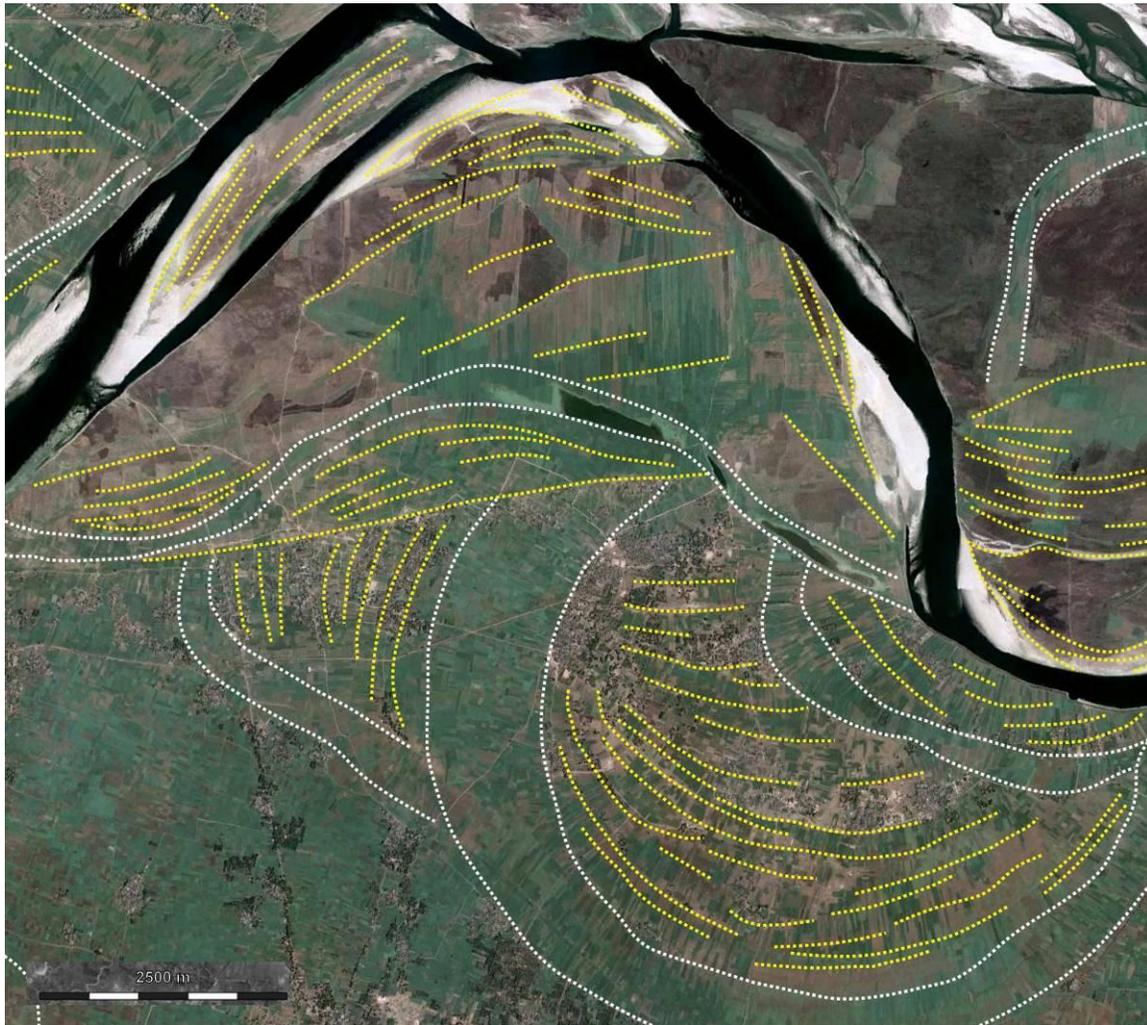


BTA/TG/11-18

**Point bars and clay plugs surface map
near Patna (Bihar, India) along the
Ganga River**

Damien Boeser

21 September 2011



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TA Report number : BTA/TG/11-18

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Abstract

Clean drinking water is essential for life. In Bangladesh and the northern part of India however, around the 30 and 40 million people are estimated to be exposed to Arsenic in drinking water at concentrations above the 50 $\mu\text{g/L}$. Studies show that the aquifers of Holocene age near the Ganga River are polluted. These aquifers are between the 10 and 50 meters deep. Also, there are huge differences in the spatial differences in the arsenic concentrations in the groundwater.

Some studies in India have shown that the spatial distribution of arsenic concentrations has an association with geomorphologic features. Therefore the different geomorphologic elements in the area near Patna are mapped using the satellite images. On these images, the great difference in morphology is visible. Some of the aquifers are completely surrounded by clay. In these aquifers, the arsenic concentrations might be the highest, because the arsenic can not migrate away. The search for clean drinking water will be easier if the locations of this kind of aquifers are known

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Introduction

A large part of India and Bangladesh suffers from high concentrations of arsenic (As) in the groundwater. Around 30 to 40 million people are affected by the high As concentrations. This problem was first discovered in Bangladesh in 1980 (Smedley and Kinniburgh, 2002) and at the beginning of the 21st century in India (Shah, 2010) The concentrations are between <0.5 and 3200 µg/L, while the recommended limit for safe drinking water of the World Health Organisation is 10 µg/L. (Shah, 2007) The As is adsorbed on hydrated-iron-oxide, which is present as coatings on clay, biotite and chlorite minerals. (Acharyya and Shah, 2007) However, under reducing conditions, the desorption of As from iron oxides occurs, and As is dissolved in the groundwater. The main sources of the polluted sediments are sediments of Holocene Age deposited by the Ganga, Brahmaputra and Meghna river systems. (Smedley and Kinniburgh, 2002) These sediments are approximately 10 to 50 meters deep. (Shah, 2010) The sediments of the Pleistocene and older are all flushed by the groundwater. (Smedley and Kinniburgh, 2002) Also, there are large spatial differences in As concentrations. Arsenic in groundwater exhibited a wide spatial variation, even more than 90 times within a distance of 150 m. (Saha, 2009) Studies from arsenic-affected areas in West Bengal have shown that arsenic-contaminated wells have a spatial association with abandoned channels and swamps. (Shah, 2007a) Still, the question is: what is that association? To answer that question, it is necessary to map those different channels and swamps.

This report will focus on a small area near Patna in the Bihar state in India along the Ganga River. The figures 1 and 2 on the next page show the location of the study area. The maximum measured As concentration near Patna is 1800 µg/L. (Saha, 2009)

The objectives of this report are:

- 1) Mapping the different geomorphologic elements of the Ganga River in the study area, to check if there are huge spatial differences in the geomorphology.
- 2) Measuring the dimensions of the geomorphologic elements to see whether there is a relation between the different dimensions. If there is a relation, a rough volume estimation of an aquifer is easier done.

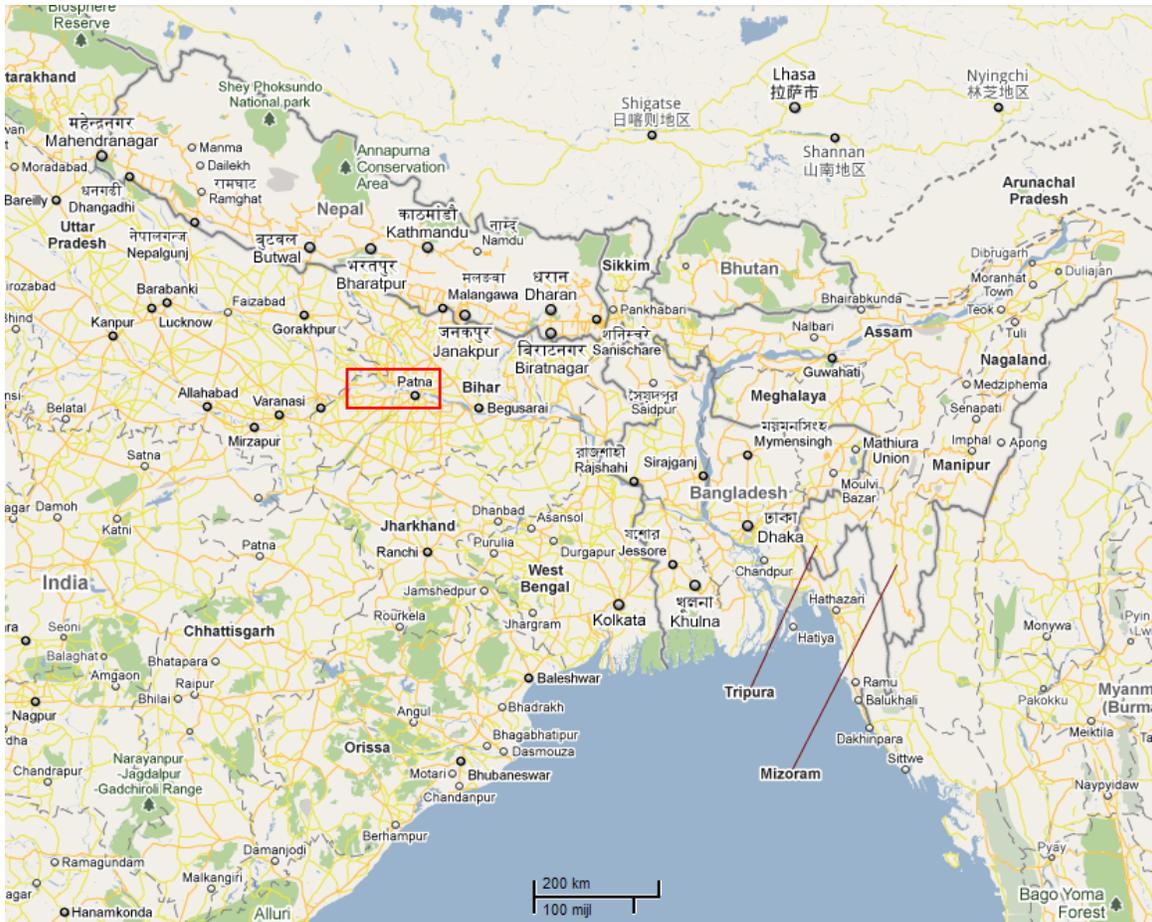


Figure 1: Location of the study area (red box)

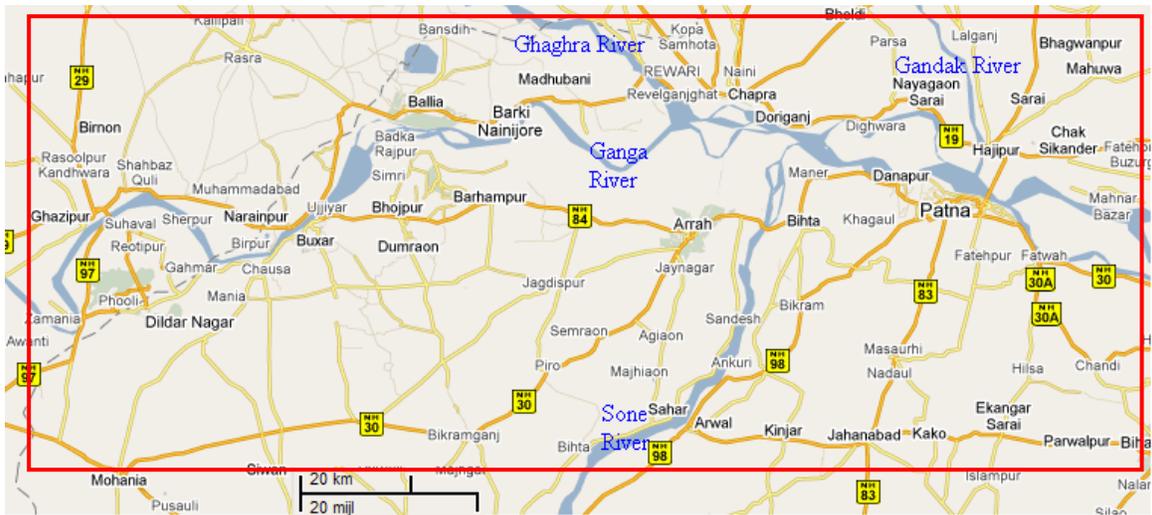


Figure 2: Map of the study area (red box).

Geological Setting

The Ganga Plain is part of the Himalayan foreland and the tectonics there is still active. It is controlled essentially by the Himalayan tectonics and shows a number of geomorphic features, which are related to the active tectonics. (Singh 2008) First, the orogeny of the Himalayas is described, then the tectonics of the study area and finally the depositional environment is described.

Orogeny of the Himalayas

About 200 million years ago, when Pangaea broke apart, India began to forge northward with a rate of 9 meters a century. When India rammed into Asia about 40 to 50 million years ago, the advance of India was slowed by about half. Both the collision and the decrease in the rate of movement are interpreted to mark the beginning of the rapid uplift of the Himalayas. Figure 3 shows the movement of India. (USGS, 1999)

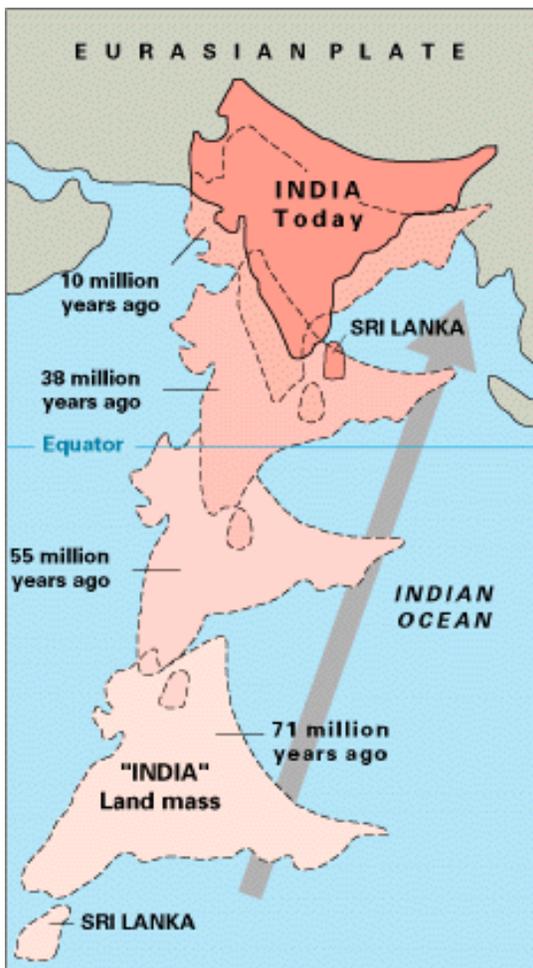


Figure 3: The journey of India through time. (USGS, 1999)

The Indian crust underthrusts the Eurasian crust. (Powers et al, 1998) This process started in the Early Miocene. (Sinha et al, 2005) As a response to the advancing orogenic load, the Indian Plate is flexing downward. See figure 4. (Powers et al, 1998) The Ganga Foreland Basin had then small dimensions. During the Middle Miocene to Middle Pleistocene, the Basin was underfilled. This means that there was a topographic low between the thrust belt (Himalayas) and the peripheral bulge (India). This under-filled condition developed due to an efficient transport system for the sediment supplied, which removed the bulk of the sediment to the Ganga delta and Bengal fan. the northern part of the Ganga plain was uplifted and thrust basinwards, and the Ganga basin shifted southward (cratonwards) in response to thrust loading in the orogen During the Pliocene, the Basin was dominated by transverse river systems due to erosion-driven uplift. the symmetric subsidence of the Basin. However, during Late Pliocene to Pleistocene, there was a little asymmetric subsidence and uplift. This combined with large sediment fluxes caused that the Ganga River was displaced to the edge of the Basin. (Sinha et al, 2005) During all these periods, the deposition of sediments in the Basin took place exclusively by fluvial processes, because this deposition occurred 100 – 200 meters above the sea level. Thus, no marine sediments from the Bay of Bengal could enter deep into the Basin, only the delta region has witnessed some marine deposition. (Singh, 2008)

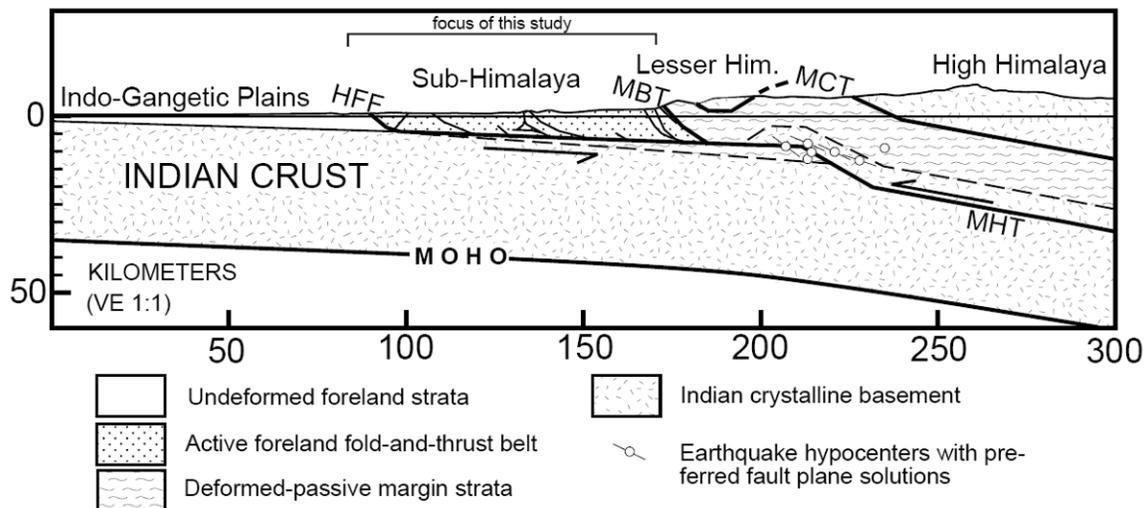


Figure 4: Indian crust untherthrust the Himalayas. Through the orogenic load, The Indian Plate flexes downward. The Ganga Plain lies on the left side. (Powers et al 1998)

Regional tectonics

In the study area, there are several faults caused by the Himalayan orogeny. The locations of the faults are shown in figure 5.

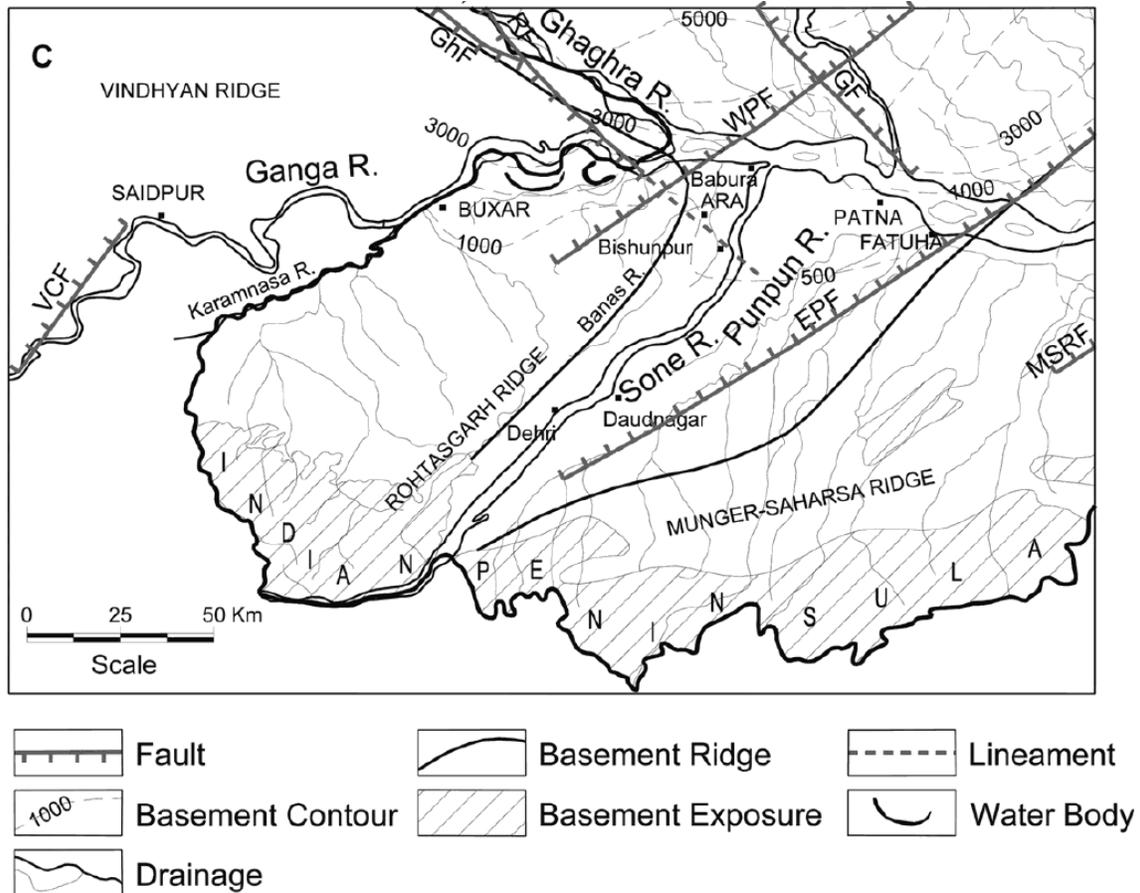


Figure 5: The locations of the faults in my study area. These faults are Varanasi-Chunar Fault (VCF), Ghaghra Fault (GhF), Rapti Fault (RF), East Patna Fault (EPF), West Patna Fault (WPF), Gandak Fault (GF) and Munger-Saharsa Ridge Fault (MSRF). (Sahu et al, 2010)

A block bound by the EPF and WPF at its eastern and western sides respectively is tilting. Those faults are reverse faults and are caused by the northwards movement of the Indian Plate. There is uplift at the southeast end along the EPF and subsidence in the northwest corner along the WPF. This means that the displacement of the EPF is higher than the displacement of the WPF. The net result has been a structural inclination of the block to the north and northwest. The consequences of this inclination are a slow and gradual migration of the Ganga River ten to twenty kilometers to the north between Buxar and Patna, and sudden and disastrous avulsions of the Sone River. This is shown in Figure 6, with I the oldest channel and X the present channel of the Sone River. (Sahu et al, 2010)

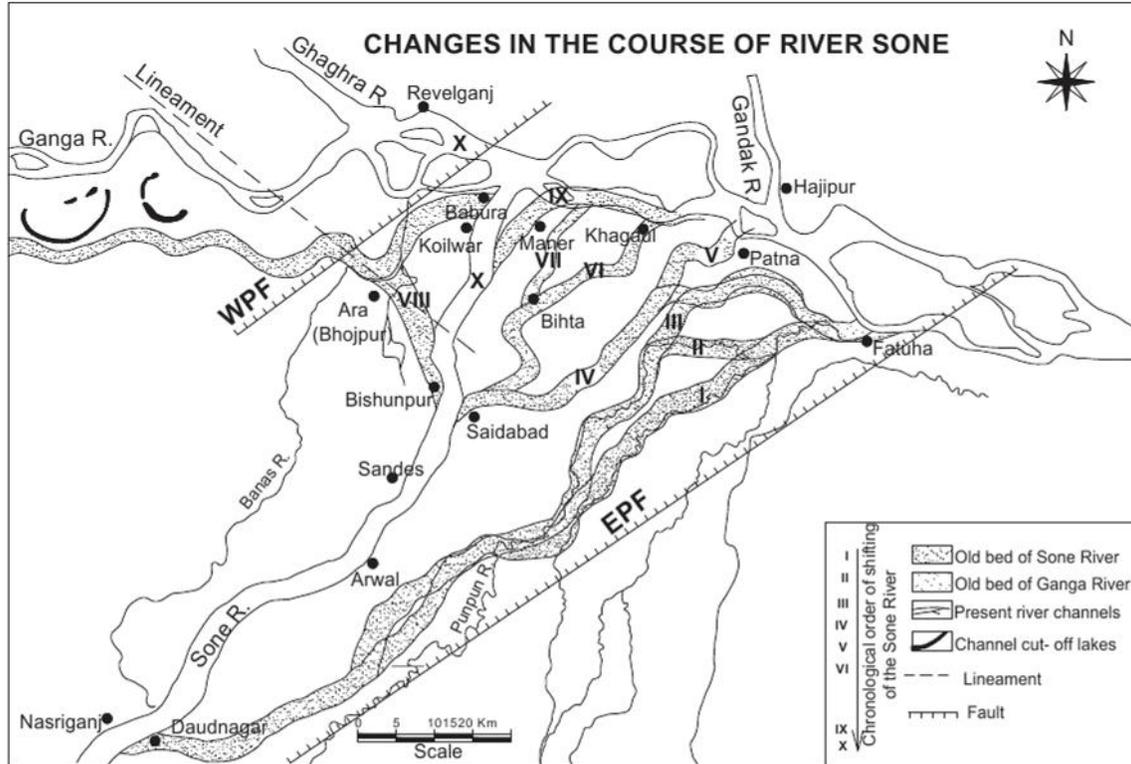


Figure 6: Changes in the course of the Sone River and the Ganga River. (Sahu et al, 2010)

Geomorphology

In the study area, the Ganga River has two different channel patterns. Left of the Ghaghara River (see figure 2), the Ganga River has mainly meandering channels. Right of the Ghaghara River, the Ganga River has mainly braided channels. (Sahu et al, 2010) The different geomorphologic elements that are related with a meandering river are point bars, old river channels and floodplains. The point bars are sands deposited on the inside of each meander loop. Old river channels are filled with clay. The flood plains are covered with clay. (Skinner et al, 2004) See figure 7.

As mentioned in the paragraph above, the Ganga River has already migrated ten to twenty kilometers to the north. An indication for this migration is the floodplains on the south bank of the river. These plains are flat, have many point bars and oxbow lakes and have swale topography. Most of the meander scars are pointing with their convex side to the south (Sahu et al, 2010).

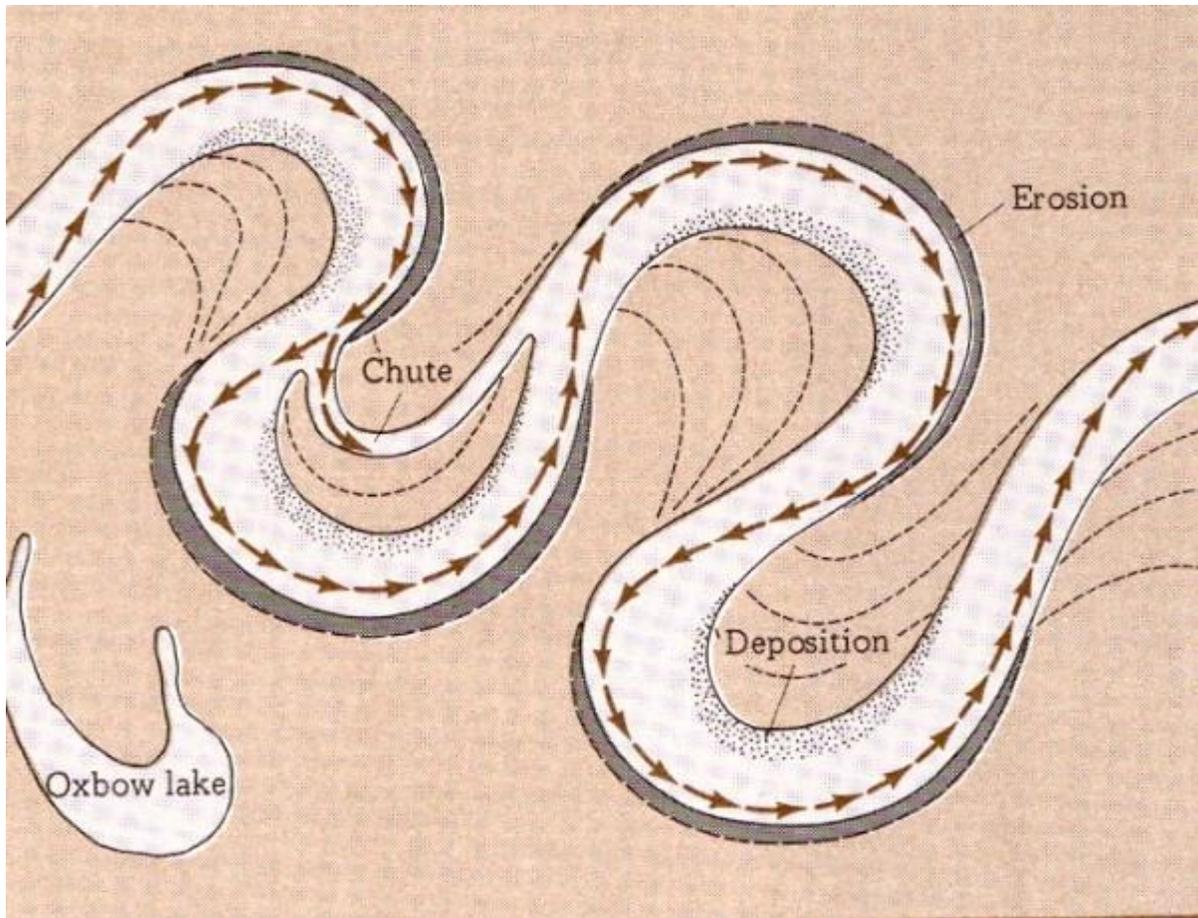


Figure 7: Deposition of sediments in a meander river. The yellow areas are the point bars made by the river (Geocaching, 2009)

Methods

In this section, the methods of making the maps of the study area will be explained. First, Google Earth was used to extract detailed partial images of the study area. Next, Photoshop was used to merge these images to a large map of the total study area. Then Illustrator was used to draw the interpretations of morphological elements in the fluvial facies in the study area. The different morphological elements are the point bars, the old river channels and the floodplains.

Google Earth

First of all, it is necessary to make a satellite image of the area. The software that was used was Google Earth. There, the cities Manhar Bazar and Dheena were located. These two cities are the east and west boundaries of the study area. After setting the boundaries, the scale bar of Google Earth was set at exactly 2500 meter, for the best image resolution possible. The first image was made in the northeast corner of the study area, the second one more to the south and so on. The overlap of the images is about three centimeters. All the images were saved as jpg files.

Adobe Photoshop

It is not very efficient to analyze every image alone. Most of the structures in the area are a few images wide. So before the images were analyzed, the images were merged in Photoshop. It is necessary to do this step very precise, because you will see even the smallest deviation in the end product. The dimensions of the merged images are three small images wide and nine to eleven small images high. Just like before, these images were saved as a jpg file.

Adobe Illustrator

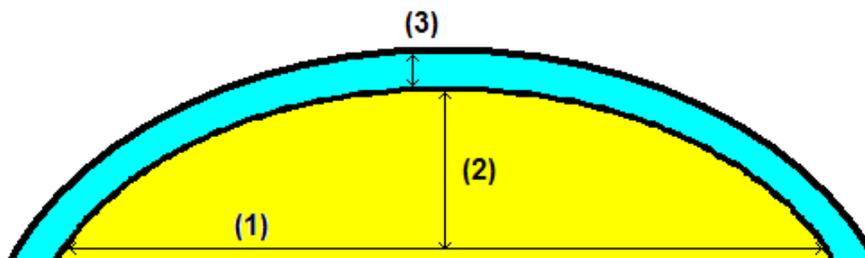
The next step is to interpret all the morphological elements in the fluvial facies. Adobe Illustrator was used to produce the photo-interpretations of the fluvial facies. In Illustrator, three layers were created. One for the point bars, one for the clay plugs and one for the satellite image.

On the satellite image, the scale bar was made with the Google Earth scale bar as reference length. After that, that layer was locked, to prevent scale errors caused by zooming. Next, the lines were drawn to delimit the ridge-and-swale morphology in the point bars and the clay plugs. Ridge-and-swale morphology is marked by color differences in the grasslands, the roads and boundaries between the grasslands, oxbow lakes and the boundaries of the villages.

Point bar size

Finally, the sizes of active and abandoned point bars were measured. Therefore three things were measured: the length and width of the point bar and the width of the abandoned river as shown in figure 8. The measurements were done with the measurement tool in Illustrator.

All the measurements were noted in an excel file. Three scatter plots were made using this data. Also, all the ratios were calculated and put in a histogram.



- (1) Length of the point bar**
- (2) Width of the point bar**
- (3) Width of the abandoned river**

Figure 8: Measuring the point bar size.

Results

First there will be a section about abandoned river channels, then the point bar shape, and finally about the point bar size.

Abandoned river channels

On the maps, the clay plugs are indicated by white dashed lines. These clay plugs are the abandoned river channels. There are two different forms of river channels as shown in figure 9. These are a part of the last image in the appendix. On the right part of the figure, there is a wide river channel with lower sinuosity. This channel was once the main stream of the Ganga River. The main direction of these channels is east-west. On the left part of the figure, there is a small river channel with high sinuosity. This is part of a lower order stream that ends in the Ganga River, so most of these channels go to the present-day Ganga River or to one of the abandoned main stream channels.



Figure 9a (left) and figure 9b (right): Two different forms of river channels. 9a shows a low-order stream of the Ganga River. 9b shows the old main stream channel of the Ganga River. Both forms are a piece of figure 22 in the appendix. The scale bar is 2500 meters.

Point bar shape

The yellow dashed lines indicate the delimitations of the ridges and swales in the point bars. Most of the point bars are green and brown. However, the point bars that are formed by the current river are sometimes white. This is shown in figure 10. The green point bars are covered with pasturages, because these are the swales of the point bars. Swales consist of clay which is fertile. The light brown and white point bars are covered with sands. On the light brown point bars, roads and villages are constructed, because these sands are a good foundation



Figure 10: Some point bars near the current River are white. Also, the small point bar in the middle is surrounded by old river channels. This is part of figure 21 in the appendix. The scale bar is 2500 meters.

The point bars also seem to have an orientation as shown in figure 11. At one side of the oxbow, the swales and ridges are more parallel to the river than on the other side. The direction of flow of the river is known, from west to east. This pattern is noticed several places along the river, and all the time, the more parallel end is at the downstream side. The reason for this pattern is that the meanders constantly migrate to the outside. This means that the meanders grow bigger and cuts their downstream neighbor's deposition. See figure 7.

Also, most point bars have their convex side pointing to the south and are positioned on the south side of the Ganga River. This is in line with Sahu (2010). And finally, some point bars are completely surrounded by the abandoned river channels, while others are still connected to the current Ganga River. Figure 10 shows these different point bars.



Figure 11: Swales and ridges with an orientation. This is part of figure 22 in the appendix. The scale bar is 2500 meters.

Point bar size

After interpreting the different oxbows and their point bars, the size of the point bars were measured. The analysis of the point bar sizes gives some interesting results. The figures 12 till 14 show the histograms of the three different ratios, and the figures 15 till 17 shows the cross plots of the measurements.

The length and width of the point bars are correlated. The cross plot (figure 15) shows a small band of dots following the line $y = 0.44 * x$. In the histogram (figure 12), there is a clear peak around the 0.4. So the point bars are nearly spherical, since the length is the diameter and the width is the radius.

The length of the point bar and the width of the river are less clearly correlated. The cross plot (figure 16) shows a big cloud of dots and the histogram (figure 13) shows a slightly wider distribution. The peak lies around the 0.075.

The width of the point bar and the width of the river are as correlated as the length of the point bar and the width of the river. The cross plot (figure 17) shows the same big clouds of dots and the peak in the histogram (figure 14) lies around the 0.2. However due to the very wide distribution, there is no relation between the width of the river and the dimensions of the corresponding point bar

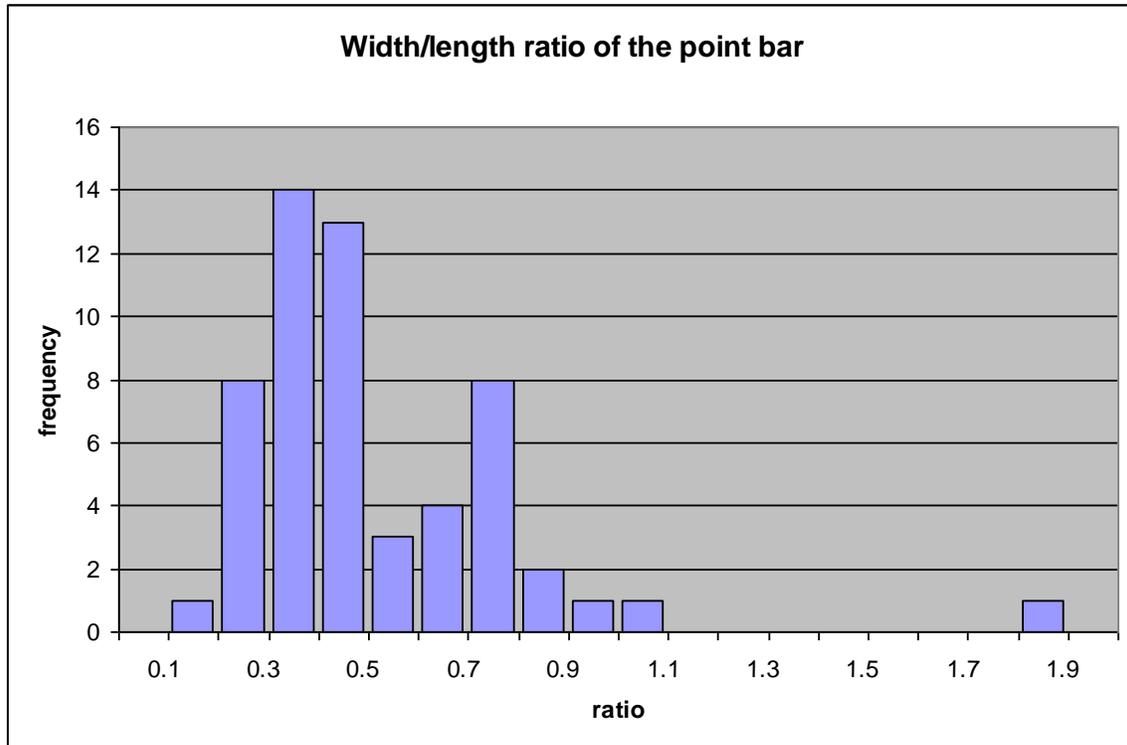


Figure 12: Histogram of the length/width ratio of the point bar

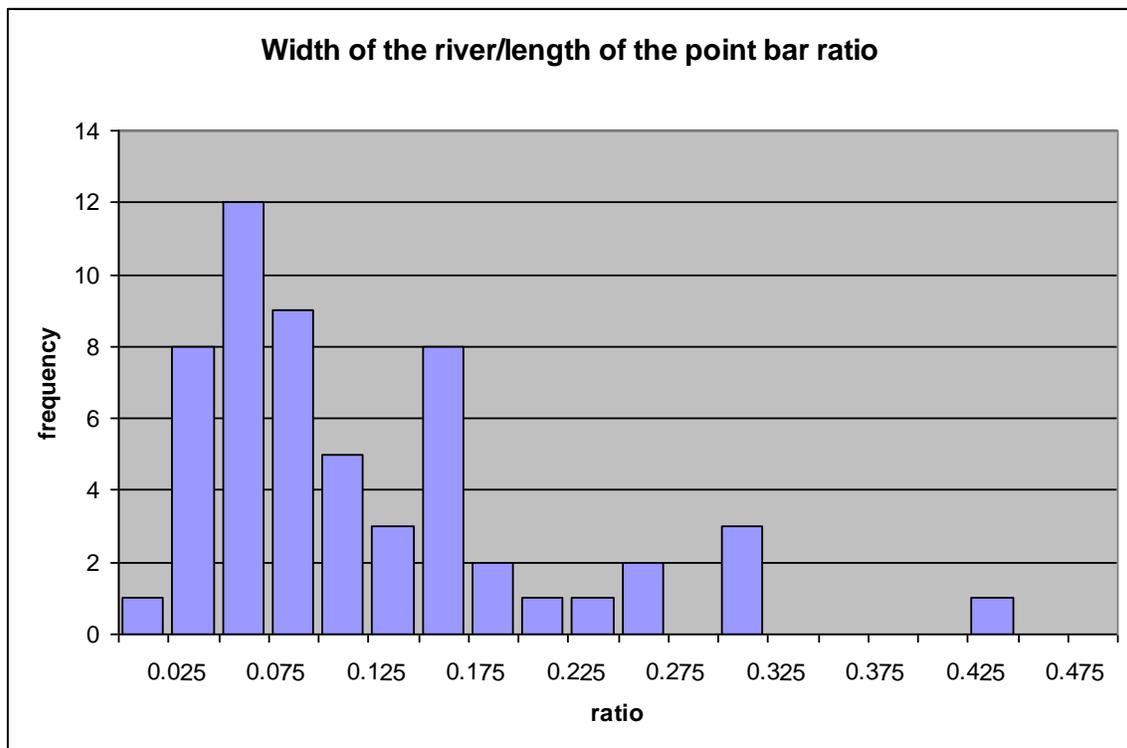


Figure 13: Histogram of the width of the river/length of the point bar ratio

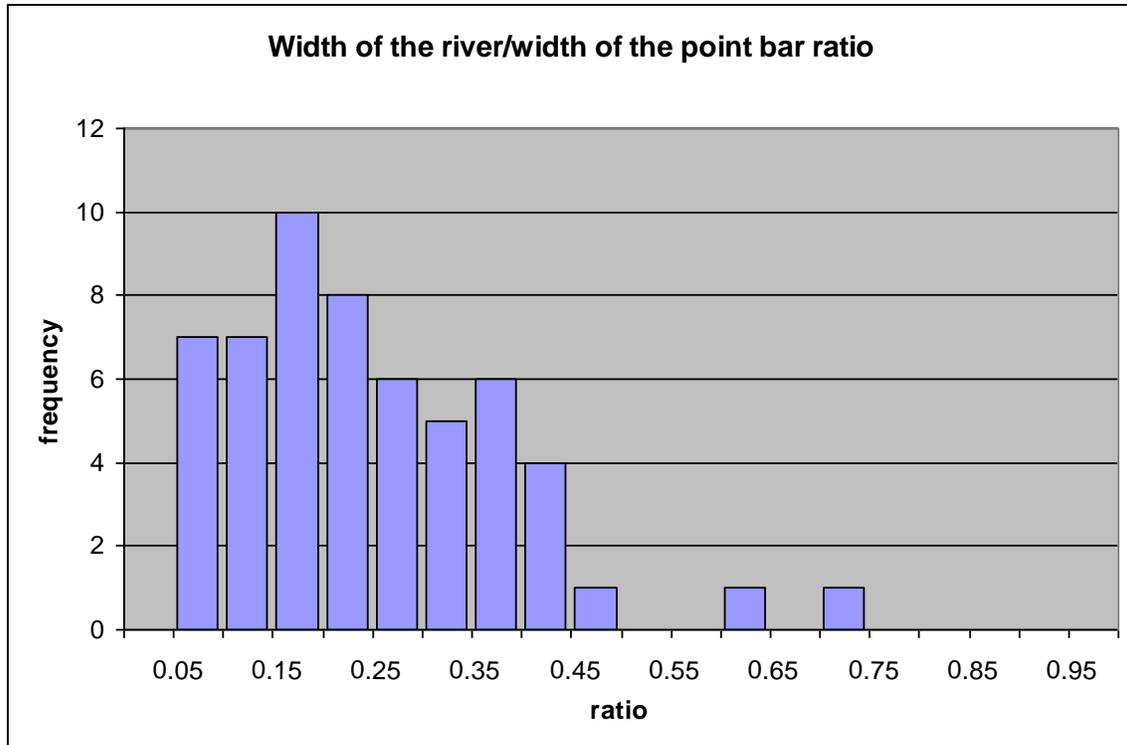


Figure 14: Histogram of the width of the river/width of the point bar ratio

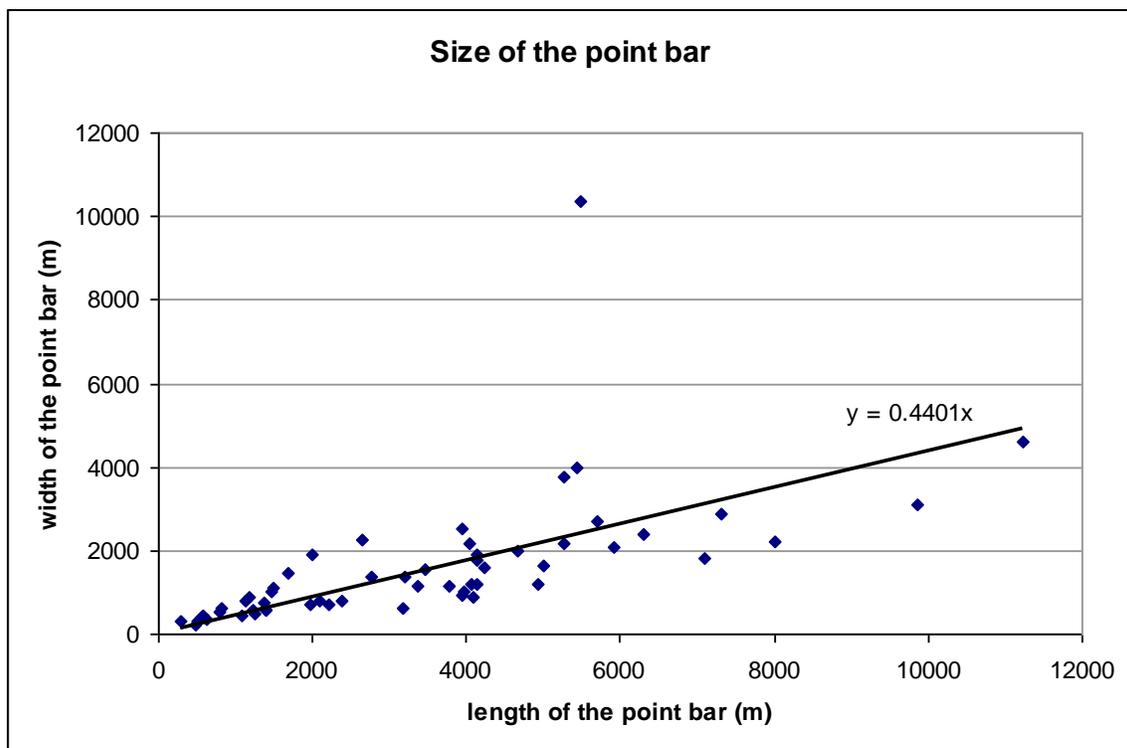


Figure 15: Cross plot of the length and width of the point bar

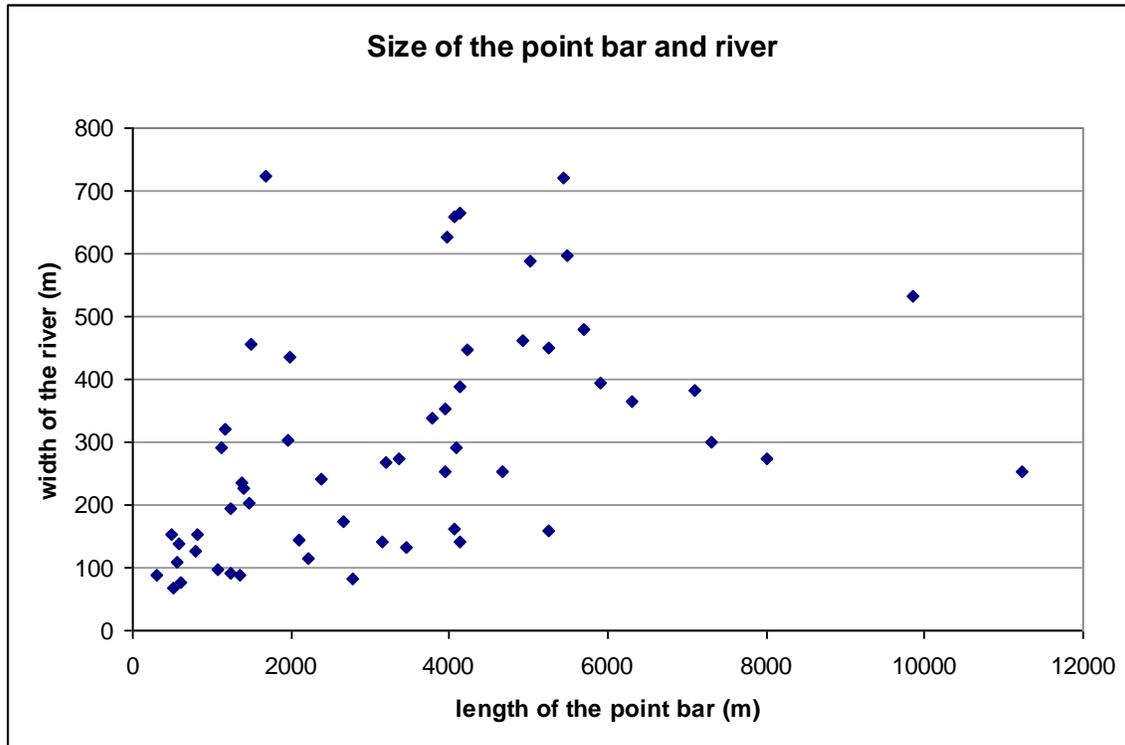


Figure 16: Cross plot of the length of the point bar and the width of the river

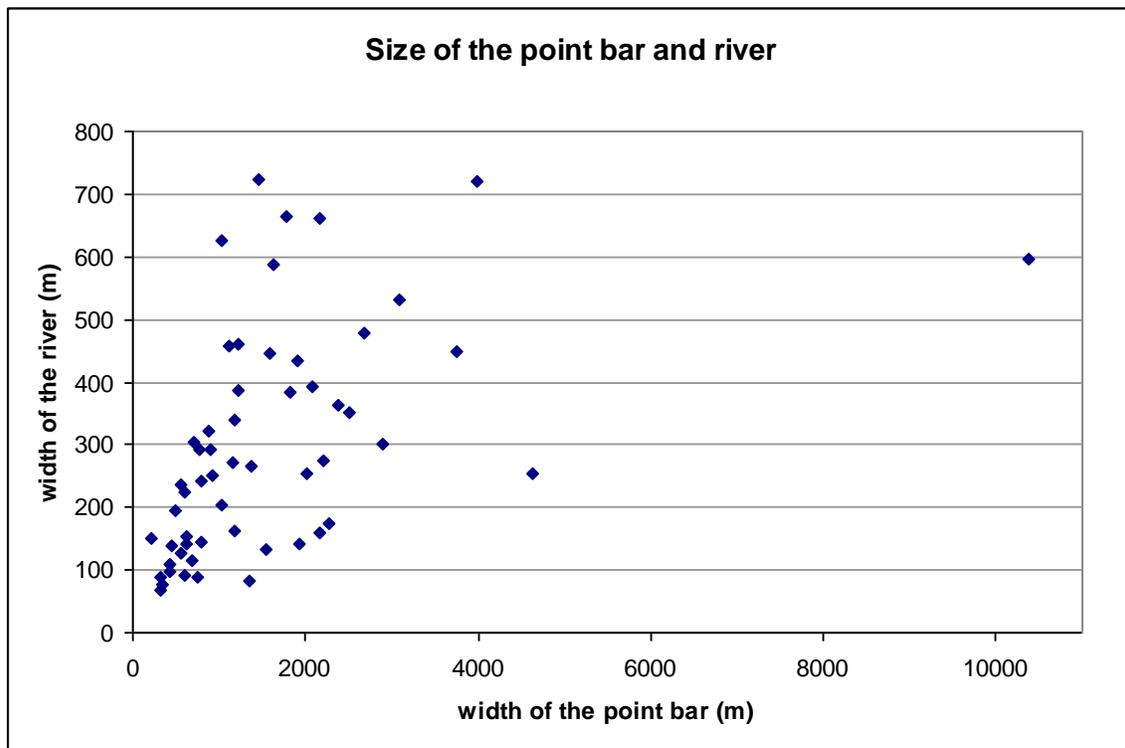


Figure 17: Cross plot of the width of the point bar and the width of the river

Conclusions and Discussion

At the start of this research, three morphologic elements were searched: point bar, river channel and floodplain. However a fourth one is found. The river channel element can be separated in a main channel element and a drainage channel element. The difference between them is that the main channel element is wider and has a lower sinuosity than the drainage channel element.

There are significant differences in the morphology in the study area. Some point bars are completely surrounded by old river channels. It might be that in those point bars, the arsenic concentrations will be high. Point bars consist mainly of sands, which has a high porosity and permeability. The old river channels consist of clay, which has a low porosity and permeability. Therefore, the groundwater will flow only through the point bars. This means that there is no flow through the point bars surrounded by river channels, so the arsenic in these point bars can not migrate away.

And finally the point bars are semicircular. This means that the rough volume estimation of an aquifer is very easy. Calculate the area of a semicircle and multiply it by its thickness. On average a point bar is 10 to 12 meters thick. It is even possible to calculate the water content inside an aquifer, if the porosity and water saturation is known.

Recommendations

First of all, not all the point bars and clay plugs are indicated on this map due to lack of time. So there is further study possible with these images.

Next, the resolution of Google Earth is not good enough to see all of the point bars and clay plugs. The results will be better with photos of Landsat, or aerial photos.

Another possibility is to check this map by doing some fieldwork in the area.

And finally check the depth component with some field work in the area. This map only shows the surface connection, but it is possible that some of the surrounded point bars are connected to the river in the subsurface.

Acknowledgments

I am sincerely thankful to M.E. Donselaar who coached me through this project.

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Appendix



Figure 18: Index map with the locations of the following maps



Figure 19: Map 1 on the index map. The scale bar is 2500 meters.



Figure 20: Map 2 on the index map. The scale bar is 2500 meters.



Figure 21: Map 3 on the index map. The scale bar is 2500 meters.



Figure 22: Map 4 on the index map. The scale bar is 2500 meters.



Figure 23: Map 5 on the index map. The scale bar is 2500 meters.

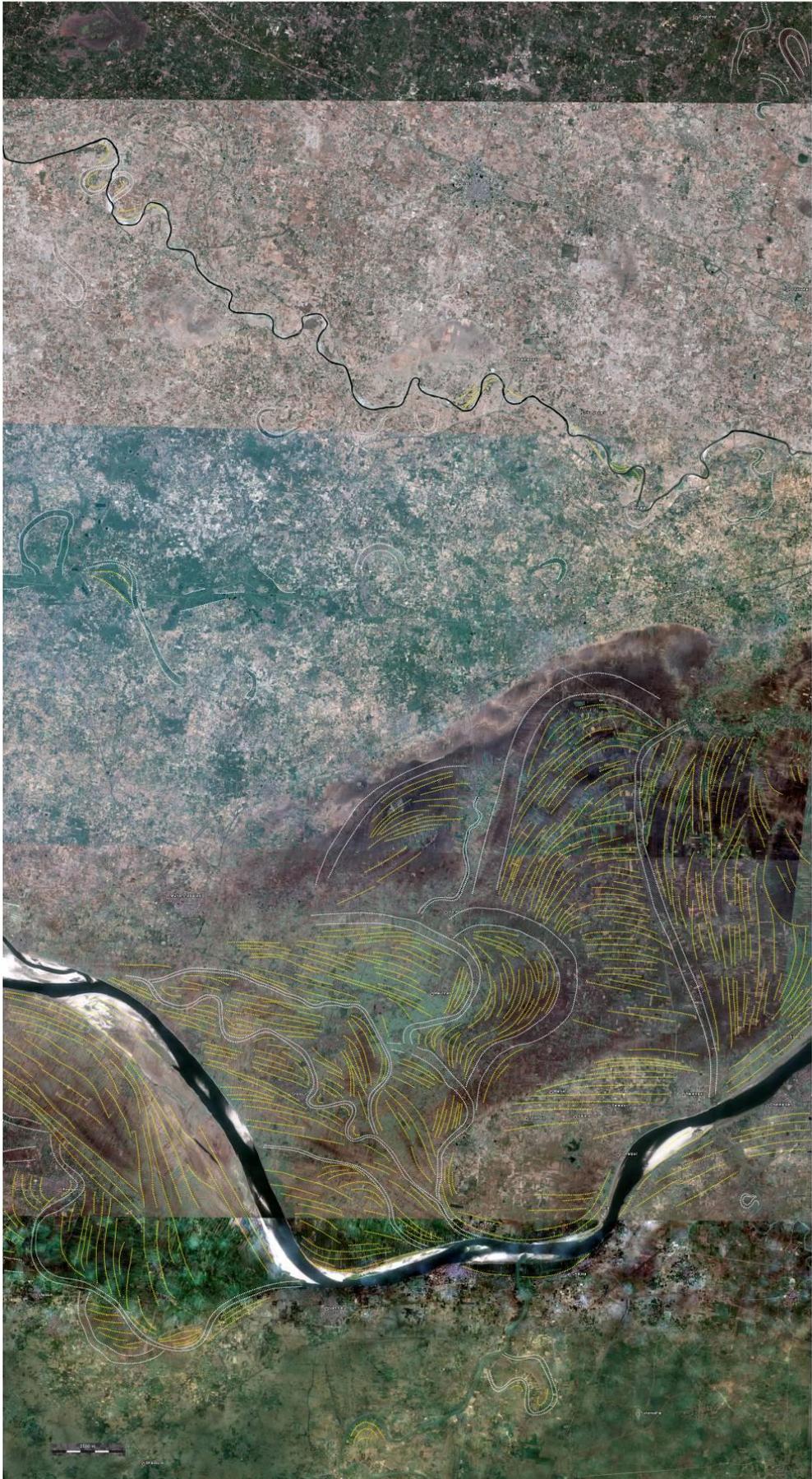


Figure 24: Map 6 on the index map. The scale bar is 2500 meters.

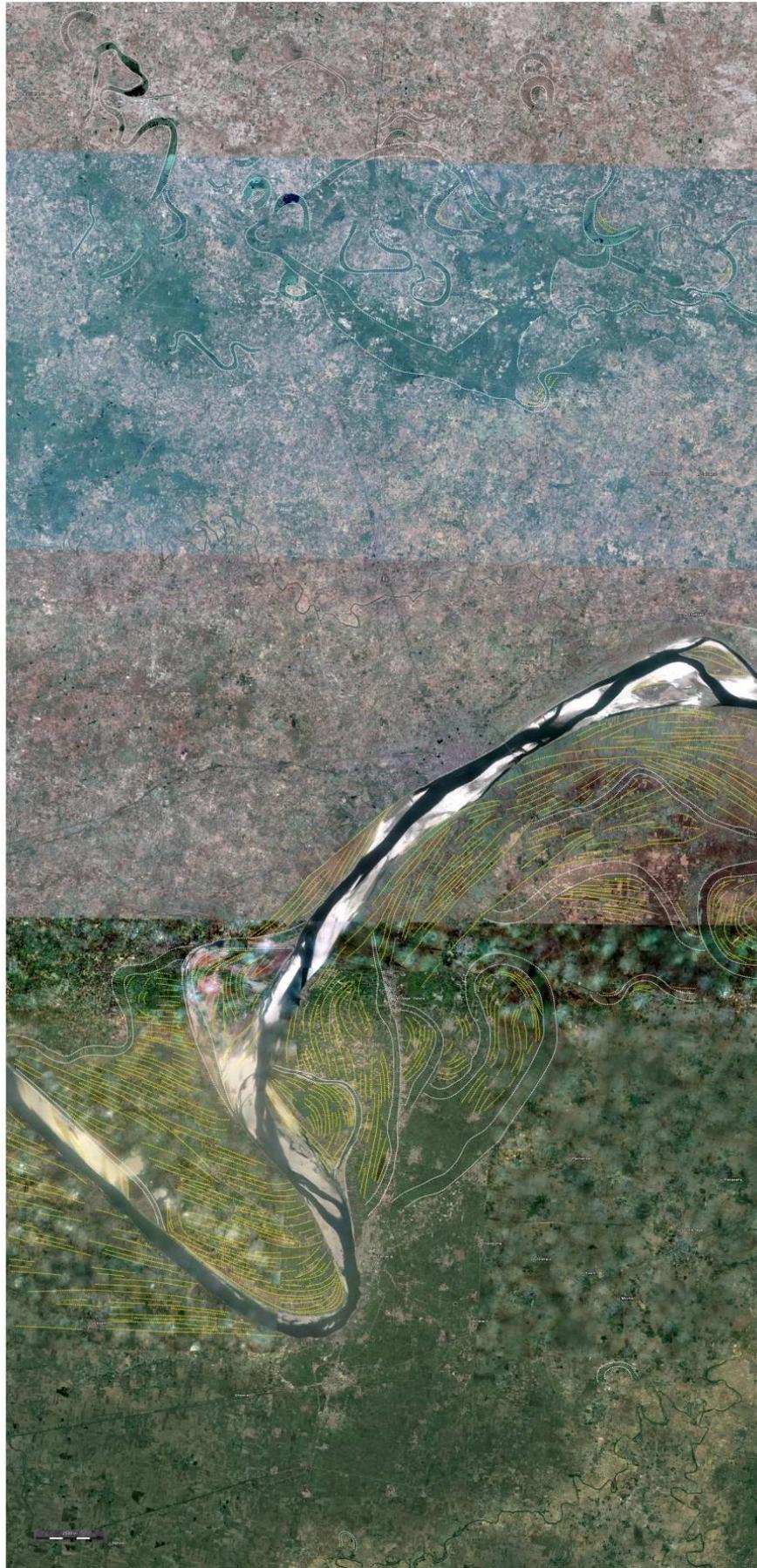


Figure 25: Map 7 on the index map. The scale bar is 2500 meters.