood depth represents the average flood depth a year.
Some areas get more flooded than others, which is depicted in Appendix 2B. It is interesting to find out, if- and how much settlements are located in the different flood areas.
>1.8 meter represents the highest flood meters. <0.5 meter the lowest flood meters. It is clear to see that the densely habited areas are located in the 'safer areas' (<0.5 meter and 0.5-1.8 meter). But still, densely areas in the south-west and north-east are facing floods of an average of 0.5-1.8 meters high each year.
The flood areas match with the height of the landscape; the lower the landscape, the higher the floods, see Appendices 2B and 2C. This makes sense, because the flowing water fills up the deeper areas. The hills in the north-east are a good example where the floods are low. The hills in the south-east seem not very suitable to live. At the bottom of the hills the conditions seem much better to live. The densely area around the capital city Sylhet, is build on elevated grounds, as can be seen in Appendices 2A and 2C.

The graph below (Figure 12) shows the results of the *Combinatorial And* tool. This tool has combined the settlements and the flood areas, to make clear in what flood area each settlement is located. Figure 12 corrects for the total surface areas; the settlements are calculated per km².

Input 1: Settlements
Input 2: Flood depth

Figure 11 shows that 10% of all settlements is located in the flood depth area of >1.8 meter. The other two categories are evenly spread; both represent 45% of the settlements. It is remarkable that the flood areas of 0.5-1.8 meters are suitable enough to live.

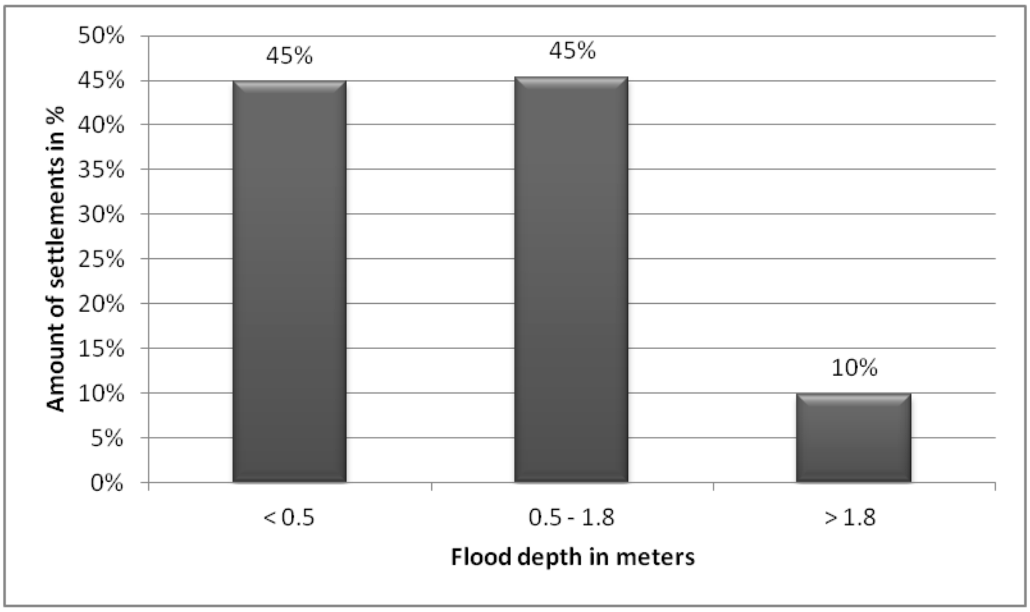

FIGURE 11 SETTLEMENTS PER FLOOD DEPTH AREA

Figure 11 shows the amount of settlements per km² for each flood depth category. The category where the average flood is <0.5 meter has the second largest surface area, 6356 km² but the highest amount of settlements per km². This flood depth category is the most densely habited. The category 0.5-1.8 meter has the largest surface area, 7118 km² and is also very densely habited. As Figure 11 already pointed out, the category where the average flood depth is the highest, live the fewest people. The surface area of this category is 6194 km², so it really is clear that this area is the least attractive place to live.
It seems that the flood depth is an important variable for the location of settlements.

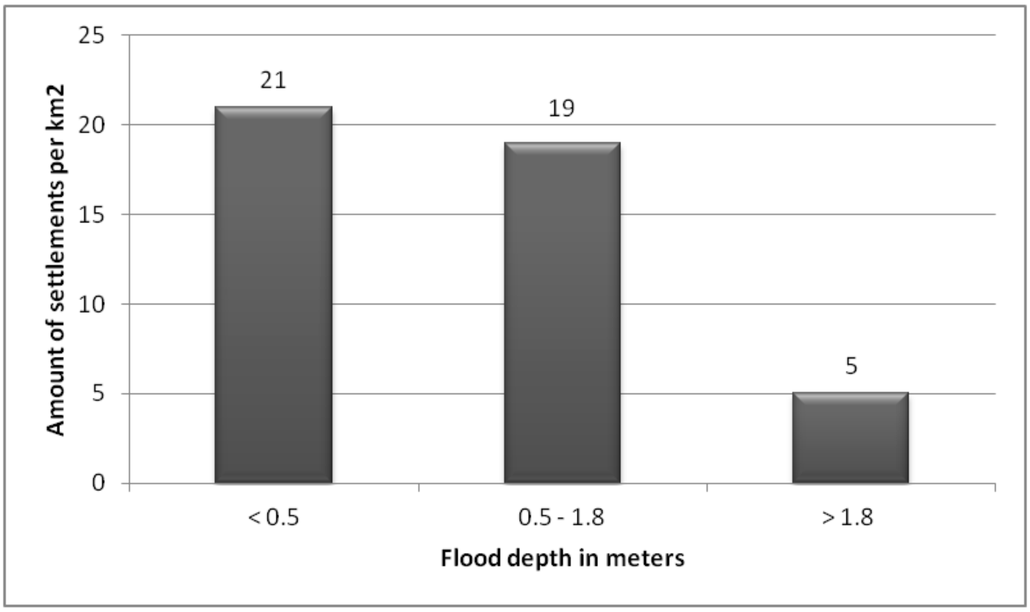

FIGURE 12 SETTLEMENTS/KM² PER FLOOD DEPTH AREA

Geology

This data set contains different types of depositions and soils, provided on a map that can be found in Appendix 2D. The reclassified map can be found in the Appendix.

Comparing Appendix 2A and 2D, it seems that on each geology type have settlements been built, the settlements are spread all over the district. But, it is imaginable that not all types are suitable enough.
It is obvious that alluvial silt or clay, covers a large part of the district, and is represented by lots of settlements. This in contradiction to the predominant Marsh clay and peat. If we compare Appendix 2B and 2D, it is obvious that Marsh clay and peat is corresponding with the deepest flood areas. Results of the Combinatorial And tool show that 20% of all settlements are still located on this soil type. See Figure 13 below.

Input 1: Settlements
Input 2: Geology

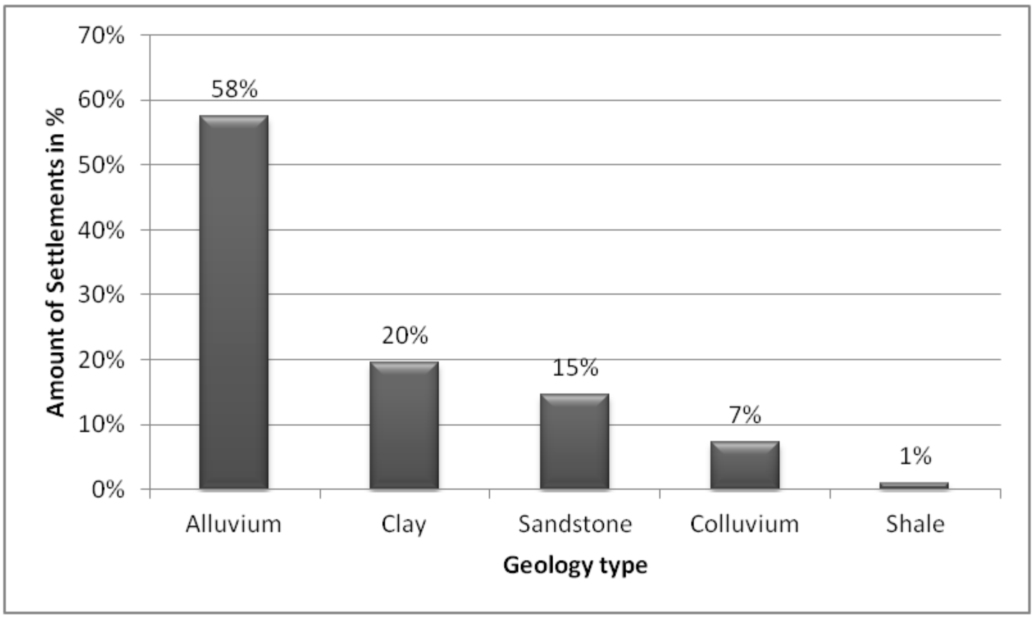

FIGURE 13 SETTLEMENTS PER GEOLOGY TYPE

The most settlements, 58% are located on Alluvium. Alluvium is loose material that is deposited by flowing water.

Figure 14 shows the amount of settlements per km² of the geology types. It should be noted that the surface areas of Colluvium and Shale are the smallest; respectively 204 km² and 808 km². Just observing the density of the geology types, colluvium and alluvium are the most popular and clay the least.

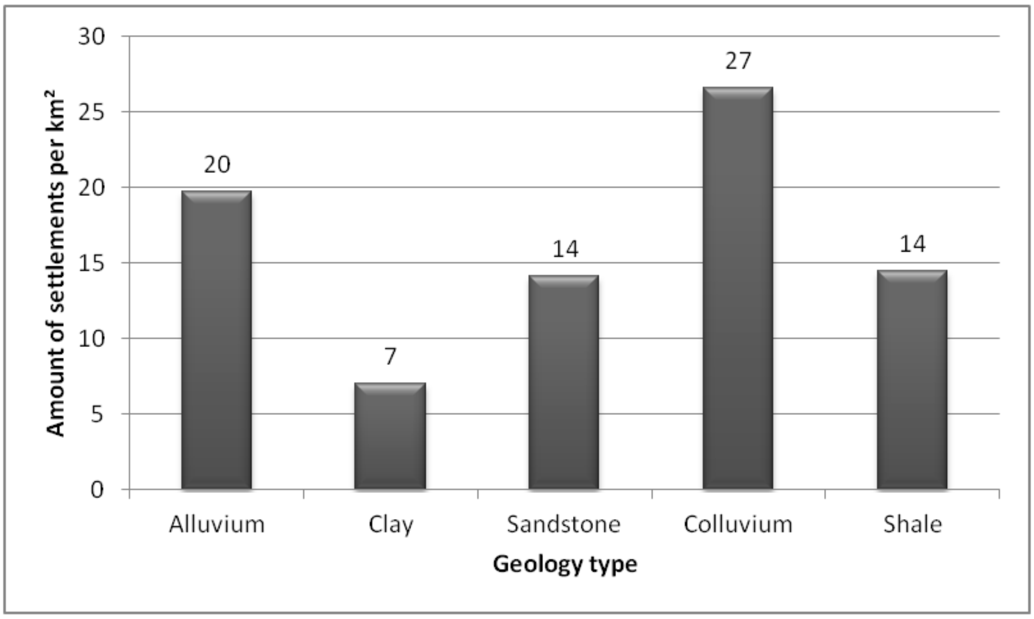

FIGURE 14 SETTLEMENTS/ KM² PER GEOLOGY TYPE

Distance to the river

Appendix 2B depicts the rivers that flow trough Sylhet. Lots of rivers from the north, east and west come together in one big river that flows southwards. Rivers can be a useful way of transportation for people and products. Especially in the monsoon season, in which the accessibility of areas is hampered, the river provides opportunities. The expectance is that settlements are built on an efficient distance from the river, so that the transport costs and -businesses are optimal.

The *Combinatorial And* tool shows that the majority of the settlements (63%) is located on a distance of 1 to 3 km distance from the river. Figure 15 shows that most of the people do not want to live too close to the river, even though this could be more efficient for transport. It is a fact that still 20% of the settlements are located on a distance of 0 to 0.5 km to the nearest river. These houses are probably built on dikes, which is a well known method to fight against the flooding rivers and is getting a more and more familiar method, according to A.K.M. Hasan, Director of the Databas &IT Division of CEGIS.

Input 1: Settlements
Input 2: Distance to river

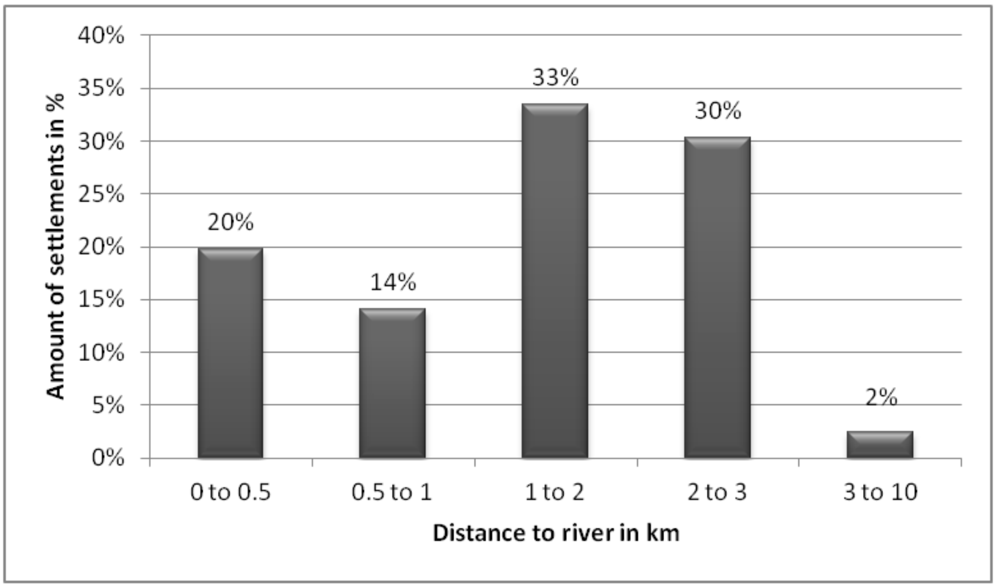

FIGURE 15 SETTLEMENTS PER DISTANCE TO THE RIVER

3.1.3 Socio Economic variables

Availability of safe drinking water

Appendix 2J represents the categories of safe drinking water in Sylhet, per Thana (sub district). It is obvious that in most parts of the district more than 60% of the habitants have safe drinking water. Just one region in the north east is very critical where less than 30% of the habitants have safe drinking water. In four other regions in the north east 31-60% of the people have safe drinking water.

The question is; is the availability of safe drinking water related to the location of settlements? Appendices 2I and 2J tell that the areas that have less certainty about the safety of their drinking water are densely populated. The *Combinatorial And* tool will provide more information on this. The result is showed below in Figure 16.

Input 1: Settlements
Input 2: Availability of Safe Drinking Water

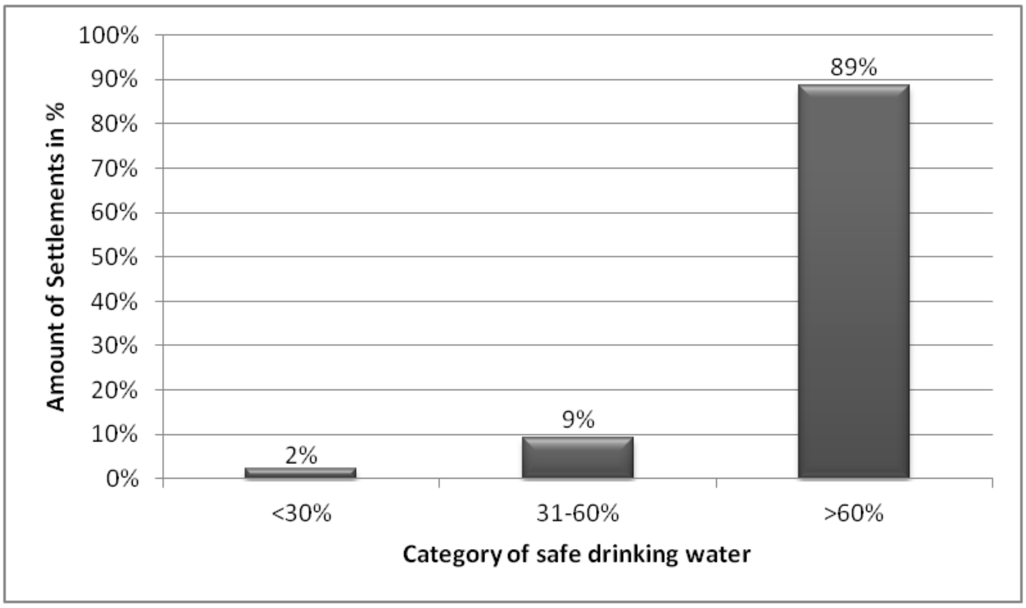

FIGURE 16 SETTLEMENTS PER CATEGORY SAFE DRINKING WATER

Only 2% of the settlements is located in an area where less than 30% of the habitants have safe drinking water. 9% is located in areas where the 31-60% of the habitants has safe drinking water. Most of the settlements, 89%, have good access to safe drinking water (>60%).

Because in almost all parts of Sylhet, more than 60% of the people have access to safe drinking water, it is hard to conclude if safe drinking water is an important variable for the location of settlements. The regression analysis might tell more about this, in the next chapter.

Food insecurity

Appendix 2K depicts the food insecurity per Thana (sub district). There seems a global trend of increasing food insecurity from the east to the west. In between are areas of different classes. The sub district of the capital city Sylhet is located in a low food insecurity area.

Looking at the results of the *Combinatorial And* tool (Figure 17) only 25% of all settlements are located in areas where food insecurity is low. More than half of the settlements (52%) are located in areas where the insecurity of food is high or very high.

Input 1: Settlements
Input 2: Food Insecurity

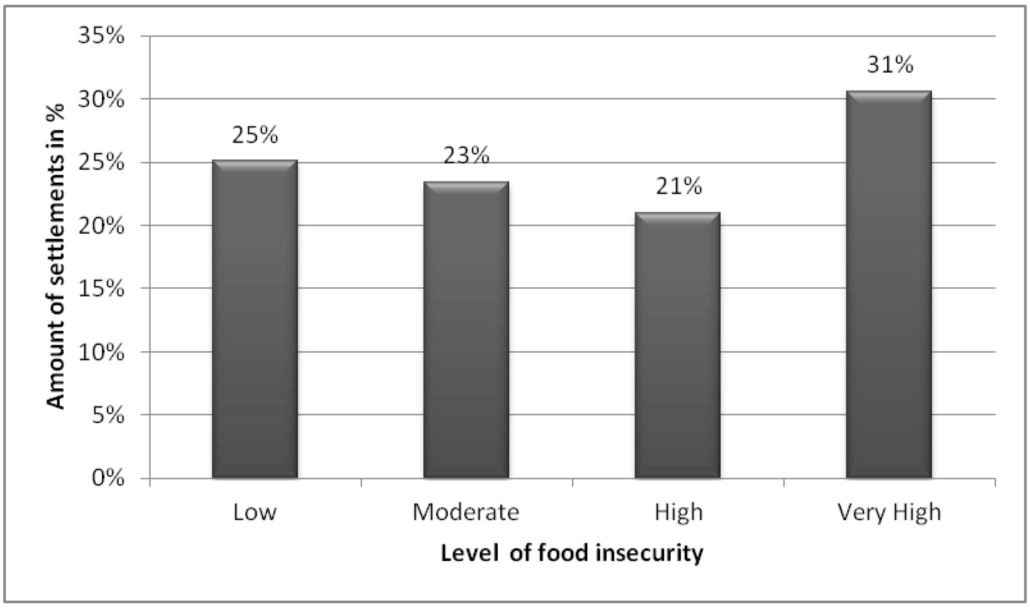

FIGURE 17 SETTLEMENTS PER CATEGORY OF FOOD INSECURITY

The question if the location of settlements is related to the availability of food is difficult to answer. 50% lives in areas with low/moderate food insecurity and the other 50% lives in high/very high insecurity areas. From these results is not possible to make a clear conclusion. The regression analysis might tell more about this, in the next chapter.

Distance to the road

Appendix 2H shows the road network of Sylhet. The areas with a densely road network correspond to the densely habited areas. This does not seem like a coincidence, because more houses come along with more people and more demand for transport. It is interesting to know if the settlements are close to the roads. A calculation has been made, where the distance from settlements to the nearest road is calculated. The distances are given in kilometers.

The result of the *Combinatorial And* tool, Figure 18, shows that 84% of the settlements are located with a distance up to 0.5 km from a settlement to the road. Half of them are in between a distance of 0 and 0.2 km. Only 26% lives in between 0.1 km of the road.
It can be concluded that the majority of the settlements in Sylhet lives in between 0 and 0.5 km distance to the road. Distance to the road seems an important variable.

Input 1: Settlements
Input 2: Distance to road

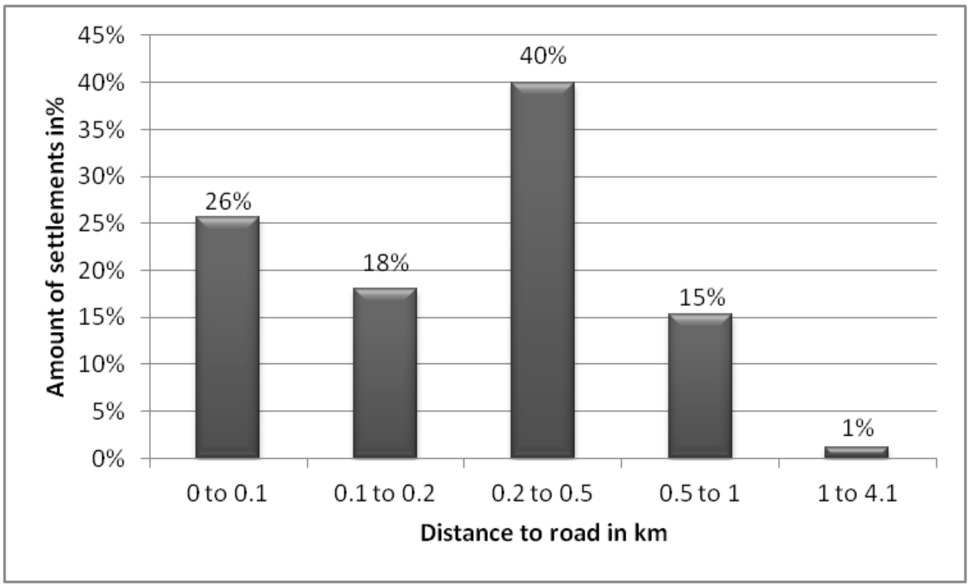

FIGURE 18 SETTLEMENTS PER DISTANCE TO THE ROAD

3.1.4 Earth scientific vs. Socio economic variable

Flood depth vs. Food Insecurity

It is interesting to combine data of settlements in the different flood depth areas with the insecurity of food. Then a conclusion can be made if the houses in a lower flood risk area have lower or higher food insecurity than houses in a higher flood risk area. The data sets of Settlements, Flood depth and Food insecurity has been used.

In this approximation, the three flood depth categories have been analyzed separately; the amount of settlements located in each flood category is linked to the food insecurity in the specific flood areas. The results have been put together and are depicted in Figure 19 below. The colors of the graph are related to the Flood depth map, Appendix 2B. Flood 1 represents the low flood depth category and flood 3 represents the high flood depth category.

The percentages form a total of 100% per flood category. An example: 30% Low in flood1 means that 30% of the total settlements in the lowest flood areas have a low food insecurity.

Interesting to see is that the categories flood1 and flood 2 are almost evenly spread over the different food insecurity levels. Flood3 has a divers spreading, ranging from 15% to 47% settlements.

Another interesting fact is that the highest priority for food occurs in the deepest flooded areas (flood 3).This means that is it not so attractive to live in the flood 3 areas and this might be a reason why the amount of settlements is low, see Figure 11. This makes the flood depth (again) a very important variable in this analysis.

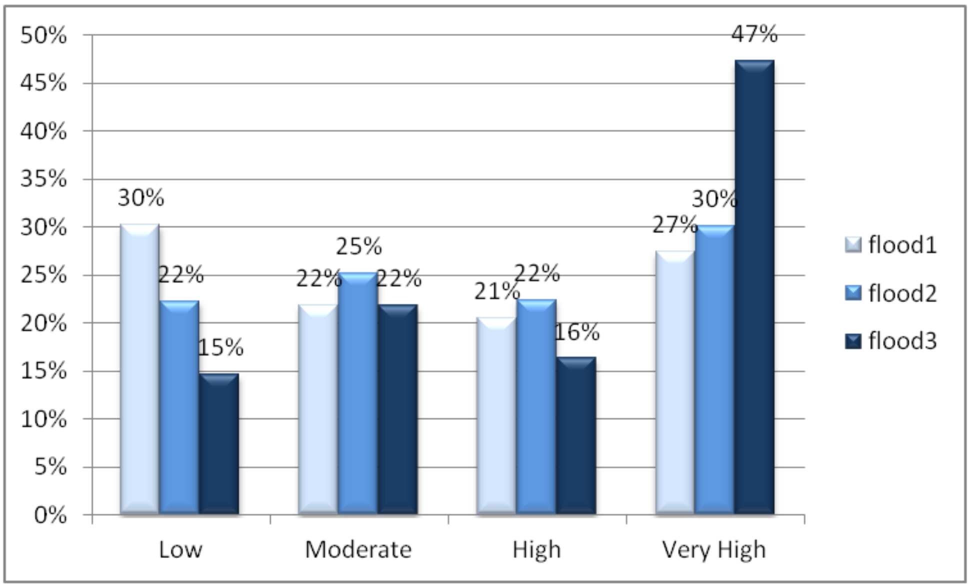

FIGURE 19 FLOOD DEPTH VS. FOOD INSECURITY

3.1.5 Initial conclusions and hypothesis

Earth scientific conclusions:

(Physical) Flood depth: most settlements are located in the zones <0.5 meter and between 0.5-1.8 meter. Only 10% of the settlements is located in the areas >1.8 meter. In these areas, the food priority is very high, so flood depth seems to have a negative effect on settlements. See Figure 11, Figure 19 and Appendix 2B.

(Physical) Geology: Alluvial soils are the most popular soils to live on, since 58% of all settlements are built on it.
Shale is expected to be not so popular, according to Figure 13. But its surface area is so small, that it there are actually 14 settlements per km².
Clay has the second most percentage of settlements, but it does not seem to be likely that it is attractive to live, looking at the Figure 19 and Appendix 2B. The deepest flooded areas are corresponding with the clay soil type. There is high food insecurity and a high flood depth.

(Accessibility) The increasing distance from settlements to rivers is expected to have a positive effect on the locations of settlements, because 63% of the settlements are on a distance of 1-3 km away from the nearest river. See Figure 15.

Socio Economic conclusions:

(Accessibility) The increasing distance from settlements to roads is expected to have a negative effect on the locations of settlements. 84% of the settlements is less than 0.5 km away from the nearest road. See Figure 18.

(Necessity of life) Safe drinking water: almost 90% of all settlements are located in an area that provides more than 60% of safe drinking water. It is hard to conclude if the availability of safe drinking water has a positive or negative influence on the location of settlements, because almost all sub districts have access to safe drinking water. See Figure 16 and Appendix 2J.

(Necessity of life) Food insecurity: half of the settlements are located in low/moderate food insecurity areas and the other half is living in high/very high food insecurity areas. There is no proof that the availability of food has a positive/negative influence on the location of settlements. See Figure 17.

TABLE C EXPECTATIONS AFTER THE SPATIAL ANALYSIS

Variable	Spatial Analysis
Flood depth	-
Sandstone	+/-
Clay	-
Colluvium	+
Shale	+/-
Alluvium	+
Food Insecurity	+/-
Availability of Safe Drinking Water	+/-
Distance to road	+
Distance to river	-

Table C on the previous page gives an overview of the expected results per variable. The geology soil types are hard to predict, because in the cases of sandstone and shale, there is not enough information to tell if the influence is positive or negative. Alluvium scores such a high percentage and it is expected to have a positive influence on settlements. The same accounts for Colluvium that scored a high amount of settlements per km². Shale has the opposite effect, where a negative influence on settlements is expected. Clay is also expected negative, because it is mostly located in the deepest flooded areas, where the food insecurity is high. See Figure 19 and Appendix 2D.

Previous conclusions lead to the following hypothesis:

The Physical driving force seems to have the most influence on the locations of settlements. The Accessibility seems to play a role as well. The results of the spatial analysis do not give obvious information about the influence of the Necessity of life.

3.2 Results of the logistic regression analysis

A logistic regression analysis is used to test how various the variables influence the presence of settlements at a specific location. See Table A and Table B for a specification of the used variables.

Only four of the five data files of geology were used as input; the fifth one acted as a reference. Sandstone was chosen as a reference, because looking at the results of the spatial analysis, sandstone is neither a leading nor uninteresting factor.

Table D represents the output table of the binary regression, contributed in SPSS. All significant levels are 0.000, so the test is significant. All variables, except geology, have been standardized, so it is possible to compare the variables.

TABLE D OUTPUT TABLE OF BINARY LOGISTIC REGRESSION

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	reclass_cl(1)	-.421	.009	2442.265	1	.000	.656
	reclass_co(1)	.054	.010	29.200	1	.000	1.055
	reclass_sh(1)	-.422	.022	381.998	1	.000	.656
	reclass_al(1)	.127	.007	355.202	1	.000	1.136
	Zt_flooddep	-.336	.003	14040.417	1	.000	.715
	Ztimes_road	-1.086	.005	46657.488	1	.000	.338
	Ztimes_rive	.058	.002	778.823	1	.000	1.060
	Zt_safedw	-.091	.002	2000.019	1	.000	.913
	Ztimes_food	-.239	.002	12670.658	1	.000	.787
	Constant	-2.396	.013	34737.400	1	.000	.091

a. Variable(s) entered on step 1: reclass_cl, reclass_co, reclass_sh, reclass_al, Zt_flooddep, Ztimes_road, Ztimes_rive, Zt_safedw, Ztimes_food.

Reclass_cl(1) = clay
Reclass_co(1) = colluvium
Reclass_sh(1) = shale
Reclass_al(1) = alluvium
Zt_flooddep = flood depth (standardized)
Ztimes_road = distance to road (standardized)
Ztimes_rive = distance to river (standardized)
Zt_safedw = availability of safe drinking water (standardized)
Ztimes_food = food insecurity (standardized)

TABLE E B AND EXP(B)

		B	exp(B)
positive effect	alluvium	0.127	13,6%
	distance to river	0.058	6,0%
	colluvium	0.054	5,5%
negative effect	distance to road	-1.086	66,2%
	shale	-0.422	34,4%
	clay	-0.421	34,4%
	flood depth	-0.336	28,5%
	food insecurity	-0.239	21,3%
	availability of safe drinking water	-0.091	8,7%

Table E is based on Table D and represents the B and exp(B) values for each variable. The variables are sorted on type- (positive/negative) and in size of effect. See Appendix 3 for the calculations of the exp(B).

Appendix 3 describes the thoughts behind the values, here only a conclusion will be shown. The variables with the largest impact are distance to road, shale and clay and have a negative influence on the location of settlements (B=-1.086, B=-0.422 and B=-0.421).

Availability of safe drinking water, distance to river and colluvium have the smallest impact on the locations of settlements (B=-0.091, B=0.058 and B=-0.054) but have a positive effect.

The distance to river has a positive B, but should be interpreted as; the influence on settlements of an increasing distance to the river is positive. A shorter distance would have a negative influence. Since the exp(B) is only 6%, this effect is small.

The distance to road has a negative B, but should be interpreted as; the influence on settlements of an increasing distance to the road is negative. A shorter distance would have a positive influence. This variable seems very important, since it has the largest impact on the locations of settlements (B=-1.086).

The availability of safe drinking water has a negative B, a negative influence on the settlements. The legend ranges from 'few people have access to safe drinking water to most people have access to safe drinking water'. Apparently, the increase of the availability of safe drinking water is negative. But, in almost every Thana of Sylhet, the availability of safe drinking water can be assured to 60% of the people. This can also be seen on Appendix 2J.

Looking at Table D and Table E, the following statements about the geology can be made:
The odds of alluvium are 13,6% bigger than sandstone: People prefer to settle on alluvium rather than sandstone.
The odds of colluvium are 5,5% bigger than sandstone: People prefer to settle on colluvium rather than sandstone.
The odds of shale are 34,4% lower than sandstone: People prefer to settle on sandstone rather than clay.
The odds of clay are 34,4% lower than sandstone: People prefer to settle on sandstone rather than clay.

This results in a popularity of soils:
1) Alluvium
2) Colluvium
3) Sandstone
4) Clay/shale

This list matches somehow with the result of the Spatial Analysis, see Figure 13. Alluvium and colluvium are the most popular. Sandstone is the mid class and clay and shale have the lowest amount of settlements per km².

3.3 Comparison results Spatial- and Regression Analyses

Table F shows an overview of the results of the spatial analysis and the results of the regression analysis. Almost all expectations after the spatial analysis were confirmed by the regression analysis. The variables food insecurity and Availability of safe drinking water were unsure, but seemed to have a negative influence on settlements. Colluvium appeared to have a positive influence. Sandstone was the reference layer, so there is no information if this variable has a positive or negative influence on settlements.

TABLE F COMPARISON OF THE RESULTS OF THE SPATIAL- AND REGRESSION ANALYSIS

Variable	Spatial Analysis	Regression Analysis
Flood depth	-	-
Sandstone	+/-	0
Clay	-	-
Colluvium	+	+
Shale	+/-	-
Alluvium	+	+
Food Insecurity	+/-	-
Availability of Safe Drinking Water	+/-	-
Distance to road	+	+
Distance to river	-	-

The spatial analysis lead to the following hypothesis:

The Physical driving force seems to have the most influence on the locations of settlements. The Accessibility seems to play a role as well. The results of the spatial analysis do not give obvious information about the influence of the Necessity of life.

The conclusion after the regression analysis is that this hypothesis is not completely correct, but it will not be rejected. Results of the regression analysis have shown that the distance to road and the geology types shale and clay have the most influence on the determination of the location of settlements. Two of them are divided under the Physical Driving Force, see Figure 5. Accessibility plays a bigger role; especially the distance to the road (highest B value). The regression analysis has showed insights about the Necessity of life. The food insecurity does have an impact on the location of settlements, more than the availability of safe drinking water.

4 Conclusion

Sylhet is a flat, low and vulnerable district of Bangladesh that is afflicted by floods every year. Climate changes might have an impact on the current situations, which will threaten the population and their belongings. The country Bangladesh is in need of a proper organization that can adapt to the expected changes. The Climate Adaptation Atlas will provide the information this country needs. A Future Land Use model will be created and information about locations of settlements is one element needed. The results of this thesis provide this information.

After all analyses, answers to the sub questions are found:

1. **Where are the settlements located at this moment?**

Settlements are mostly located near roads.
Shale and Clay are least favorite soils to live on.
Settlements are located where the floods do not have the highest level.
More than half of the settlements are built on Alluvial soils, Colluvium is next best.
Most settlements have a distance of 1 kilometer away from the river.

2. **What are explanations from the perspective of earth sciences?**

Flood depth is an important variable; an increasing flood depth has a negative effect on the locations of settlements.
The spatial analysis showed that only 10% of the settlements are located in areas where the floods are higher than 1.8 meter. The other 90% of the settlements are spread over the other two categories: <0.5 meter - >1.8 meter. See Figure 11.

The soil type Alluvium and Colluvium has a positive effect on the presence of settlements. The soil types Clay and Shale have a negative effect on the presence of settlements.
It turned out that alluvium is the most habited soil type at this moment: 58% of all settlements are located on alluvium, where shale only has 1%. See Figure 13*. The regression analysis showed that clay and shale both have a negative effect. See* Table D*.*

The increasing distance from settlement to the river has a positive effect on the location of settlements.
People incline to live with a certain distance from the river: 68% of the settlements are more than 1 kilometer away from the closest river. See Figure 15*.*

3. **What are explanations from the perspective of socio economics?**

The increasing distance from settlements to the road has a large negative effect on the location of settlements.

84% of the settlements are located on a distance from 0 to 0.5 kilometers to the road. See Figure 18*.*

In almost all Thana's of Sylhet, safe drinking water is available for more than 60% of the people.
Safe drinking water does not seem to be a determining factor for the location of settlements. See Appendix 2J and Table E*.*

The increase of food insecurity has a negative effect on the location of settlements. *See* Table E*.*

The main research question was:

How can the location of current settlements in the climate-sensitive region Sylhet (Bangladesh) be explained?

The location of settlements can be explained by several variables. The spatial- and regression analyses showed that some variables are more important than others. Physical driving forces appeared to have a big influence, Accessibility and Necessity of life follow. Physical processes as floods and soil types play such a role, that the habitants have to adapt and find other places to live. Roads are an important variable that have to be close to the settlements, while people prefer to keep the rivers on a distance.

5 Discussion

This thesis only used 6 variables in the analyses. These variables have been chosen, but it is imaginable that other variables play a role in the locations of settlements. Weather aspects as rainfall or droughts are reasons why a population would avoid places; it could ruin their houses and agricultural lands. The locations of agricultural land, tea plantations or fishing activities have not been taken into consideration either. All three are the most important businesses in Sylhet and it is imaginable that each activity needs its own land type. The distance from settlements to these agricultural lands might be an interesting variable to consider in a next study.

There is a problem with the variable distance to roads. According to the results of this thesis, roads have a positive effect on the locations of settlements. This assumes that houses are built because of the roads. But, it is imaginable that it works the other way around; the road has been built because of the settlements. Land use changes can be observed with historical data and will give more insight in the developments of houses and roads. It is clear that roads are needed for the connectivity between villages. This thesis has found that most villages have a distance of 0.5 km to the roads, which should be taken into account for future land use planning in Sylhet. Other studies have pointed out that investments in roads have a positive effect on economic growth and reduce poverty (Khandker et al. 2009). An expanded and improved rural road network leads to an increase of agricultural production, lower input- and transportation costs and a higher demand for labor. It also led to more secondary school enrollment, which results in more educated people. Ahmed and Hossain (1990) confirm that roads and transport networks are the key to development in rural areas.

Similar examples of variables that need historical data to analyze land use changes could be the distance from settlements to schools, the distance from settlements to markets and the distance from settlements to health facilities. Analyses of historical data will make clear what was built first, the houses or the facilities.

This thesis assumed that people want to live close to the river for fertile grounds, irrigation and transport. It turned out that most settlements are located on a distance of 1 km of the river, probably because of the threatening flood risk. The nature of the river determines people's life (Ahamad and Khondker, 2010), so next studies could take the behavior of the rivers and floods in consideration. Technologies could offer opportunities to live closer to the river, which could lead to improvements of the connectivity, transport of products and demand for labor.

This thesis has concluded that the food insecurity is gravest in regions of the highest flood risks. Another study confirms that the households that are located near the riverbank are more food insecure than in the mainland (Ahamad and Khondker, 2010). Bangladesh's current rate of population growth and level of technology make it impossible to produce enough food for the population (Mahtab and Karim, 1992). Bangladesh should control its population growth and improve the agricultural technologies, to be able to feed all the people.

The introduction of tube wells has caused a major progress of the quality of drinking water in Bangladesh. Unfortunately, the insurance of safe drinking water is still a problem, while most regions in Sylhet can provide more than 60% of the habitants of safe drinking water. Water testing should be expanded, to ensure the quality of the water (Ahmed et al, 2006). Groundwater from deep wells is a good source of drinking water and does not require treatments. Ahmed et al (2006) expects that when the population continues to grow, many shallow wells become contaminated with human, agricultural and industrial waste.

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http://www.answers.com/topic/alluvium
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http://www.hanken.fi/student/media/3618/spssregressionmodels160.pdf
http://www.himgeology.com/himgeol/vol_22(2)/abstract6.htm
http://www.iufro.org/download/file/.../Bangladesh_pdf/
http://www.jstor.org/discover/10.2307/4313886?uid=41302&uid=3738736&uid=2129&uid=2&uid=70&uid=3&uid=67&uid=5911848&uid=41301&uid=62&sid=47699114734937
http://www.lpcb.org/lpcb/index.php?option=com_docman&task=doc_view&gid=11139&Itemid=32
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2928105/
http://www.ru.nl/publish/pages/525898/logistischeregressie.pdf
http://www.sciencemag.org/content/314/5806/1687.full
http://www.sme-fdi.gc.ca/eic/site/sme_fdi-prf_pme.nsf/eng/02165.html

List of figures and tables

Appendix

Appendix

Appendix 1 Geology data set

This appendix describes the approach of the Geology data layer. It originally consisted of 16 different soil types, categorical. Because of both aspects, this data set needed a different approach then the other data sets. The data is reclassified into fewer classes and got special attention in the binary regression analysis.

Reclassification

Sylhet is divided into 16 different soil types, see Figure A1A. These 16 different geology types have been reclassified into five classes. The function in ArcMap is called *Reclassify* and is listed under the Spatial Analyst Tools. The reason behind this reclassification is that it is useful for the regression analysis to have fewer classes.

The explanation of the reclassification of the geology types below, is based on the description of the soil types of Sylhet, found in the paper *'Stratigraphic evolution and geochemistry of the Neogene Surma Group, Surma Basin, Sylhet, Bangladesh'*. See Figures A1A and A1B for the result.

Alluvium is loose material that is deposited by flowing water. Examples of river sediments are particles of silt, sand, clay and gravel. This is why the old classes alluvial sand, -silt, -silt and clay, - young gravelly and chandina alluvium can be classified into one class called **Alluvium**.

Sandstone is the second class and characterized by geology types that consist mainly of sandstone and are sometimes combined with pebbles, siltstone and clay (stone). On Figure A1B it is clear to see that these types are mostly adjacent to each other.

The bokabil formation, bhuban formation and jaintia group can be seen as one, because they all consist of shale. This is why they are added to the class **Shale**.

Marsh clay and peat and madhupur clay residuum are added together in the class called **Clay.** Madhupur clay residuum consists mainly of pebbly sandstone and sticky clay. (www.herkules.oulu.fi). Looking at the geology map, Figure A1A, the Madhupur clay residuum is a very small area (6.5 m2) surrounded by alluvial silt and marsh clay and peat. So it was reasonable to add it to the clays.

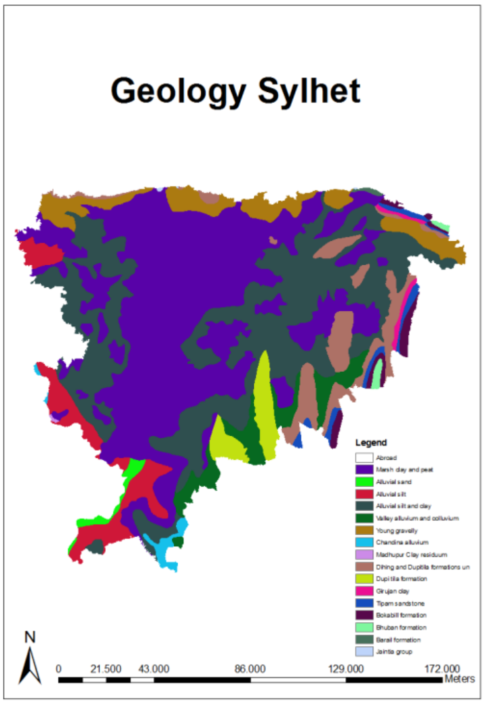
The hills located in the south east of Sylhet (near the Indian border) are eroding (by gravity or wind) and drops it on the bottom of the slope. This type of geology is called **Colluvium** and consists of silt, sand, gravel and clay. It is not added to another class, because it has a specific origin.

Table A Reclassified Geology

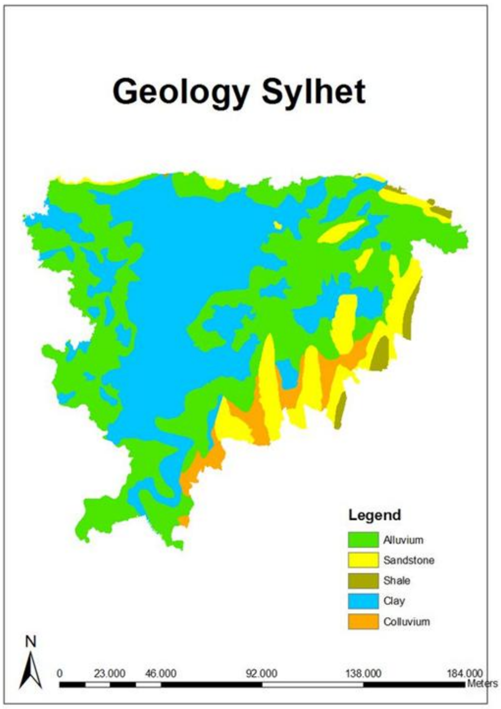
Old class	New class	Area in m2
Alluvial sand	Alluvium	136
Alluvial silt	Alluvium	1036
Alluvial silt and clay	Alluvium	6080
Young gravelly	Alluvium	1157
Chandina alluvium	Alluvium	144
Dihing and Dupitila formations	Sandstone	2143
Dupi tila formation	Sandstone	527
Girujan clay	Sandstone	96
Tipam sandstone	Sandstone	223
Barail formation	Sandstone	23
Bokabill formation	Shale	235
Bhuban formation	Shale	63
Jaintia group	Shale	6
Marsh clay and peat	Clay	8128
Madhupur Clay residuum	Clay	7
Valley alluvium and colluvium	Colluvium	808

Table B Surface Areas of new classes

New class	Area in m2
Alluvium	8553
Clay	8135
Sandstone	3012
Colluvium	808
Shale	204



A Geology Sylhet



B Reclassified Geology

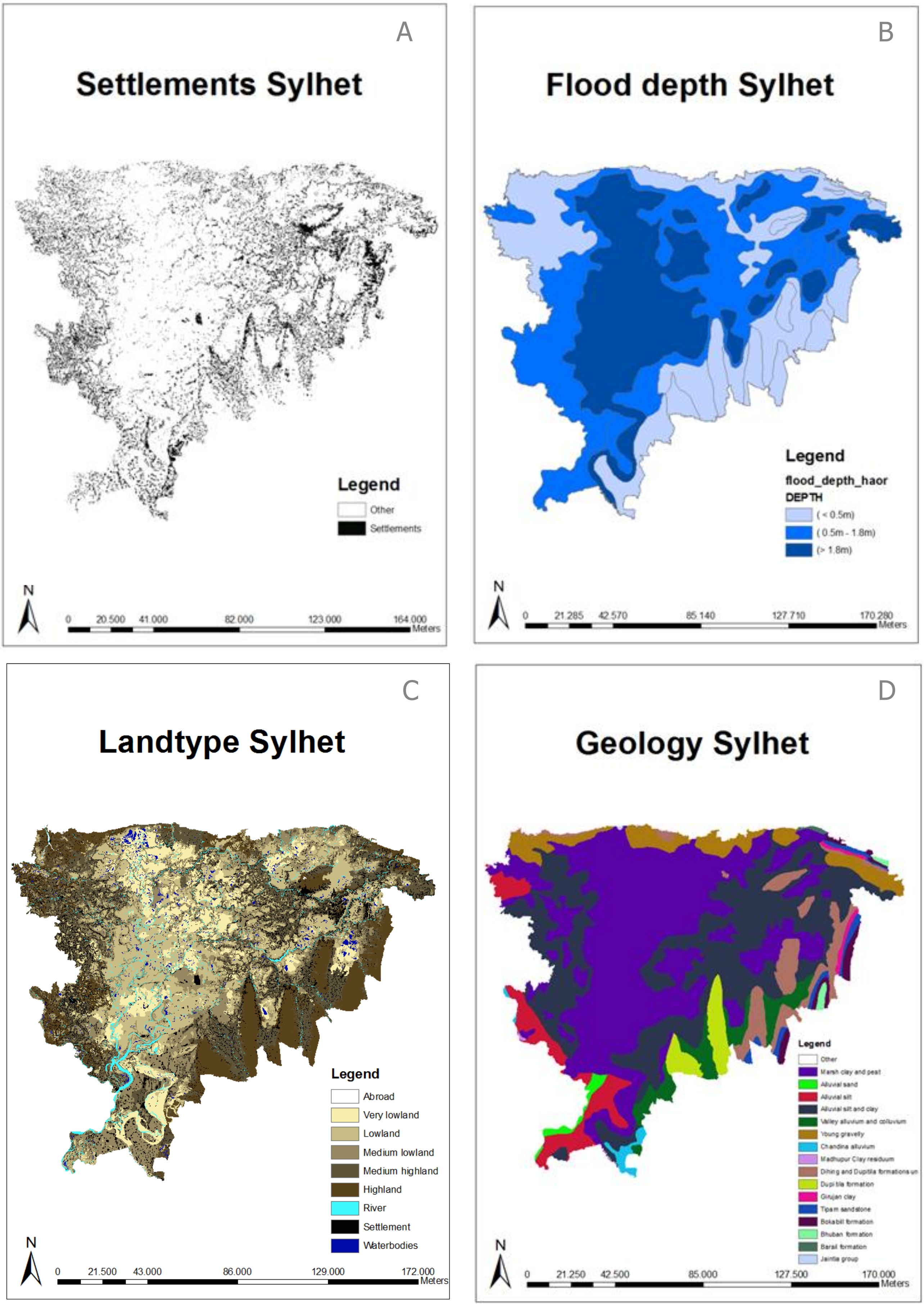
Regression analysis

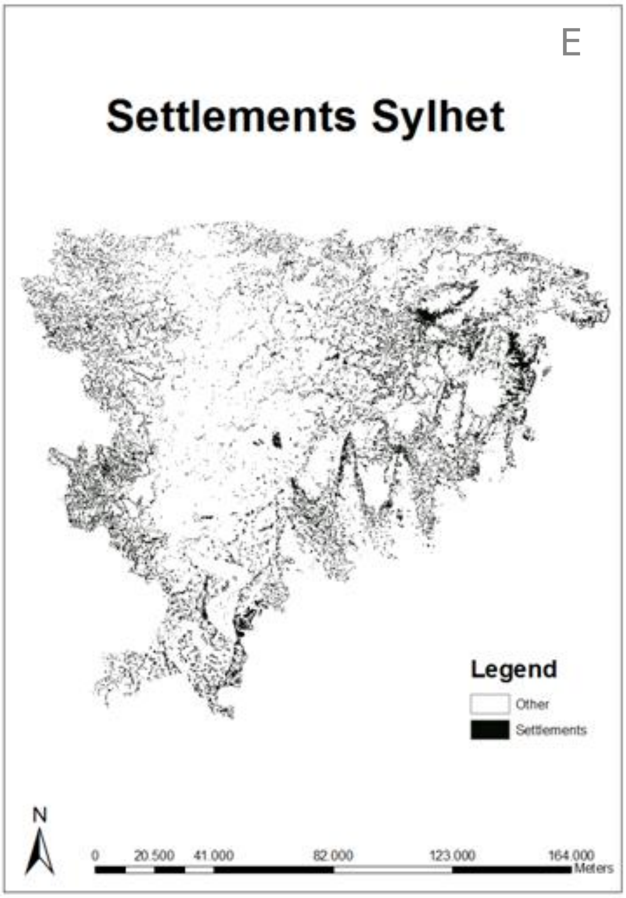
The five soil types fill up the total area of Sylhet (see Appendix 1B). Each soil type is reclassified into a separate map with 0 and 1 data (0=other 1=specific soil type). Only four of the five geology categories will be used as an input in the binary regression analysis. This way, the fifth one will be seen as a reference for the others.

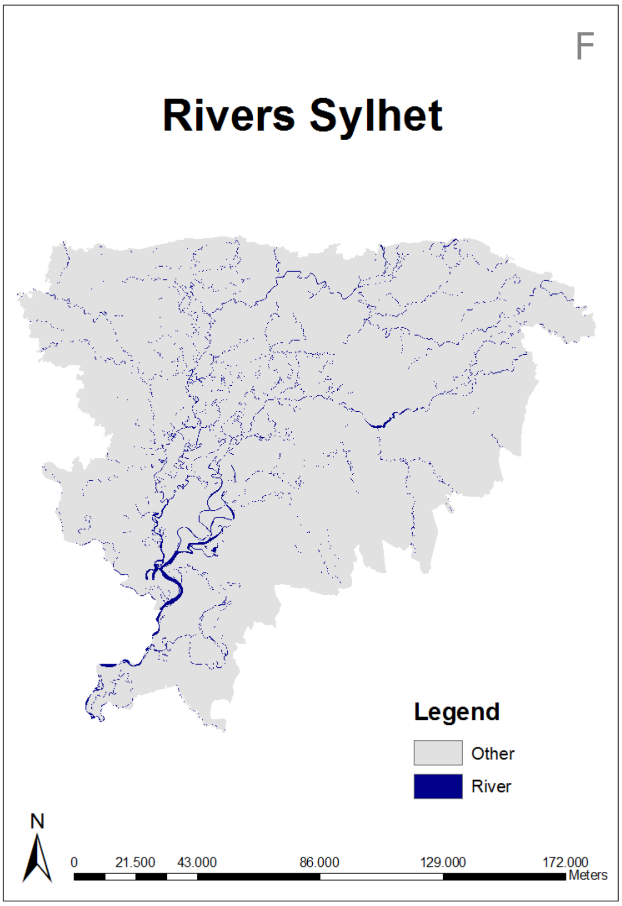
Each categorical covariate can be assigned with a *contrast*. The interpretation of the categorical independent variables depends on the contrast that is used. This analysis chooses for *difference*, where each category of the independent variable (except the first) is compared to the average effect of the previous categories. The categorical geology layers give information about the difference between the independent variable and the chosen reference layer.

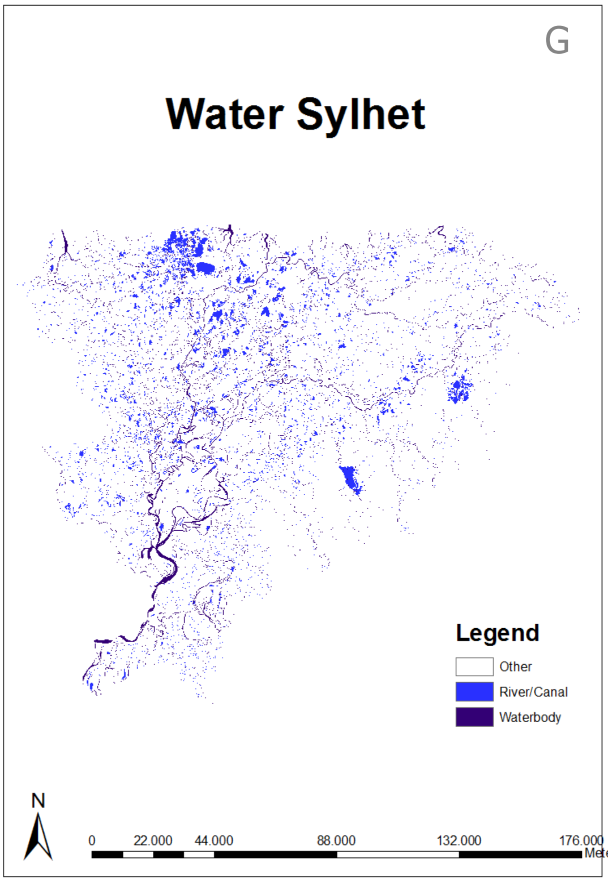
This is why the interpretation is a little different with categorical data sets. For example, the column *Exp(B)* has the number 0.656 for the soil type clay. Since sandstone is the reference layer and its *Exp(B)* is 1.000, the number of 0.656 can be interpreted as follows: The odds of settlements on clay are 34,4% smaller than settlements on sandstone ((1-0.656)x100%).

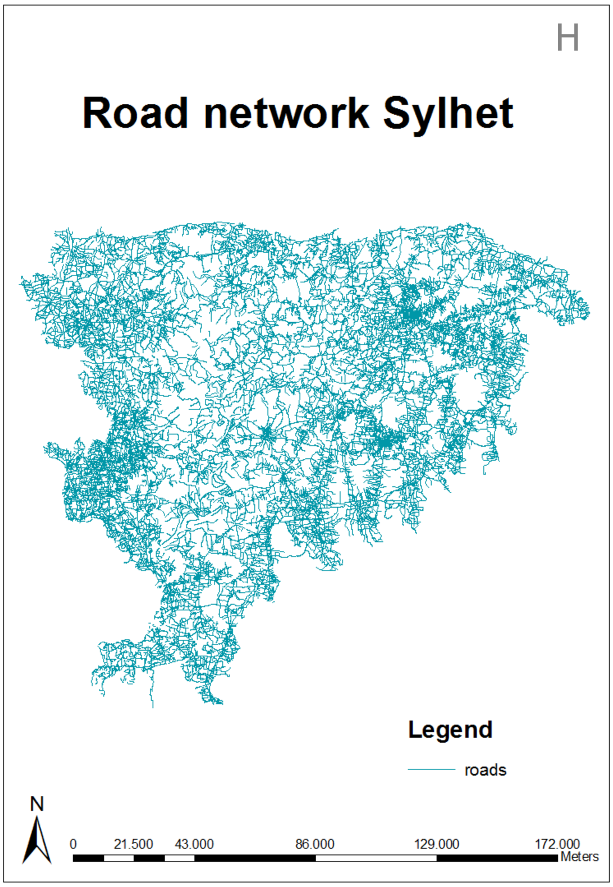
Appendix 2 Maps of Spatial Analysis

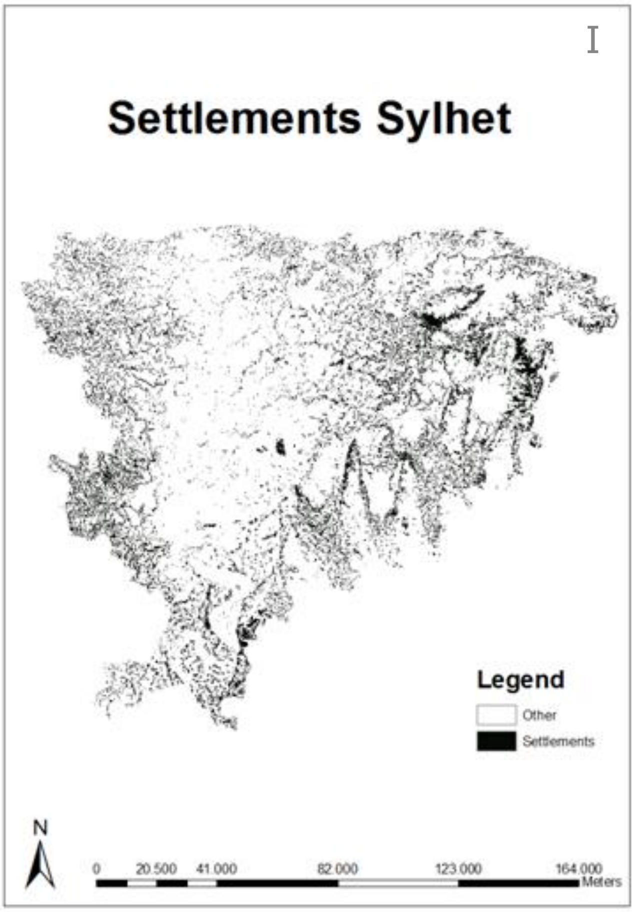


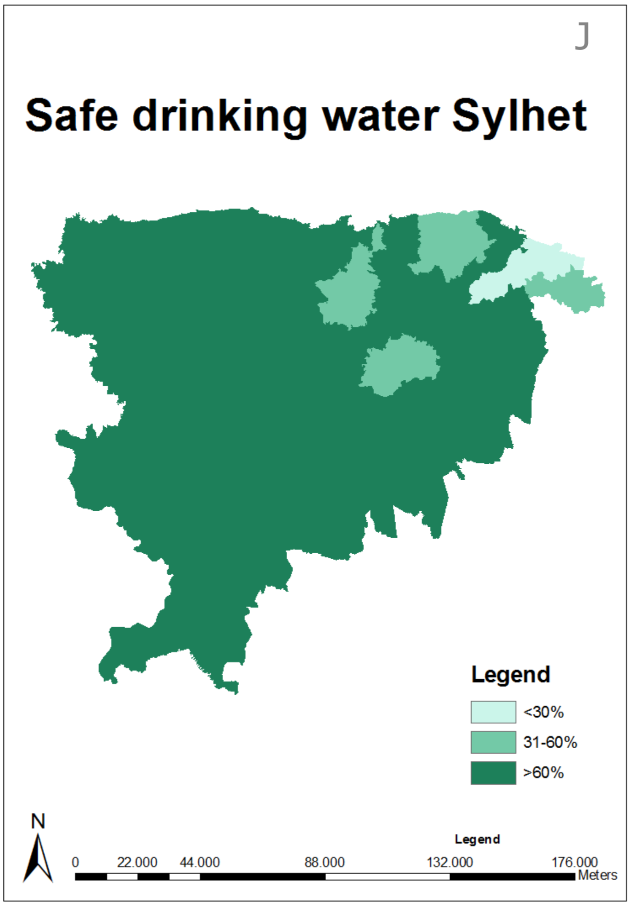

E
Settlements Sylhet
Legend
Other
Settlements
N
0
20.500
41.000
82.000
123.000
164.000
Meters

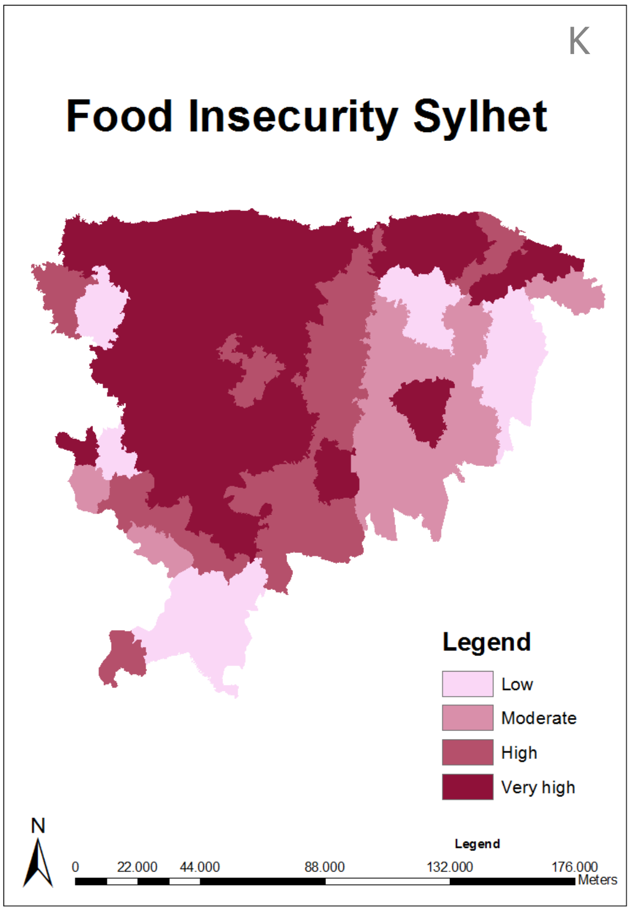

F
Rivers Sylhet
Legend
Other
River
N
0
21.500
43.000
86.000
129.000
172.000
Meters


G
Water Sylhet
Legend
Other
River/Canal
Waterbody
N
0
22.000
44.000
88.000
132.000
176.000
Meters


H
Road network Sylhet
Legend
roads
N
0
21.500
43.000
86.000
129.000
172.000
Meters


I
Settlements Sylhet
Legend
Other
Settlements
N
0
20.500
41.000
82.000
123.000
164.000
Meters


J
Safe drinking water Sylhet
Legend
<30%
31-60%
>60%
N
Legend
0
22.000
44.000
88.000
132.000
176.000
Meters


K
Food Insecurity Sylhet
Legend
Low
Moderate
High
Very high
N
Legend
0
22.000
44.000
88.000
132.000
176.000
Meters

Appendix 3 Interpretations of the regression analysis

Variables with a **negative** influence on the settlements (negative B):

Geology: shale (-)
Negative B: the presence of shale has a negative effect on the location of settlements. (B= -.422)
Exp(B)= .656, the odds of settlements on shale are 34,4% smaller than settlements on sandstone. ((1-0.656) x100%).

Geology: clay (-)
Negative B: the presence of clay has a negative effect on the location of settlements. (B= -.421)
Exp(B)= .656, the odds of settlements on clay are 34,4% smaller than settlements on sandstone. ((1-0.656) x100%).

Flooddepth: (-)
Negative B: the flood depth has a negative effect on the location of settlements. If the flood depth increases, there are less settlements. (B= -3.36)
Exp(B)= .715, the probability of settlements in a higher flood depth area gets smaller with 28,5%. ((1-0.715)x100%)

Since the data layer is ranged from low to deep flood depth and the B is negative, it is not attractive to live in deeper flooded areas.

Distance to road (-)
Negative B: the distance to the road has a negative influence on the location of settlements. (B= -1.086)
Exp(B)= .338, the probability to live/or not to live close to the road gets smaller with 66,2%. ((1-0.338) x100%)

Since the data layer is ranged from close- to far distance from the road: a conclusion is that it is not attractive to live far from the roads.

Safe drinking water (-)
Negative B: the availability of safe drinking water has a negative effect on the location of settlements. (B= -0.091)
Exp(B)= .913, the probability of settlements in a region with good availability of drinking water gets smaller with 8,7%. ((1-0.913) x100%)

Since the data layer is ranged from scarce availability- to lots of availability of safe drinking water, it seems to have a negative effect to live in areas with lots of water.

Food insecurity (-)
Negative B: the presence of food insecurity has a negative effect on the location of settlements. (B= -0.239)
Exp(B)= .787, the probability of settlements in a region with high food insecurity gets smaller with 21,3%. ((1-0.787) x100%)

Since the data layer is ranged from low food insecurity to high food insecurity, it seems that it is not attractive to live in areas with food insecurity, since the B value is negative.

Variables with a **positive** effect on settlements (positive B):

Geology: alluvium (+)
Positive B: the presence of alluvium has a positive effect on the location of settlements. (B=.127)
Exp(B)= 1.136, the odds of settlements on a alluvium soil are 13,6% bigger than on sandstone. ((1.136-1) x100%)

Geology: colluvium (+)
Positive B: the presence of colluviums has a positive effect on the location of settlements. (B= 0.054)
Exp(B)= 1.055, the odds of settlements on a colluvium soil are 5,5% bigger than on sandstone. ((1.055-1) x100%)

Distance to river (+)
Legend is from close to far, the closer, the worse(?)
Positive B: the distance to the river has a positive effect on the location of settlements. (B= 0.058)
Exp(B)= 1.060, the odds of settlements away from the river gets bigger with 6%. ((1.060-1) x100%)

Since the data layers of the distance to river increases and this has a positive B value, it is more attractive to live further away from the river.

Appendix 4 Correlations

The tables below are obtained with SPSS. Analyze > Correlate > Bivariate.
A Bivariate correlation measures the strength of the relationship of two continuous variables. The result is a value between 0 and 1, the closer to 1, the more correlated the variables are. A positive value represents a positive relation and a negative value represents a negative relation.

TABLE C CORRELATION FLOOD DEPTH AND FOOD INSECURITY

		t_flooddep	times_food
t_flooddep	Pearson Correlation	1	.285**
	Sig. (2-tailed)		.000
	N	1966878	1966878
times_food	Pearson Correlation	.285**	1
	Sig. (2-tailed)	.000	
	N	1966878	1966878

**. Correlation is significant at the 0.01 level (2-tailed).

TABLE D CORRELATION FLOOD DEPTH AND LANDTYPE

		t_flooddep	t_rc_landt
t_flooddep	Pearson Correlation	1	-.459**
	Sig. (2-tailed)		.000
	N	1966878	1966878
t_rc_landt	Pearson Correlation	-.459**	1
	Sig. (2-tailed)	.000	
	N	1966878	1966878

**. Correlation is significant at the 0.01 level (2-tailed).

TABLE E CORRELATION FLOOD DEPTH AND RECLASSIFIED GEOLOGY

		t_flooddep	reclass_ge
t_flooddep	Pearson Correlation	1	.341**
	Sig. (2-tailed)		.000
	N	1966878	1966878
reclass_ge	Pearson Correlation	.341**	1
	Sig. (2-tailed)	.000	
	N	1966878	1966878

**. Correlation is significant at the 0.01 level (2-tailed).

TABLE F CORRELATION NUTRITION AND FOOD INSECURITY

		t_nutritio	times_food
t_nutritio	Pearson Correlation	1	.679**
	Sig. (2-tailed)		.000
	N	1966878	1966878
times_food	Pearson Correlation	.679**	1
	Sig. (2-tailed)	.000	
	N	1966878	1966878

**. Correlation is significant at the 0.01 level (2-tailed).