Master project report

Irrigation mapping of Guantao County, China

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Contents

1 Summary

In arid and semi-arid areas upstream agricultural water demand takes most of the water from the rivers and as a result little water is delivered to the downstream. The phenomenon is also observed in North China Plain (NCP), where in addition to reduced surface water flows the intensity of irrigation increased by double cropping of winter wheat and summer maize. Hence, irrigation relies on groundwater aquifers. Since the 1970s a significant decline is observed (~1 m/year) in groundwater levels (Foster et al., 2004). The consequences of groundwater level decline can be:

- Permanent loss of aquifer capacity
- Land subsidence
- Decrease in water quality (e.g. by increase in salinity of water)
- Sea water intrusion
- Loss of wetlands

Sustainable irrigation management can play a significant role in preventing groundwater related issues. As irrigation is one of the main consumers of water resources and at the same time a cause of problems such as soil salinity, crop water demand models are useful in the planning and management of water resources. Particularly, irrigation models can help with optimization of crop yield and minimization of water consumption for the irrigation (Yang et al., 2010).

In this piece of work, a FAO (Food and Agriculture Organization of the United Nations) guidelines based irrigation water demand calculator (Hydrosolutions ltd.) and ArcGIS tools (ESRI 2015) were applied to have spatially distributed water demand maps of Guantao County in China. The maps can be used for:

- Decision making processes
- Sustainable irrigation management and planning
- GW level decline recovery

In addition, current irrigation management situation and its statistics data were analysed and compared with the model simulation results.

2 Introduction

2.1 North China plain

Severe water shortage is one of the biggest challenges in North China Plain. It is mainly caused by strong water demands of the large population, expanding irrigated agriculture area, commercial and domestic sectors. Agriculture has been stated as the major water consumer which approximately accounts for up to 70% of total water use in the North China Plain (Hu et al., 2010).

Surface water in the plain is strongly controlled and almost completely reserved for urban area purposes consumption. For this reason irrigation water demand requirements are usually met by groundwater pumps. The practice of groundwater exploitation for irrigation reasons have resulted in steep groundwater decline in the region (Yang et al., 2010).

2.1.1 Ground water level decline

The population and economic activity growth are noticed in the last 25 years in the region. However, the majority of those developments have been heavily dependent on groundwater resources. The significant exploitation of groundwater (according estimation in 1988 at 27,000 million m^3/year in the Hai He basin) has obtained large socio-economic benefits in relation to farming employment, poverty reduction, grain production. Nonetheless, it has also faced increasing significant difficulties concerning:

- Decline in groundwater table in the shallow aquifer
- Subsiding groundwater levels in the deep aquifer
- Risk of aquifer salinization as a result of inadequately controlled pumping practices

Most of the rural areas with piedmont plain stretching onto the alluvial flood plain, the shallow aquifer has experienced a decline in water table more than 15 meters over the past 40 years (Figure 2). Most of the greatest declines have been observed mostly in urban centres.

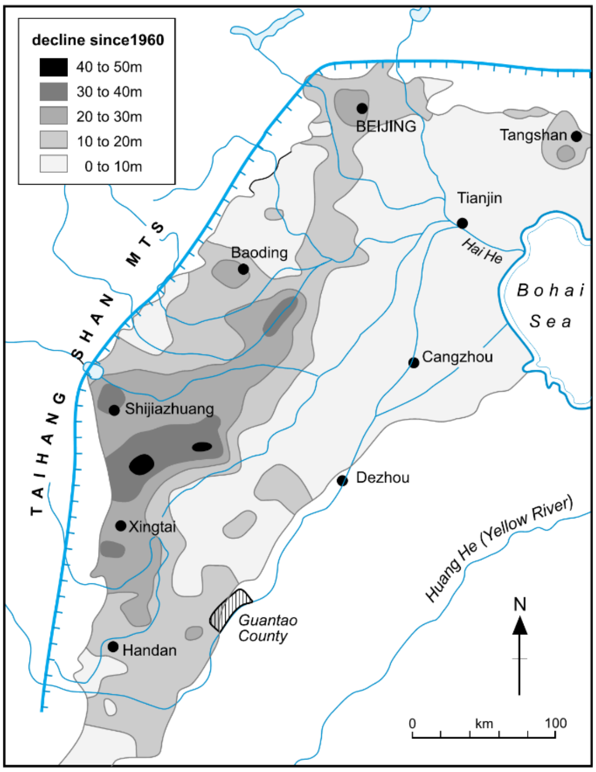

Figure 2 Cumulative groundwater table water table lowering of the shallow aquifer of the North China Plain between 1960 and 2000 ((Foster et al., 2004)

Although a substantial lowering of groundwater levels is often necessary with major groundwater development, it has been stated that in the year of 1988 average groundwater abstraction exceeded recharge around by 8.800 million m^3/year in the Hai river basin. According to the reasonable range of values for specific yield of the strata drained, the continuous long-term water table decline of 0.5 m/year approximately equals to an average recharge deficit of 40-90 mm/year (Foster et al., 2004).

2.1.2 Current irrigation management

Approximately 50% of China's wheat and 33% of its maize are produced in the North China Plain. Winter-wheat and summer-maize are the main cultivated grain crops in the plain by double cropping agricultural practice. Double cropping is explained as the way of cultivating two types of crops in one year. Thus, first winter wheat is cultivated and later, after harvesting winter wheat, summer maize is planted. Winter wheat and summer maize have an estimated annual evapotranspiration (ET) of 850 mm which significantly exceeds the long term average annual precipitation of 550 mm. Because of this considerable difference between irrigation demand and precipitation and the lack of surface water, severe groundwater problems are faced. For instance, they include groundwater level decline, sea water intrusion and soil salinization (Hu et al., 2010).

Although reducing irrigation water consumption might help solving groundwater and other water resources related issues, it might also result in serious crop yield reduction which has economic and social consequences. The proper approach in case of North China Plain issue lies in more holistic way, combining different sustainable water usage measures and methods. For example, by means of computer models and simulations, it is possible to have suitable and sustainable planning and management practices using methods such as scenario analysis (Foster et al., 2004; Hu et al., 2010; Yang et al., 2010; Bastiaanssen et al.).

3 Scope and Objective

3.1 Guantao County

3.1.1 General information

Guantao County is located in the southern part of Hebei Province (Figure 3), with a total area of 456 km^2 and its average precipitation is 550 mm/year. The County has a shallow freshwater aquifer covering about 60-70% of its land area, but with the underlying brackish-water aquifer at relatively shallow depth. Lower than the shallow aquifer, there is a deep freshwater aquifer with very low salinity. Thus good quality water is present all over the region as deep aquifer water.

Table 1 in Appendix demonstrates data about the major crop types and its corresponding areas in the county. As it can be seen from the table, summer grains which are harvested in summer play a significant role. In this particular case it is a winter wheat which is a major summer grain. Winter wheat it also believed to consume majority of the irrigation water in the region (GCWRB).

3.1.2 Irrigation management in the county

Major types of crops in Guantao County are wheat, maize, cotton and vegetables. Mostly, two types of groundwater pumps are applied to extract water. First type extracts water from shallow aquifer. Second type pumps water from the deep aquifer which has good quality with less salinity. However, in practice farmers tend to use mixing shallow aquifer water and deep aquifer water and irrigates by switching two types of water. The reason is the fact that shallow water pumps area easier and more available to install by the farmers. For the sake of convenience and cost, farmers make a trade-off between two kinds of irrigation water sources.

As an irrigation method, mainly flood irrigation is conducted. However, transport loss during the water delivery to the field is very small, because pumped water from groundwater is sent by pipes. Firstly, it is transported with big sized piped and later water is allocated to the pipes of small size and eventually flood irrigation occurs. As the area of flood irrigation is highly controlled and has a small size, the efficiency of flood irrigation gets high as well.

As mentioned above, two sorts of agricultural strategies are used in the region: single and double cropping system. Single cropping system involves usually soybeans and millet, however double cropping system involves winter wheat and summer maize. Water Footprint of grain in NCP is 2.9 kg grain per 1 m^3 of water (Foster et al., 2004; Kinzelbach et al. , 2015; Statistical yearbook; GCWRB).

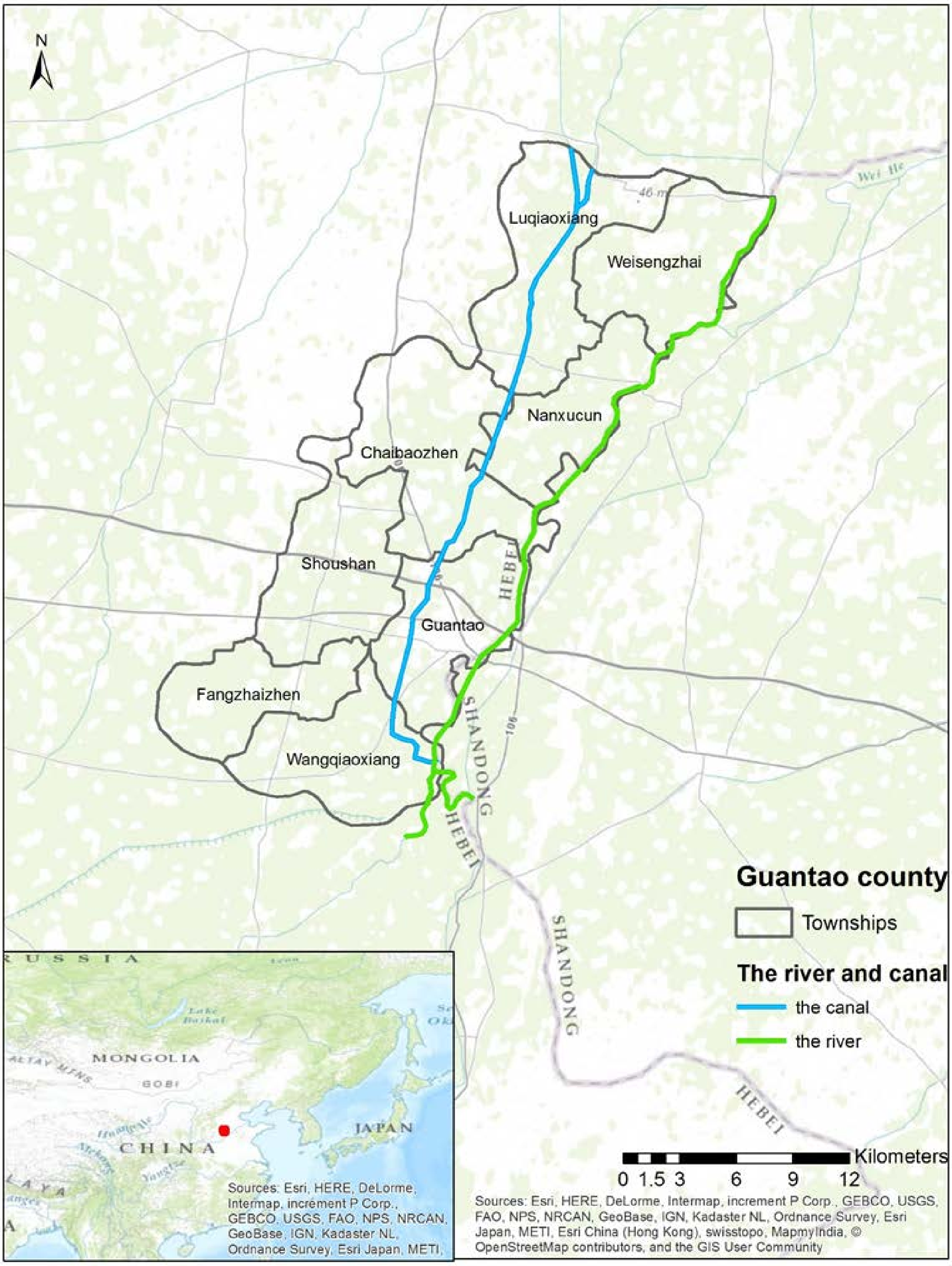

Figure 3 Topographic map of Guantao County

3.2 The aim of the work

The aim of the research is to construct an irrigation water demand map which can be used for:

- Sustainable irrigation management and planning
- Irrigation water balance
- Water consumption reduction in agricultural practices
- Optimal water allocation and less groundwater consumption
- Linkage of groundwater model and crop model

3.2.1 Irrigation water demand

In order to get irrigation maps of the Guantao County, an irrigation calculator, remote sensing data on crop type and data about actual water consumption are used. Irrigation calculator of Hydrosolutions ltd. and Landsat satellite crop type images were applied in the project.

The irrigation calculator requires manual choices such as soil type, irrigation type and crop type. If spatially distributed maps of soil type, irrigation type and crop type is used as in input, it is possible to make the irrigation calculator automatic so that it automatically choses the types of crop and soil and calculates crop requirement for whole region at once and later it can be plotted easily as a map. However, in order to do it, some georeferenced spatial data is needed like:

- Spatial distribution of crop types
- Spatial distribution of soil types
- Spatial distribution of irrigation types

3.2.2 Irrigation water demand and recharge by irrigation backflow maps of Guantao County

Depending on the availability of data about the recharge by irrigation backflow, spatially distributed map of the recharge by backflow can also be made. To date, not much is known about the recharge in the region. However, estimates and experiments exist in the nearby Shijiazhuang (Kinzelbach et al. , 2015). It has to be investigated how to link recharge by backflow to the irrigation calculator. The irrigation calculator also to some degree accounts for recharge but possibly it has to be modified (Hydrosolutions ltd.).

Irrigation map and recharge maps of Guantao County are compared and validated with the local statistics data. Those maps can be used later for:

- Decision making processes
- Sustainable irrigation management and planning
- GW level decline recovery

4 Materials and methods

4.1 Data about irrigation management in Guantao County

The main data about agriculture and irrigation management situation in Gauntao County were collected from Guantao department of water resources. Some crucial statistics about land use area and water consumption of the county were analysed and plotted.

4.1.1 Trends in land use area and crop types

In terms of crop land area in Guantao county it can be noticed that in general the trends are stable (Figure 4). Some changes occurred in autumn grain crop areas between 1997 and 2008. Cotton crop area also experienced some fluctuations between the period of 1998 and 2007. In relation to total cropped area, only in the duration from 2003 and 2006 some changes happened, but laterwards the trend has become stable. The reason for achieving stability is due to some local regulatioins (Foster et al., 2004).

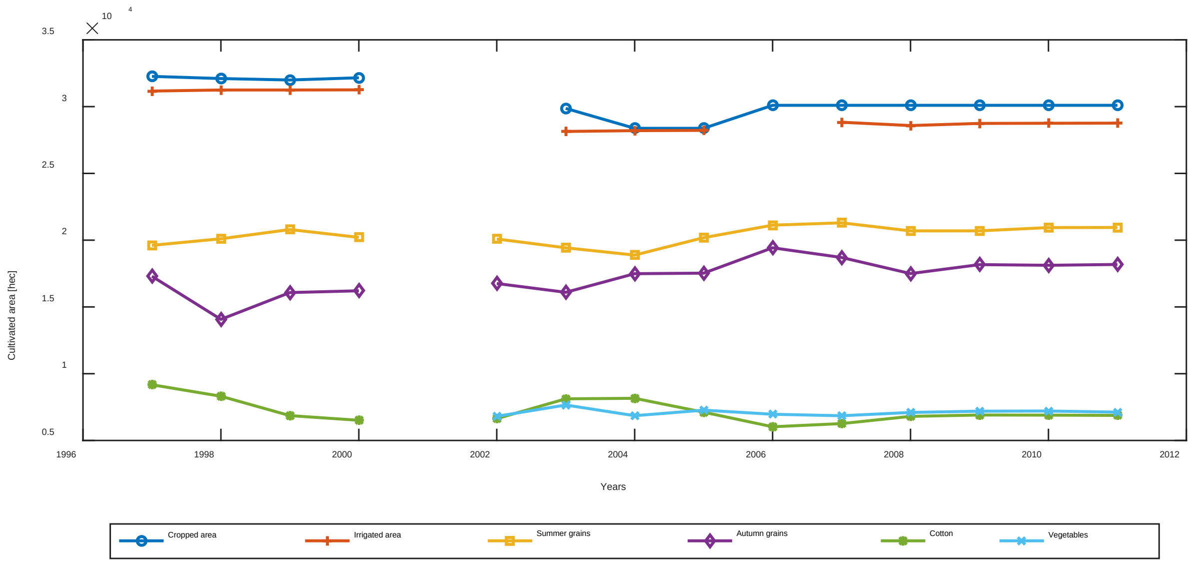

Figure 4 Trends in cropped area between the period of 1997 and 2011

In order to see some relationship between electro-mechanical wells and electricity usage, they were plotted in Figure 5. There are seems to be a correlation between these two factors. Nevertheless, despite the fact that the plot shows some correlation, it should be used with caution as there is no direct cause and effect relationship between them. For example, electricity consumption might increase if there is an increase in domestic appliances or in livestock. Therefore, the more numbers of electro-mechanical wells does not necessarily mean the more electricity usage. Figure 6 demonstrates overall trend in irrigated areas, the numbers of electro-mechanical wells and the electricity usage. Electro-mechanical wells and electricity usage show increasing trend, but irrigated area shows some dramatic changes. Between 2000 and 2004 a steep decline in the irrigation area occurred.

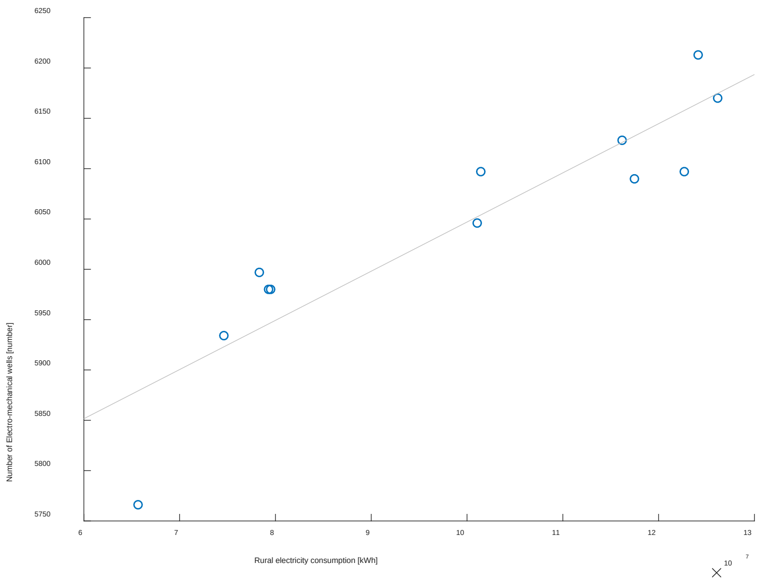

Figure 5 Correlation between number of Electro-mechanical wells and electricity usage between the period of 1997 and 2011

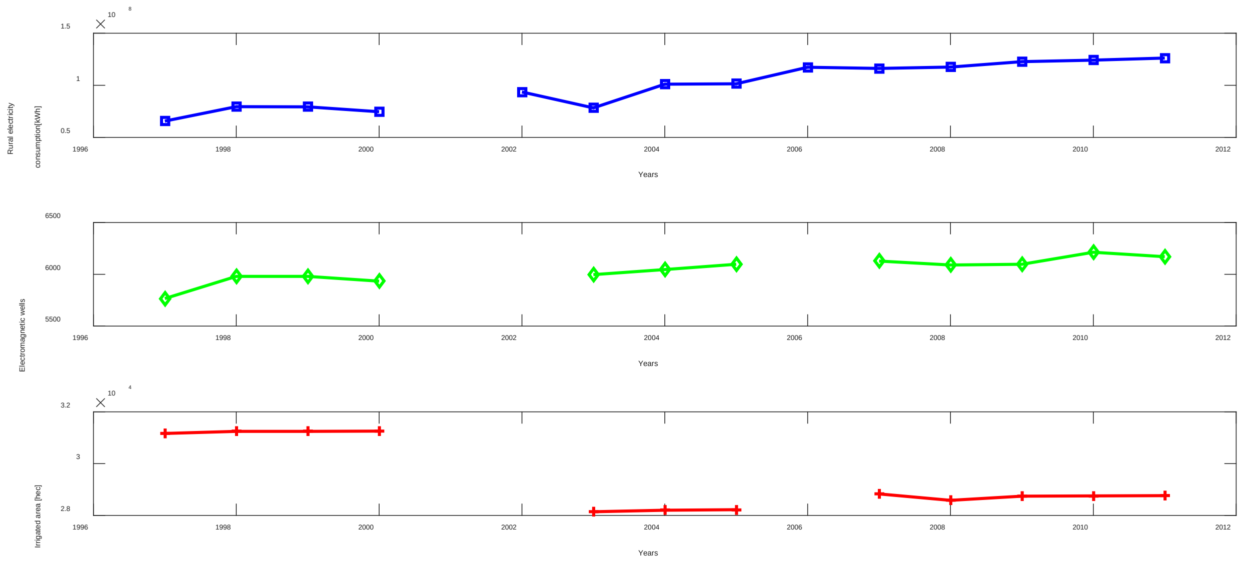

Figure 6 Trends in wells and electricity consumption between 1997 and 2011

4.1.2 Areas of cultivated crop types

Guantao County has eight townships. Using data about crop areas in each townwhip, different maps were produced in ArcGIS software. The maps in Figure 7 illustrates ratio of wheat, maize, cotton and vegetables area to the total crop area.

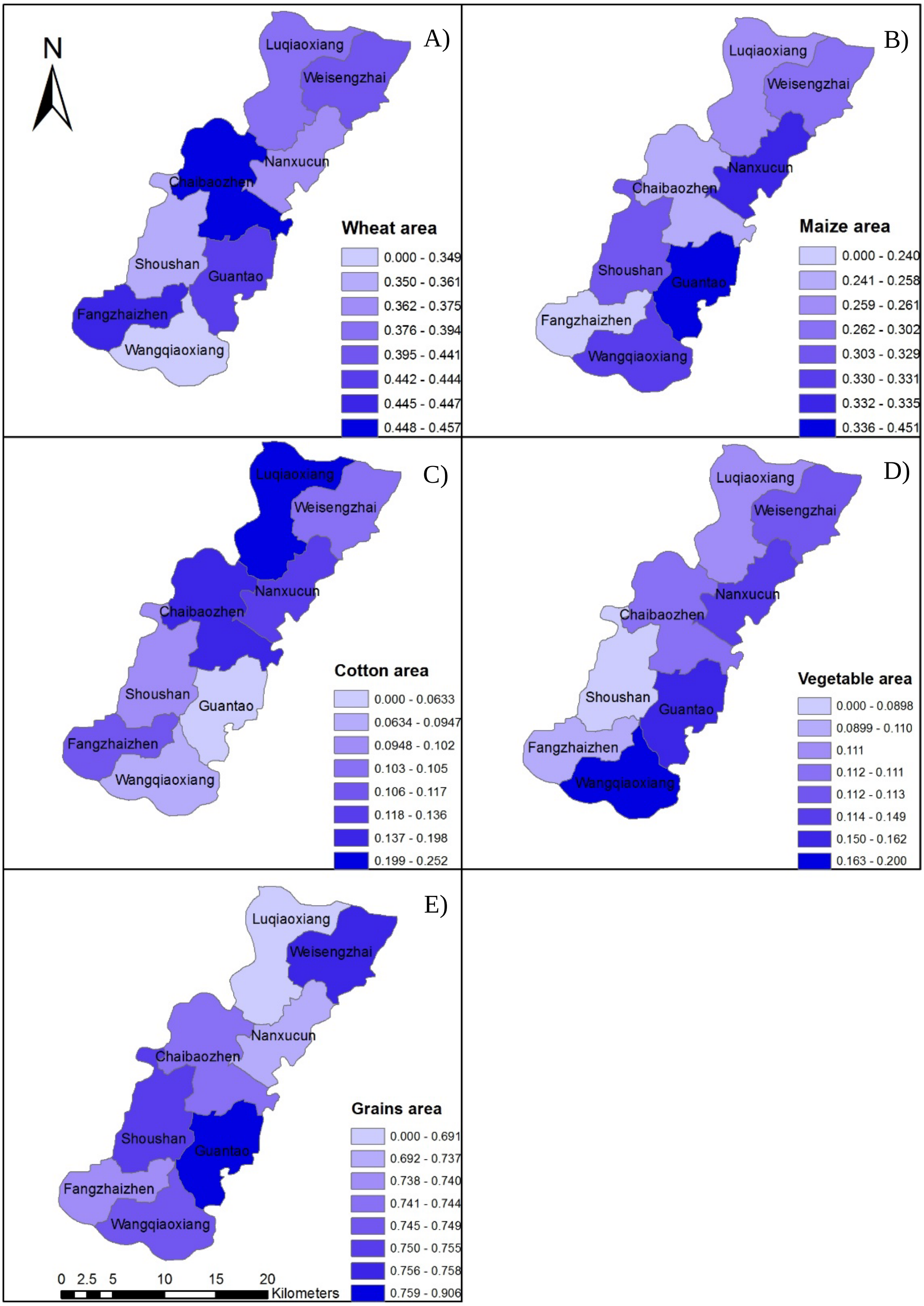

Figure 7 Ratio of each crop area to the total cultivated area in terms of wheat (A), maize (B), cotton (C), vegetables (D) and total grains area (E) averaged for the period 1998–2013

Furthermore, total grains area was mapped to see the contribution of grains in total land use for agriculture. Approximately, 35 to 50% of land use area in each township were cultivated for winter wheat. Similar pattern can be seen in terms of summer maize as well. However, summer maize area is less than winter wheat's, in spite of double cropping them.

4.2 Irrigation model

4.2.1 Model version

To calculate irrigation demand, Hydrosolutions ltd. irrigation calculator package was used. Irrigation calculator or crop water demand model illustrates the optimal water amount and irrigation interval. It also shows what dates and duration for watering to optimize the yield. The irrigation model is written in Matlab environment and considerably flexible to use.

The version of irrigation calculator takes as an input data Google Earth Pro '.kml' file type maps. These Google Earth Pro maps make the model very easy to use and apply. Users can draw their fields and quickly calculate water demand based on parameters such as soil type, crop type, irrigation method, soil salinity etc. (Hydrosolutions ltd.).

More importantly, the water demand model automatically downloads climate data for the specified region and automatically processes it to make it manageable for further use.

The output results of the model are saved both as MS Excel files and as a Google Earth format map. The map shows more visual representation of fields and their corresponding values and parameters.

In this case, as an input to the irrigation calculator, several maps of major crop types were used. The input maps will be discussed in detail in the results section.

4.2.2 Irrigation model principles

Hydrosolutions ltd. Irrigation calculator package is based on the FAO guidelines (Allen et al., 1998). Depending on the user defined description of specific crop fields, the model choses FAO's empirical coefficients. Main tables of coefficients show soil type, irrigation methods efficiency, crop type coefficients (see Appendix C).

The model follow the three main steps to calculate crop water demand. Firstly, the calculation potential and actual evapotranspiration proceeds. Then, using FAO crop coefficients, it calculates crop evapotranspiration. To get the potential evapotranspiration Hargreaves PET model is applied.

Second step involves the computation of the soil water balance. The balance equations are derived from Allen et al., 1998. The concept of this model is similar to the concept of the bucked models. Here, first model fills the soil with water by irrigating. As after some period of time, water evaporates and reaches a certain level of dryness and soil water capacity gets empty and it starts filling in again. This certain limit is called a threshold value. The threshold values is very sensitive to the final water demand values. Nevertheles, this emptying rate of soil water is crucial. The irrigation calculator uses empirically derived set of coefficents to define the rate of that emptying the soil water content.

The following equation is core soil water balance equation of the model:

$$D_{r,i} = D_{r,i-1} - (P - RO)_i - I_i - CR_i + K_s ET_{c,i} + DP_i$$

where:

$D_{r,i}$	=	root zone depletion at the end of day i [mm],
$D_{r,i-1}$	=	root zone depletion at the end of the previous day, $i - 1$ [mm],
P_i.	=	precipitation on day i [mm],
RO_i	=	runoff from the soil surface on day i [mm],
I_i	=	net irrigation depth on day i that infiltrates the soil [mm],
CR_i	=	capillary rise from the groundwater table on day i [mm],
$K_{s,i}$	=	transpiration reduction factor on day i [-]
$ET_{c,i}$	=	crop evapotranspiration on day i [mm],
DP_i	=	water loss out of the root zone by deep percolation on day i [mm].

Finally, the model calculates all the losses such as transportation loss and leakages in the canals. Those loss processes are also simplified using FAO empirical set of coefficients which define the efficiency of particular type of canals. For example, if the water is delivered by pipes, then the efficiency is 100 percent. It is assumed that there is no loss in piped water transportation.

However, it reality it might be considerably different. According to experts in Guantao County, the efficiency of pipes is around 80%. Although the model assumes 100% efficiency, in reality there are around 20% water losses during the transportation. Iteration method was used to solve the main set of equations in Matlab (Hydrosolutions ltd.).

5 Results

5.1 Digitization of maps

5.1.1 Soil map

Before beginning irrigation water demand calculations, soil map was created using ArcGIS tools (ESRI 2015). Scanned images of soil types of the region were digitized and georeferenced and saved as a soil type map of Guantao County. The created soil map shows the main 5 types of soils situated in Guantao County. Furthermore, the map was divided according to its townships. The reason as mentioned above, to compare water demand in terms of townships level. Soil type plays a significant role in the calculation of crop water demand. Each type of soil will produced different results in the crop model (Allen et al., 1998).

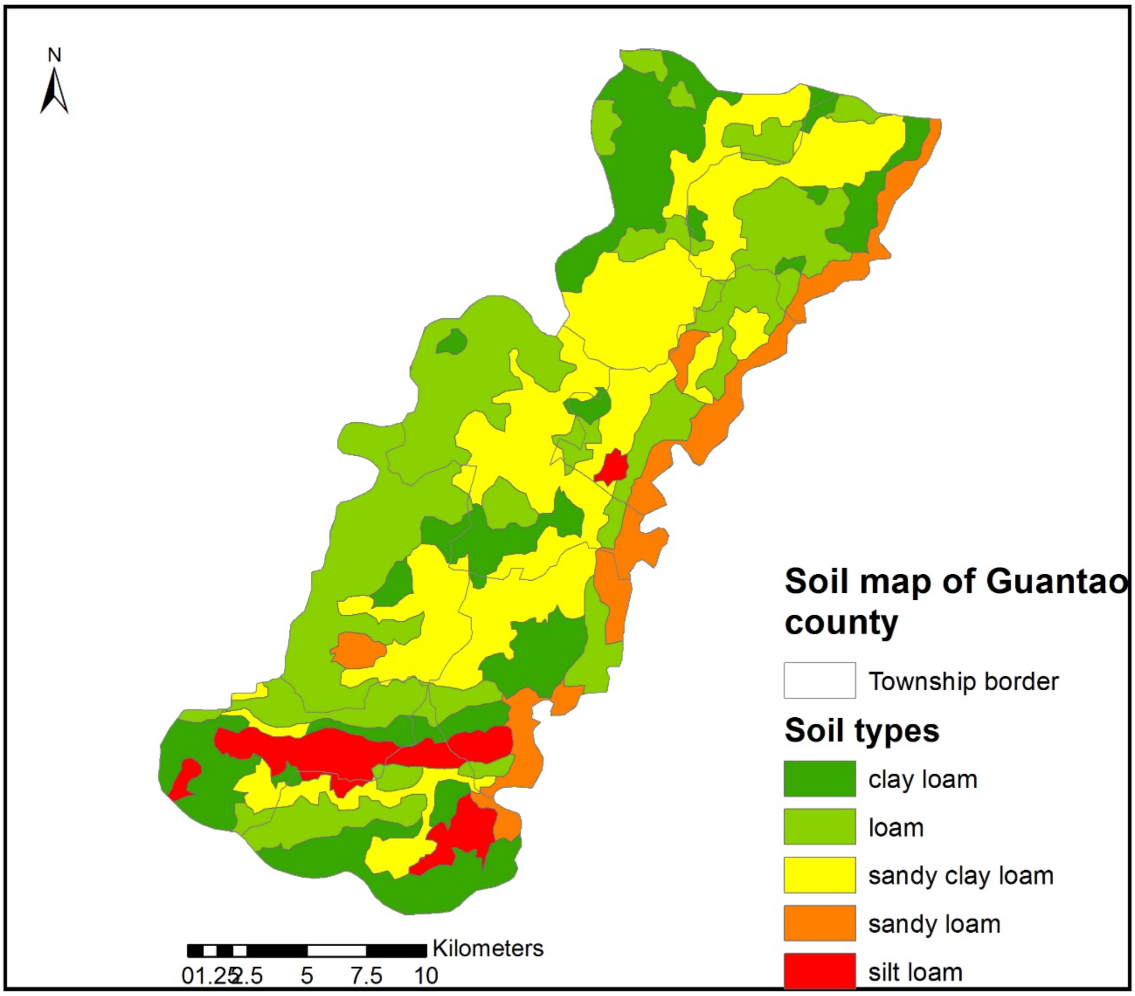

Figure 8 Soil type map of Guantao County

The achieved soil map of Guantao County was a fundamental and ubiquitous basis map for spatially distributed mapping of crop and water demand. Two parameters played a key role in the water demand mapping: spatial distribution of soil types and crop types. Crop types were also spatially distributed, but it will be described in the next section.

5.1.2 Crop type maps

As the main crop is wheat in the region, wheat was a main focus of the project work. However, at first spatially distribued maps of total crop fields and wheat field maps were analysed together. The maps were in raster format proceses and prepared from satillite images (USGS, 2014). By converting forwards and backwards between different formats and using additional image processing tools in ArcGIS, total crop area was divided to wheat, maize, cotton and vegetabe areas. From the statistical data about Guantao County, the percentages of wheat, maize, cotton and vegetabe areas were derived. Applying those ratios, it was possible to get approximated spatial maps of each crop type.

In addition, NOAA's Biogeography Branch Sampling Design Tool for ArcGIS was used to select random pixels of specific crop area. For exampe, first procedure started with given wheat area in terms of whole Guantao county. According to the experts and statistical data, wheat and maize are mainly double cropped. Therfore, it was assumed that for the same location where wheat usually grows, maize is cultivated as well. However, the size of maize cropping area is slightly smaller than wheat croppping area. Thus, spatial sampling tool was required to squize and reduce the area of maize uniformly per township. Consequently, spatial distribution of soil map is conserved. Only specific locations of maize fields were randomly selected, because it not known for each specific field in Guantao County.

The random sampling tool selects randomly each pixel(Figure 10). It continues selecting random pixels until it reaches the user defined limit or threshold. In this case, the percentage of maize in that area was entered to the tool as a limit. After the random selection, the tool choses the needed number of pixels and selected pixels were saved a new map layer. Another advantage of this random selection tool is that it selectes for 8 townships with their 8 ratios of maize and wheat area. Thus, the percentage of each tonwhip is conserved.

The same procedure was conducted in relation to cotton and tomato. Nevertheless, it should be noted that cotton and tomato usualy are not double cropped. Hence, where cotton grows, only cotton tend to grow and no double cropping with other crops. Therefore, wheat and maize cropping areas where not involved at all in regard to cotton and tomato. It was assumed that cotton and tomato does not grow in those fields where wheat and maize grow. The end results and processing steps can be seen in Figure 9.

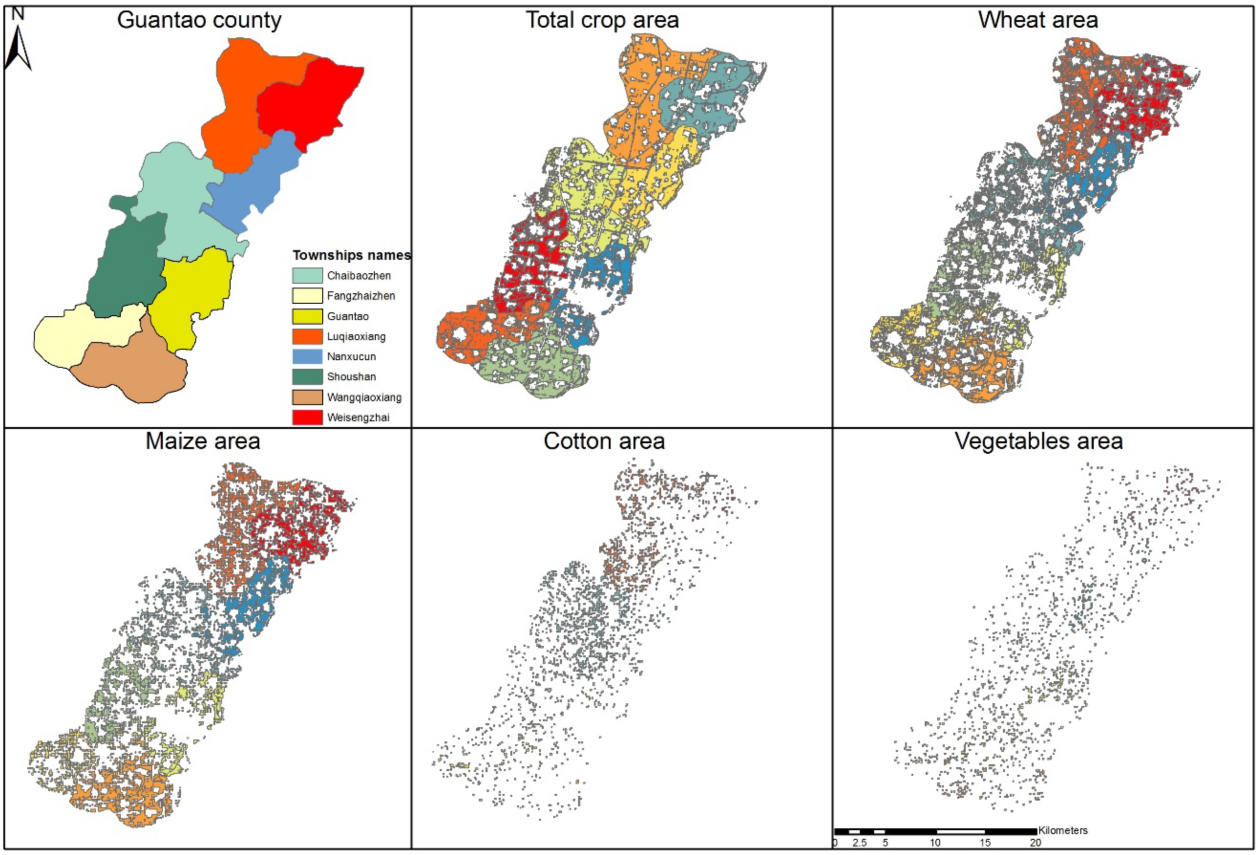

Figure 9 Crop area processing in ArcGIS

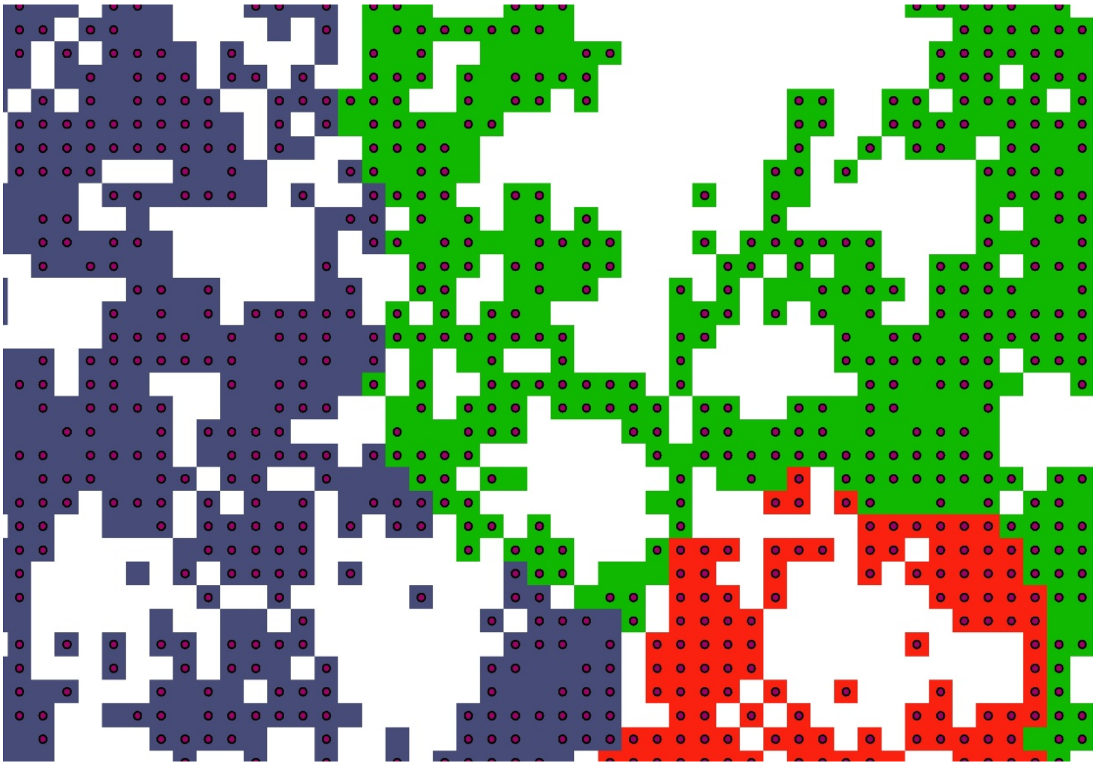

Figure 10 Random selection tool example

Figure 11 demonstrates the quality of wheat crop area. As the crop area of wheat is processed from satillite images, it is not precise. However, from Figure 11 it can be noticed that accuracy is significant as it does not cover and overlap urban areas.

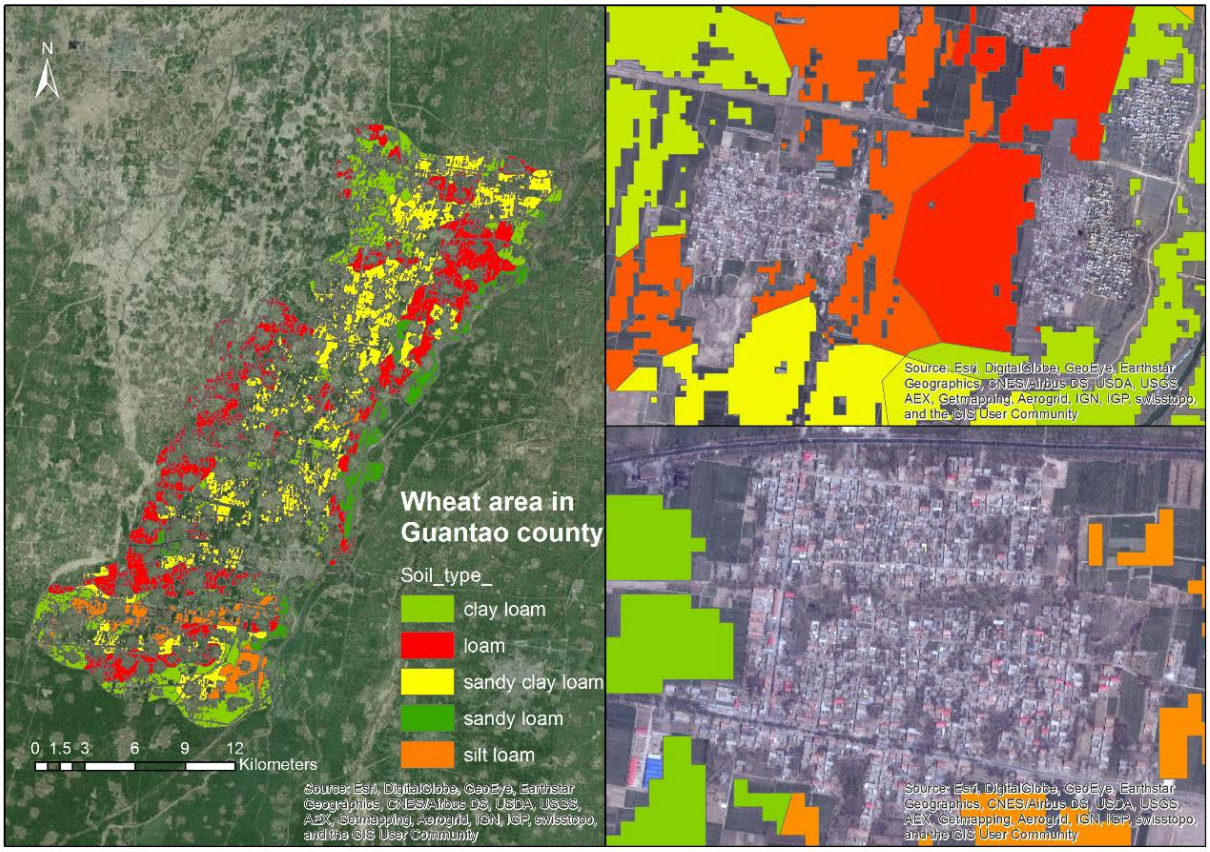

Figure 11 Winter wheat area in Guantao County with the satellite image to show that it does not overlap with the urban areas.

5.2 Crop water demand results from the model

The irrigation water demand model was run several times after making all the needed crop maps as an input. The resutls of simulation were further processed. Area weighted average method used to get average values of water demand for each township. By means of the area weighted average method the water demand [mm] values were weighted in terms each townships soil types area and total crop area. Each township has certain types of soils and their corresponding areas. Those specific soil type area of each particular townships were used to get average value of the total water demand per season. Moreover, the model was run for three main types of year climatology: dry, wet and average years in terms of precipitation.

5.2.1 Water demand

Figure 10 shows the average water demand values for each township for dry, average and wet years. The winter wheat water demand simulation was sensitive and showed slightly higher results than local irrigation norms. The local irrigation norms are the specific amount of water which is defined the responsible authorities to irrigation each water. The norms used to plan and estimate the water demand for each year. However, those local irrigation norms tend to be outdates and not optimized. For Hebei province the local irrigation norm for an average year:

wheat 239 mm, maize 67 mm and cotton 150 mm (GCWRB). In the following paragraphs these irrigation norms will be compared with the model results.

As it can be observed from the Figure 12 wheat value does vary in terms of dry, wet and average years. Dry year requires more water because the precipitation is lower. For that reason, average year water demand is significantly lower than the dry year water demand. However, the wet year results slightly higher than the average year results. Ideally, wet year should have the lowest water demand. This indicates that the model is still sensitive to wheat water demand calculations and should be further studied.

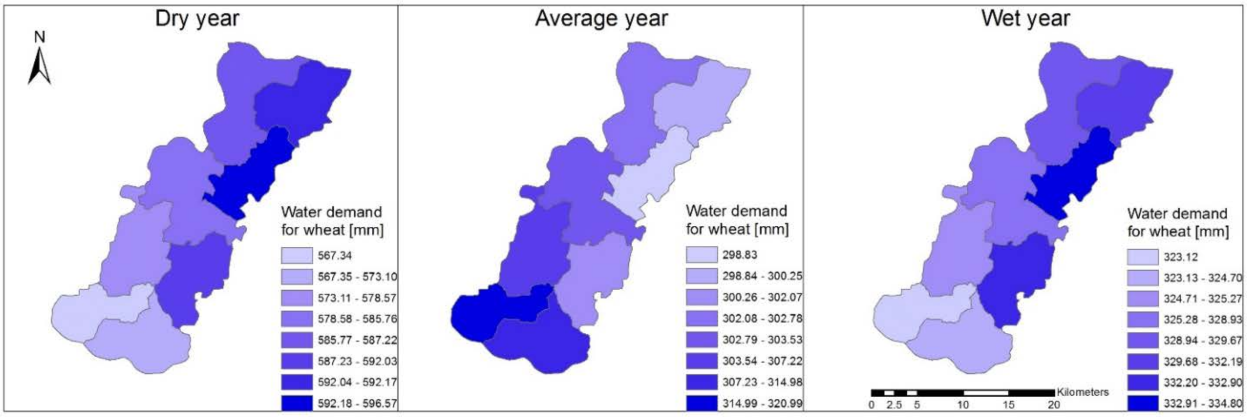

Figure 12 Water demand for wheat

Water demand for maize were closer to irrigation norms which are used in practice in China. As in the wet year there are more pricipitation available, the model did not give results for wet year in terms of maize for all townships. It is also the fact that maize grows in the rainy season in the summer time. Nonetheless, average year results seem to be very close to dry year which should be clarfied in detail in the future. Despite the fact that the irrigation norms of the region are less than the model does not necessarily mean that less water is used in practice. What amount water is exactly used in reality for irrigation is not known. Farmers usually tend to irrigate more than needed. In addition, the model shows ideal and optimal case water demands (GCWRB).

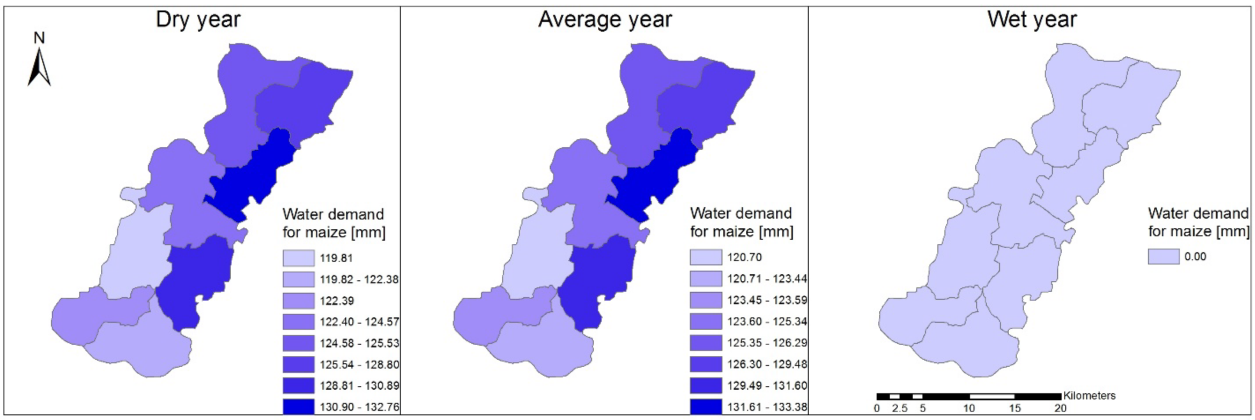

Figure 13 Water demand for maize

Figure 14 and Figure 15 illustrate the water demand values for cotton and cucumber. Although initially the area for cucumber was named as an area for vegetables, the model runs only for one specific type of crops. It does not run as a whole vegetables group. Thus, it was assumed that main vegetables production is cucumber and it was used for the model.

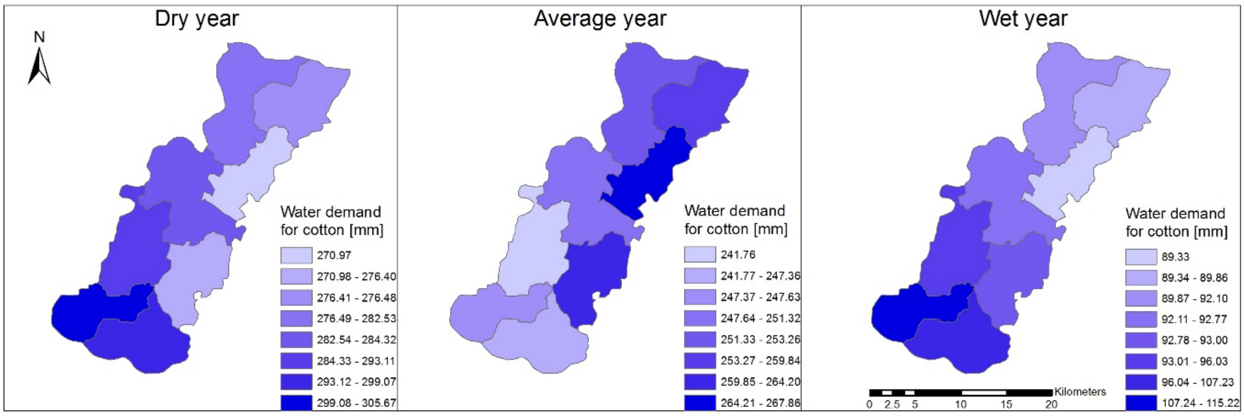

Figure 14 Water demand for cotton

Cotton and tomato does not play a significant role in the region because the area is considerably small and they can be even neglected. They were included to the simulations to identify some sensitivies of the model for different crop types. The result show higher values than local irrigation norms. Possible reasons might be similar to the above mentioned cases with the wheat and maize. Cotton shows reasonable decline in water demand from dry to wet years. Nevetheless, cucumber shows highest water demand for average year which seems to be overestimate the water demand.

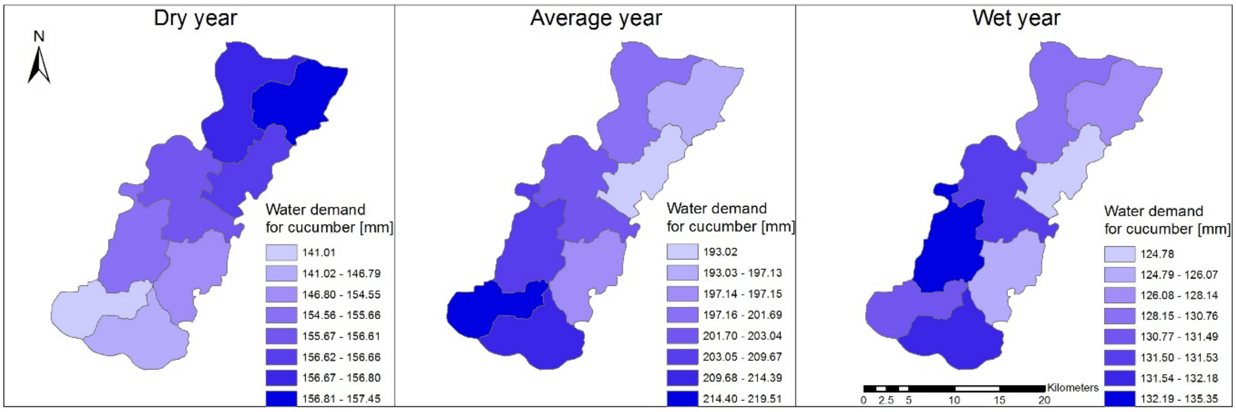

Figure 15 Water demand for cucumber

Prior to this part, the water demands were mapped only in relation to 8 townships. To get maps with finer resolution, soil type based water demand maps were constructed. As each township has certain number of fields with certain soil type, they have certain water demand as well. As a result, using those fields areas volume based water demand map was produced (Figure 16).

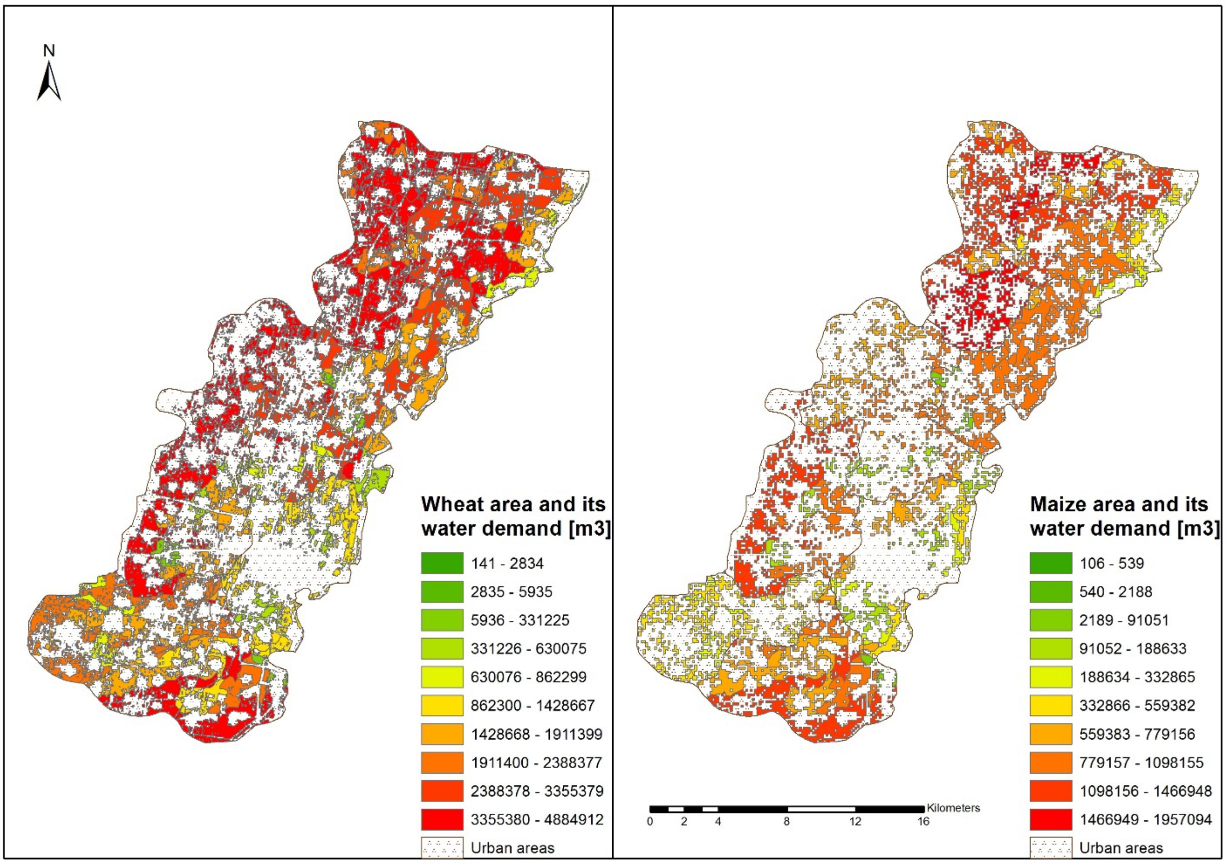

Figure 16 Finer resolution maps of water demand for winter wheat and summer maize

Next graph (Figure 17) demonstrates the contributions of each crop type to the total water demand. As mentioned above, wheat has around 80% of the total irrigated area in Guantao County. In addition, the model gave higher values (~300 mm) and as a result in the contribution plot in Figure 17 shows significantly high percentage for winter wheat. In regard to the average climatological year, maize shows 21% contribution and in wet year zero water demand. As mentioned above, maize is cultivated during the rainy season. If it rains a lot, maize does not require irrigation.

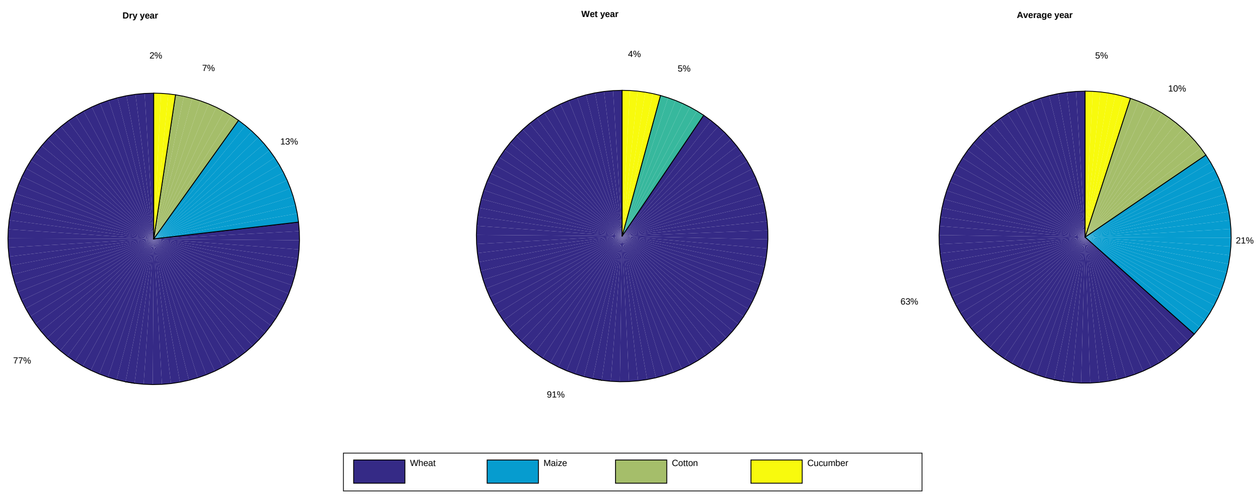

Figure 17 Percentage of irrigation demand for wheat, maize, cotton and tomato in Guantao County

5.2.2 Actual water consumption

Actual water consumption in Guantao County was compared with the model simulation results (Figure 15). As there are some wet year and dry years, it seems that model simulations and actual water consumption share some overall trends and periodicity. Nonetheless, it at the beginning and at the there are some steep increases in terms of simulation water demand results. The model should be further adjusted and tested for those periods because it shows significantly higher values.

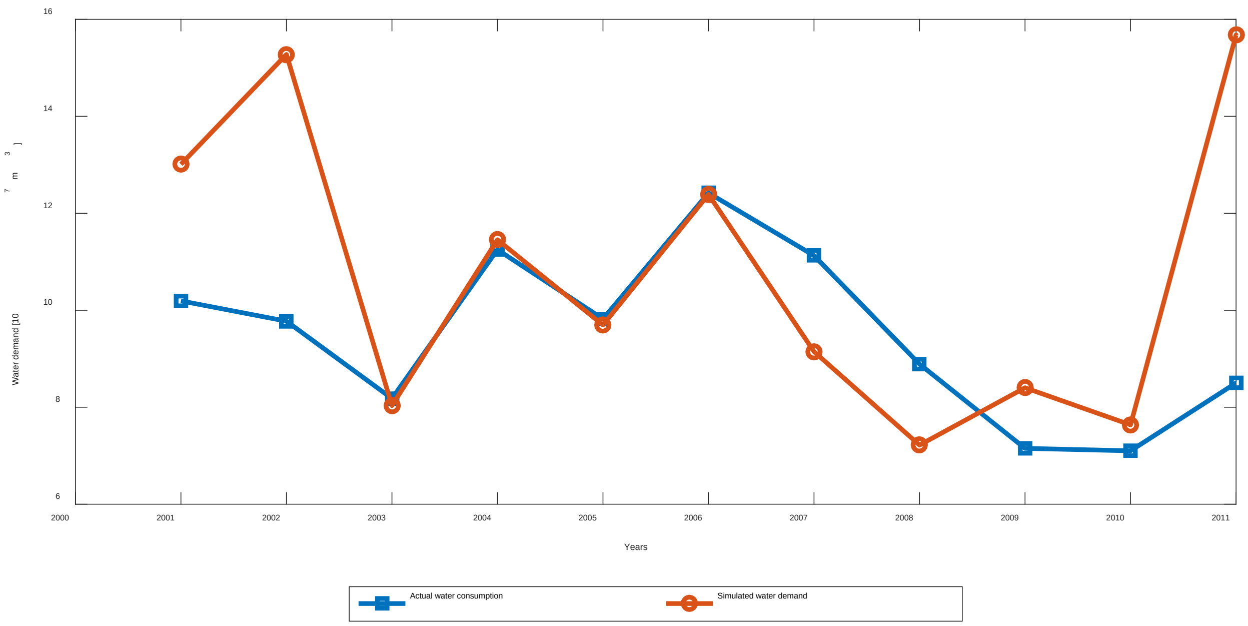

Figure 18 Comparison between actual water consumption and simulated water demand

5.3 Recharge by irrigation backflow

At the beginning the of the project work it was expected to get some calculation results which could approximate actual recharge to the vadose zone by irrigation backflow. It was achieved by manipulating water balance components and combining actual water consumption and model results.

5.3.1 Irrigation model's deep percolation to the vadose zone

Irrigation calculator partially accounts for the recharge to groundwater as a deep percolation. However, the model is aimed at optimizing which mean minimizing the water demand, it tries to minimize the recharge as well. As mentioned above, the irrigation model is analogous to simple bucked models. It tries to fill the bucked only irrigation is needed to minimize the loss. Hence, only source of deep percolation or recharge is extra precipitation which occurs more after the irrigation or when soil water content is still high. Only when the soil water content is saturated and extra precipitation, there is a deep percolation occurrences.

In order to estimate the actual recharge, the actual water consumption was added by deep percolation from the model. Then, irrigation water demand was subtracted from it. The assumption is that the model shows precisely how much water is needed. If it is subtracted from the actually consumed water as an irrigation, it is assumed that the rest of water goes to groundwater as recharge from irrigation backwater.

Figure 19 and Figure 20 demonstrate the contribution of irrigation water balance components. 4 main components are considered: precipitation, actual evapotranspiration, water demand and deep percolation from the model. Precipitation and actual ET play the crucial role. The more precipitation means less water demand. The less precipitation and the more evapotranspiration means more water demand.

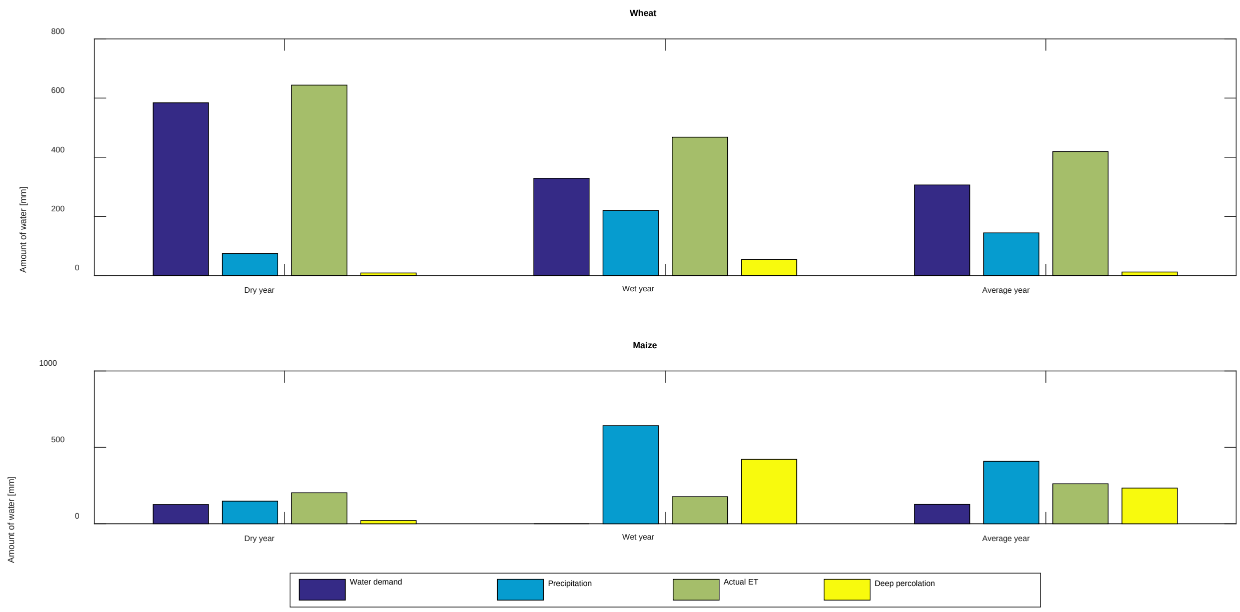

Figure 19 Contributions of water balance components

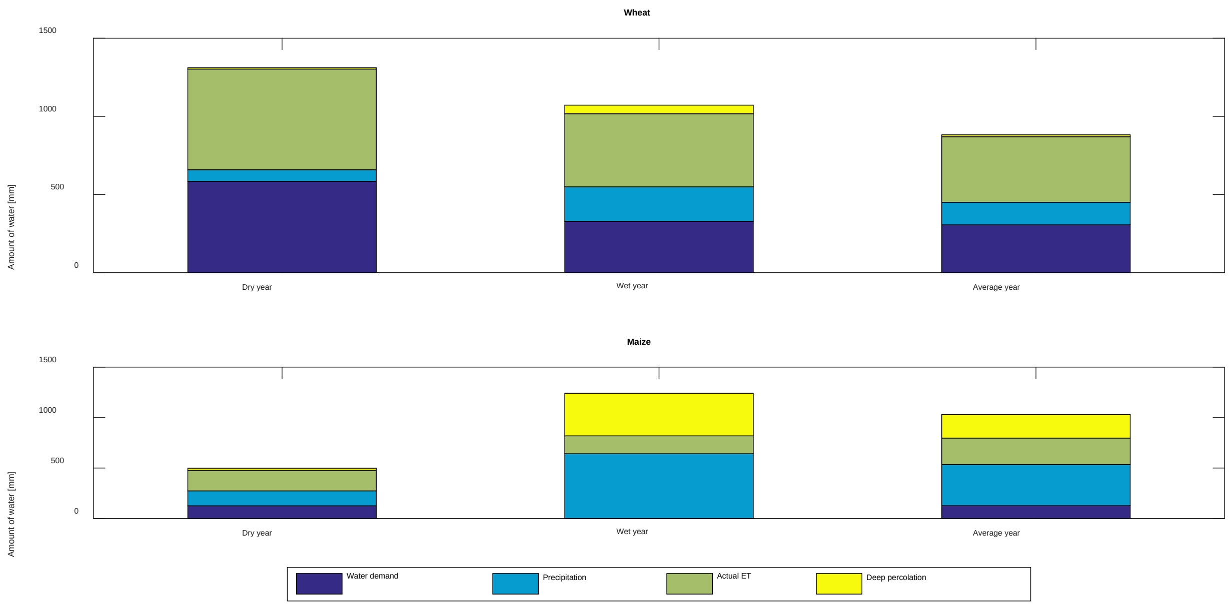

Figure 20 Contributions of water balance components

In Figure 21, the results of the irrigation calculator, actual water consumption and actual racharge by irrigation backflow are plotted in the map of Guantao County with its particular townships. Mostly, irrigation model shows higher values in terms of some townships. As stated above, it is because of high values for winter wheat as it has the biggest area as well. Recharge is directly related to the actualy water consumption. For example, if actual water consumption is higher than the simulation, the recharge is higher as well, because simulation is an indication of how much water is needed ideally.

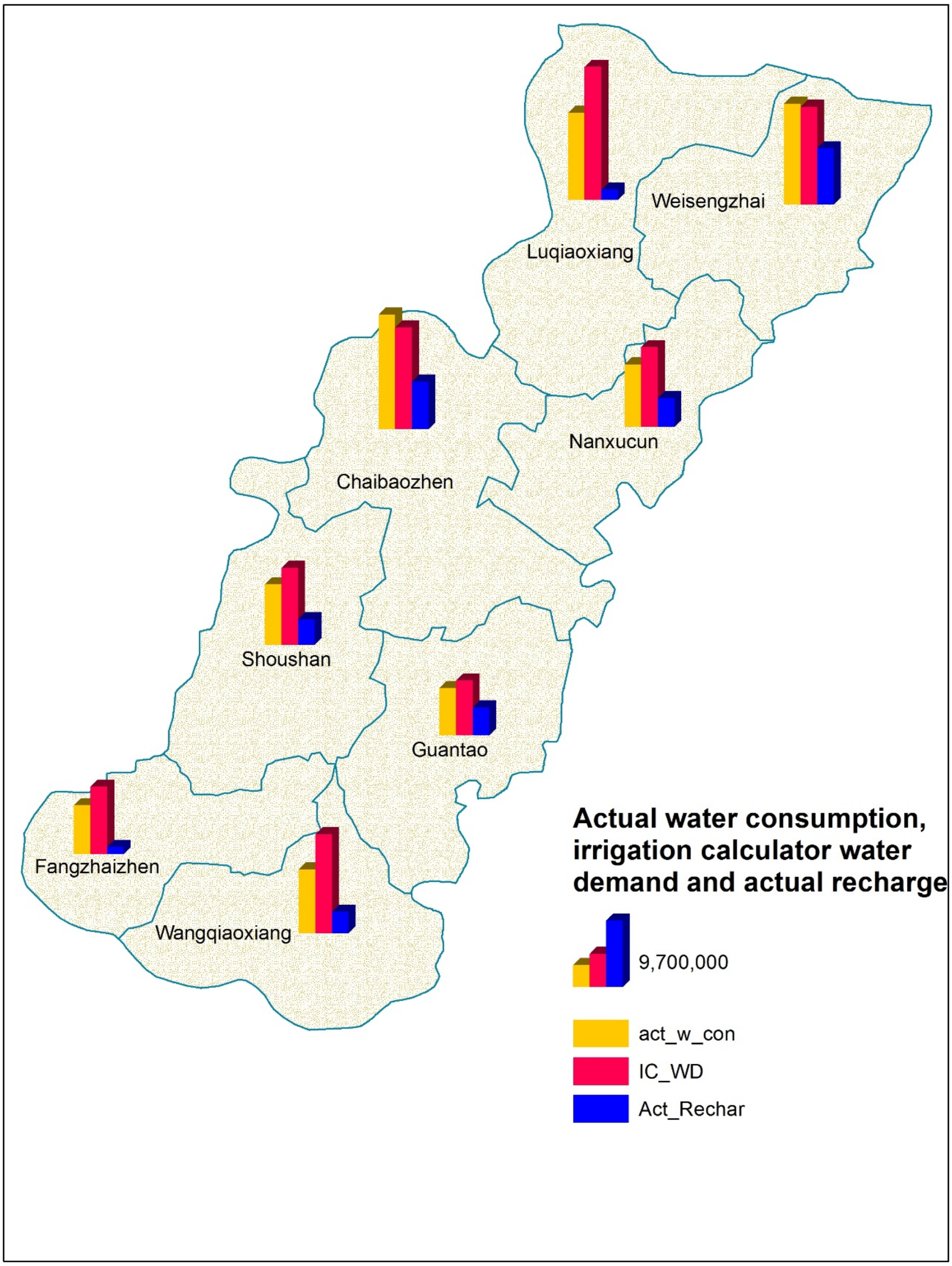

Figure 21 Comparison between actual water consumption, irrigation model water demand and actual recharge (act_w_con (yellow) stands for actual water consumption; IC_WD (red) stands for irrigation calculator water demand; Act_recharge (blue) stands for actual recharge).

5.4 Electricity usage and its correlation with the water consumption

One of the aims of the project work was to analyse and find out whether there is a correlation between water consumption and electricity. There should be the high relationship between them, because in Gunatao County the main irrigation water source is groundwater and groundwater is pumped using electro-mechanical wells. Data from statistics shows some significant results (Figure 17). The actual water consumption is more correlated to the electricity used to irrigation. Due to the high fluctuations in simulation results, the model might be less correlated. Moreover, it might be case that actual water consumption is estimated using this correlation. The limitation of this study is that the data about irrigation electricity consumption is available only for one year. The relationship should be more studied when the data is be available. To date, it is difficult to make some conclusions using this very limited data. Nevertheless, from the Figure 22 it can be noticed that there are overall some correlation in simulated water demand and irrigation electricity usage.

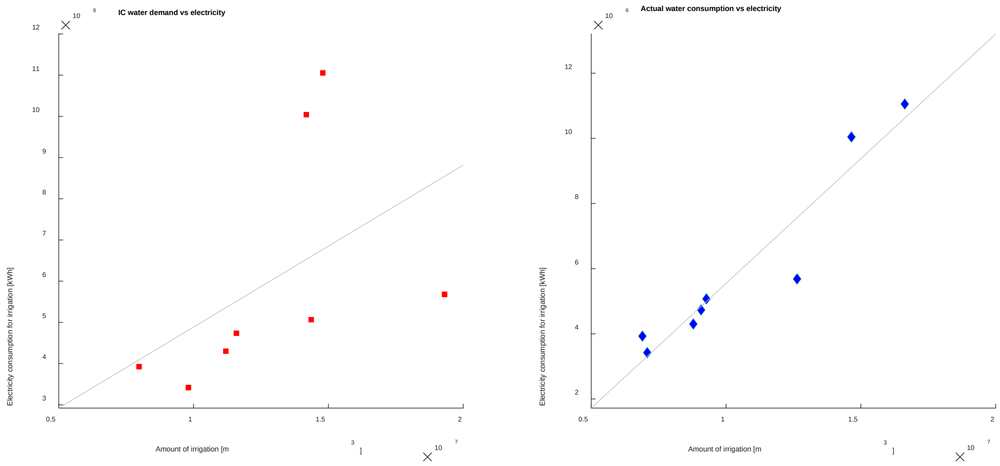

Figure 22 Correlation between Irrigation calculator (IC) water demand and electricity usage for irrigation and actual water consumption.

6 Discussion

6.1 Irrigation demand and recharge by irrigation backflow

Irrigation calculator seems to be sensitive to some parameters. Particularly, the efficiency values of irrigation types and the user defined threshold values. The model was run for the period of 2000 and 2013 using 11 threshold value ranges. Threshold values are the user defined percentages which shows when the irrigation should be started. For example, if it is 20% the model waits until soil water content gets emptied by 80%, only then it starts irrigating. Consequently this value is a sensitive parameter which varies the final result significantly. According to FAO guidelines, it is recommended to use 45% threshold value. All the water demand maps were made using this 45% threshold value.

Furthermore, to identify to what degree it varies the results, the following analysis was conducted. Figure 23 and Figure 24 illustrates a box plot of wheat and cotton water demands in relation to different threshold values. The plots shows the maximum, minimum and mean values of water demand for each values of threshold percent. It can be stated that the higher the threshold value, the higher the water demand value. The decision is made by the model users or other interested groups.

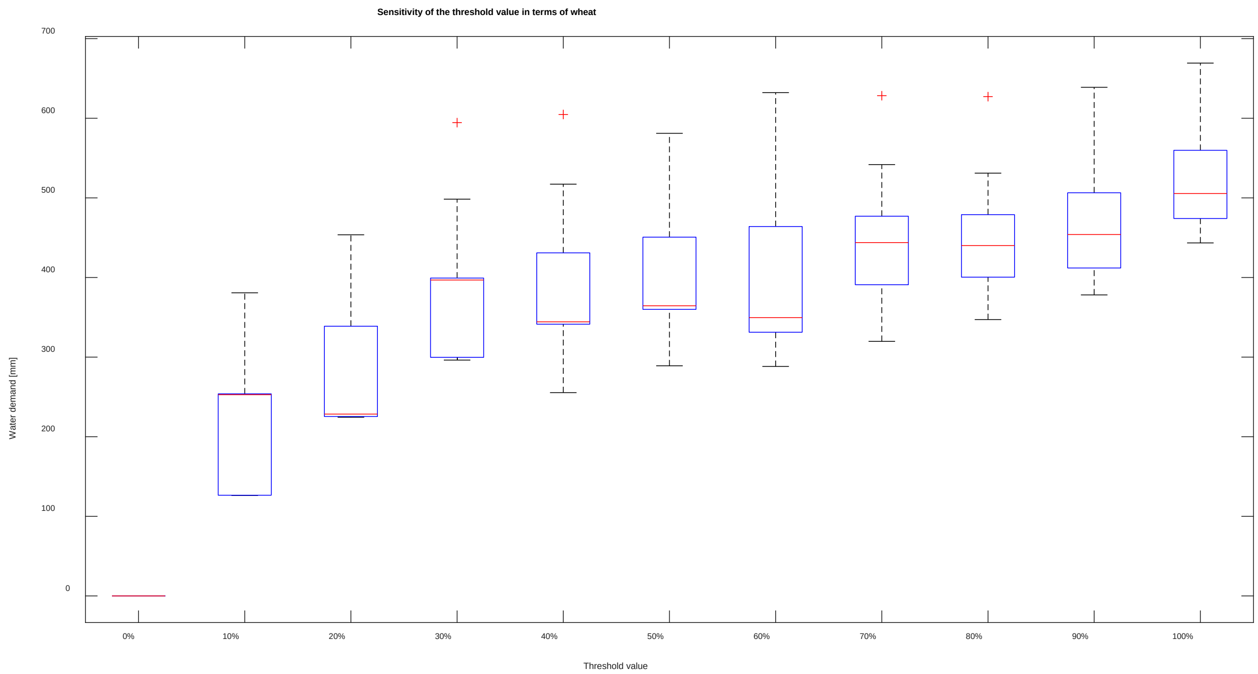

Figure 23 Box plot of threshold values to see its sensitivity in terms of wheat

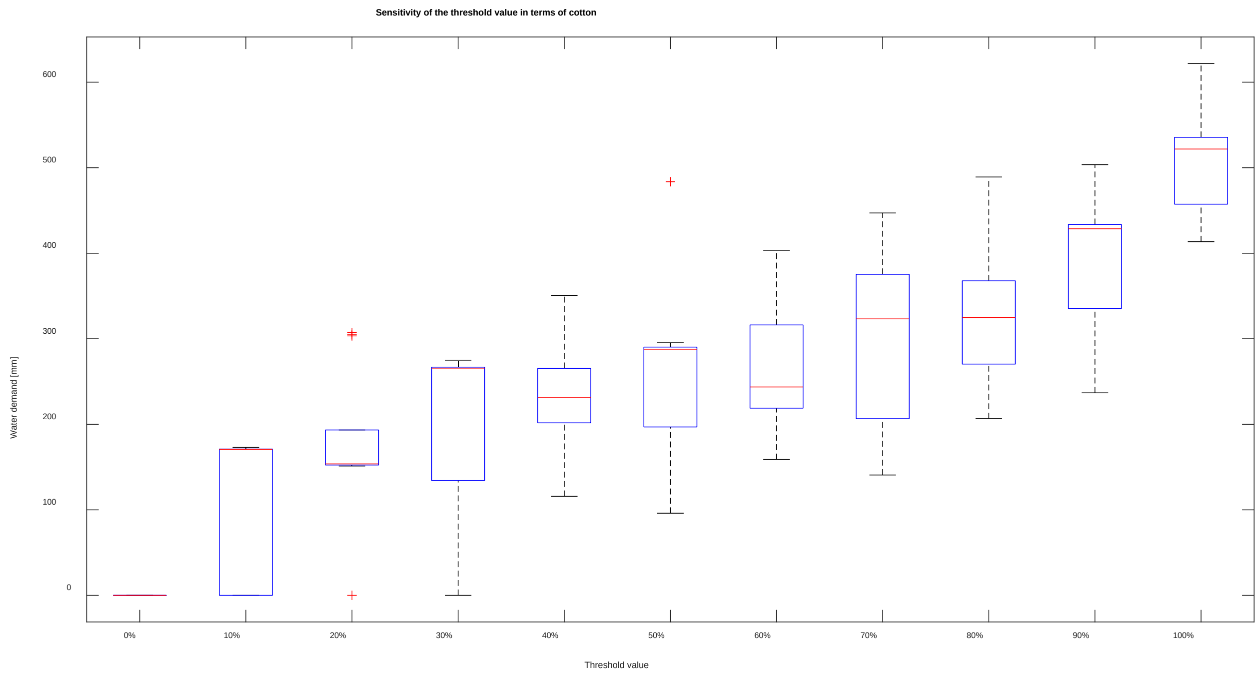

Figure 24 Box plot of threshold values to see its sensitivity in terms of cotton

The time series of water demand for wheat with 11 different threshold values shows some trends. As mention above, the higher the threshold values, the higher is irrigation demand. Figure 26 shows the correlation between the threshold values of the model and water demand for irrigation. It demonstrates that there is a direct relationship between them.

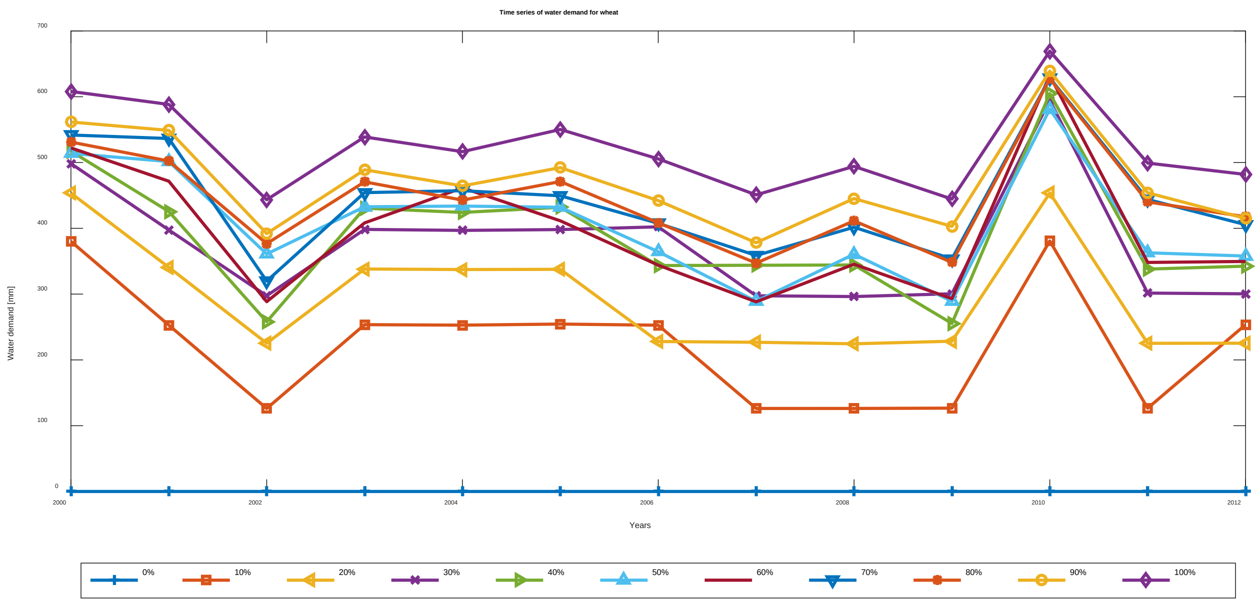

Figure 25 Time series plot of winter wheat changing threshold value in the model for the duration of 2000 and 2012

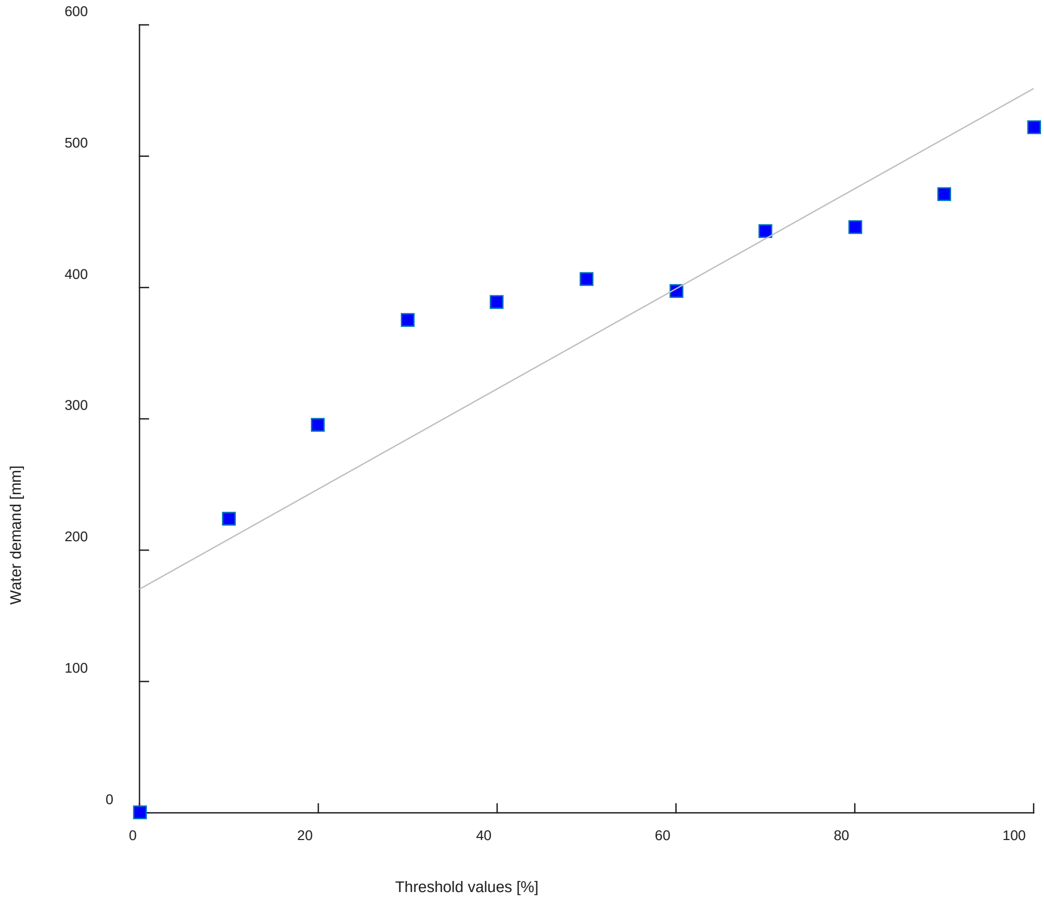

Figure 26 Correlation between the threshold values of the model and water demand

Recharge is considerably small in the crop water demand model results, because it tries to minimize the water consumption and only irrigates when it is absolutely needed. However, if it is not used properly, this irrigation strategy might induce soil salinization. Therefore, some measures like flushing at the end of the crop season should be carefully applied.

6.2 Electricity consumption

Electricity consumption and water demand in general seems weakly correlated. As it was noticed in Figure 22 the statistical data of actual water consumption shows better correlation than model simulation results. There was an attempt to see the relationship between rural electricity consumption and water demands. However, the results showed the fact that there is no correlation. Therefore, further analysis and more specific and finer resolution data of electricity consumption is required.

7 Conclusions

Applying the irrigation model and ArcGIS toolboxes many types of maps were produced. Core focus of this work, the irrigation water demand maps, were made. The results of model simulations were reasonably similar to the irrigation norms of the region and statistical data. The constructed irrigation water demand maps of Guantao County in terms of different types of crops can be used for many purposes. In addition, some sensitivity analysis were conducted in regard to the irrigation model parameters.

Most importantly the maps make possible to locate the areas which are causing most of the overconsumption of groundwater sources. It can help to make some judgements and choose alternatives between different types of crops as well. Irrigation maps are very helpful in sustainability analysis (Yang et al., 2010). The model simulation results were reasonable to compare with the statistics data and local irrigation norms.

Furthermore, it can also be used for water footprint calculation in terms of optimal and ideal scenarios. However, the irrigation mapping is mostly important for:

- Decision making processes in water resource management
- Sustainable irrigation management and planning
- Groundwater level decline recovery

Annex

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Appendix

A - Data about the Guantao County

Table 1 Different crop areas in Guantao County between 1997 and 2011 in mu (15 mu = 1 hectare)

Years	*Agricultural*	*Irrigation*	*Total grain*	*Summer grain*	*Autumn grain*	*Cotton*

	area	*area*	*crop area*	*crop area*	*crop area*	*area*
1997	-	-	550864	292733	258131	136912
1998	479130	466350	546915	300060	210015	124065
1999	477525	466350	550333	310390	239943	102409
2000	480000	466500	543540	301620	241920	97200
2001	-	-	-	-	-	-
2002	-	-	549930	299850	250080	99015
2003	445785	420015	530205	289980	240225	121185
2004	423525	420900	542873	281820	261053	121757
2005	423525	421200	562917	301278	261639	106252
2006	449220	-	605280	315285	289995	89955
2007	449220	430290	597060	317895	279165	93495
2008	449220	426600	570045	308880	261165	101580
2009	449220	429000	580095	308910	271185	103080
2010	449220	429150	583020	312585	270435	102945
2011	449220	429300	584040	312690	271350	102660

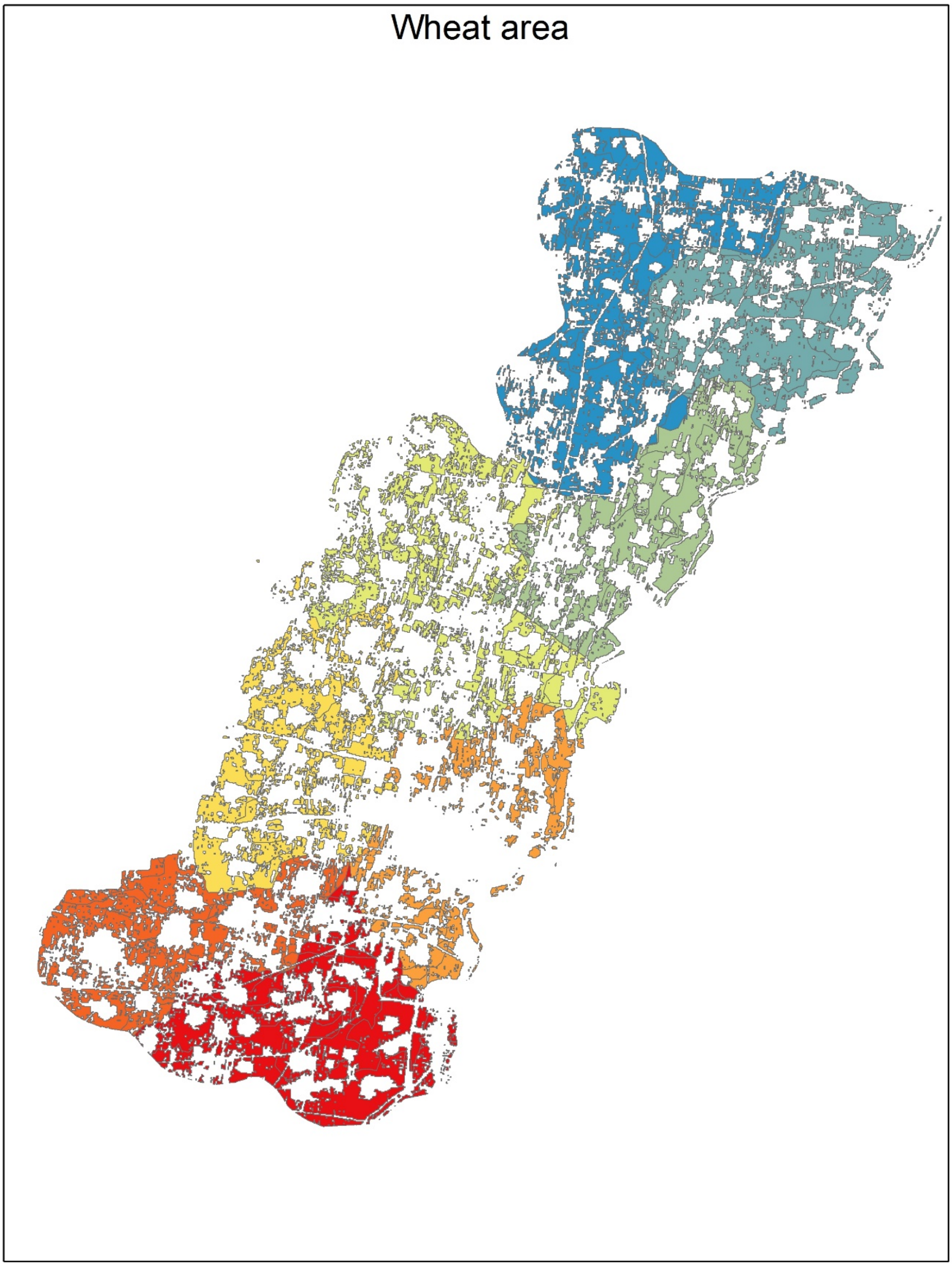

Figure 27 Wheat area per townships

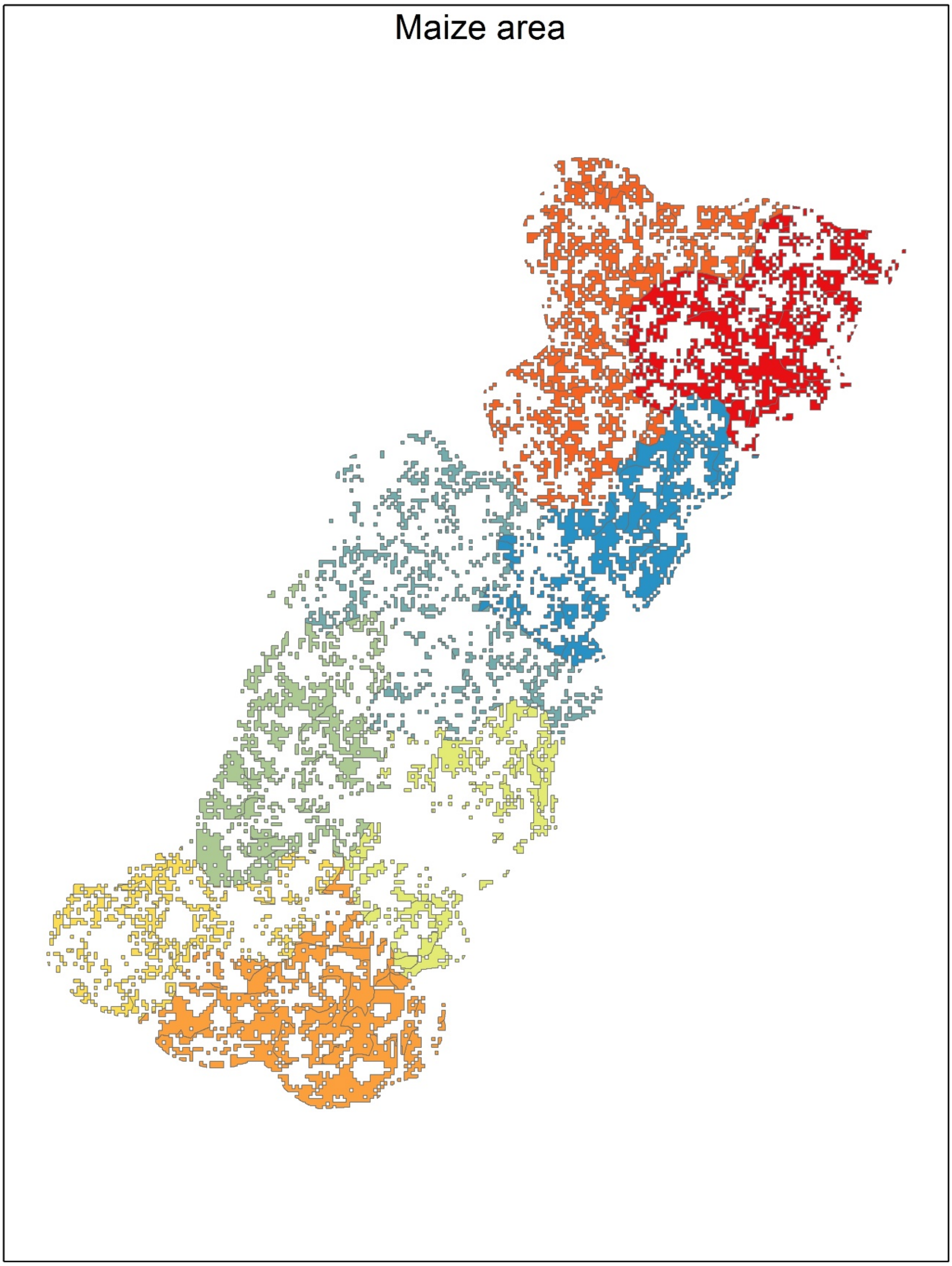

Figure 28 Maize area per townships

B - Mapping data

Table 2 Statics of Guantao County for the year of 2011

	Township	*Crop planting area*	*wheat area*	*maize*	*cotton*	*vegetables*
1	LuQiao	131743	44592	33714	34201	13621
2	WeiSengZhai	115815	48100	40000	6000	11415
3	NanXuCun	84859	27882	26658	8630	12599
4	ChaiBao	125663	53300	30410	24260	12493
5	ShouShanSi	113569	38160	34210	9708	12211
6	Guantao Zhen	68526	27877	26809	2950	10145
7	FangZhai	79485	33000	18850	7240	8485
8	WangQiao	133221	39780	38263	9673	25330

Table 3 Averaged crop data between 1998 and 2013

	Township	*Crop planting area*	*wheat area*	*maize*	*cotton*	*vegetables*
1	LuQiao	106107.7273	41764.15	27686.08	26769.23	11754.08
2	WeiSengZhai	92229.27273	40627.46	27846.62	9666.615	10405.15
3	NanXuCun	67359.27273	25264.46	22578.38	9137.308	10063.62
4	ChaiBao	105023.2727	47974.23	27070.69	20792	11691.15
5	ShouShanSi	95366.90909	34475	31394.46	9719.462	8565.846
6	Guantao Zhen	57779.90909	25676.77	26058.85	3658.615	9347.846
7	FangZhai	66962.09091	29950.31	16049.85	7811.538	7341.615
8	WangQiao	101095.0909	35294.23	33451.62	9575.615	20205.85

C - Irrigation calculator results

Table 4 Irrigation calculator coefficients table

texture	field capacity [m3/m3]	wiltig point [m3/m3]
sand	0.1	0.05
loamy sand	0.12	0.05
sandy loam	0.18	0.08
sandy clay loam	0.27	0.17
loam	0.28	0.14
sandy clay	0.36	0.25
silt loam	0.31	0.11
silt	0.3	0.06
clay loam	0.36	0.22
silty clay loam	0.38	0.22
silty clay	0.41	0.27
clay	0.42	0.3

Table 5 Irrigation calculator results for wheat

Guantao	township	Total township area	wheat			
				area_weighted_DM [mm]		
			wheat total area	dry	wet	average
1	Luqiao	71133238	39393554.75	587.2236795	329.674331	302.7835127
2	Weisengzhai	56470091.42	31954070.1	592.1683118	332.1890567	300.2487027
3	Nanxucun	44436179.34	23930579.69	596.5735236	334.8009624	298.8266783
4	Chaibao	75748345.85	28093136.41	585.7597849	328.929828	303.5339619
5	Shoushansi	60406820.79	23544356.23	578.5684243	325.2724681	307.220532
6	Guantao Town	52364965.81	15380071.5	592.0288232	332.896714	302.0727791
7	Fangzhai	42683969.03	21704849.33	567.3400384	323.1236294	320.99368
8	Wangqiao	54583177.09	29963499.5	573.1016863	324.6951558	314.9816655

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