ASSESMENT of the IMPACT of REALTIVE SEA-LEVEL RISE and MANAGEMENT of POLDERED AREAS in SOUTHERN, COASTAL BANGLADESH

CLASS PROJECT

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DATA SOURCES:

- Administrative Boundaries vector files via GADM database of Global Administrative Areas at: http://www.gadm.org/

- ASTER Global Digital Elevation Model rasters via the USGS at www.earthexplorer.usgs.gov

- Global Land Survey 2010 satellite imagery via the USGS a at www.earthexplorer.usgs.gov

- Base map satellite imagery provided via Esri Information and Technology Services in Arc Map version 10.3

I.   INTRODUCTION & PROBLEM

The purpose of this analysis is to evaluate the impact of prospective, Relative Sea-Level ("RSL") in a selected area of southern, coastal Bangladesh. Most of the nation is comprised of the watersheds of the Ganges, Brahmaputra and Meghna Rivers (with over 1,000 offtake rives and tributaries) and the delta they form when they reach the Bay of Bengal. With the exception of mountainous areas to the West and North, the land surface elevation is generally low (less than 50 meters). Hydrologically, the course of the Ganges and Brahmaputra Rivers migrate eastward over geologic time and offtake rivers to the south and west receive reduced downstream flows. As a result, coastal floodplains and watersheds become subject to enhanced tidal flows (upon waxing and waning tides) – resulting in mangrove forests (such as the Sundarbans) and tidal river systems. [§ Amir et.al. 2013]

Bangladesh is given special attention with respect to the discourse on the possible impacts of climate change. Given the low elevation of the delta, the prospect of rising sea-levels and the enhanced frequency and/or strength of tropical cyclones (and related storm surge) which periodically impact the region are of particular concern. In addition to suffering from *exposure* to these geohazards, Bangladesh also poses significant geohazard *risk* as, with an estimated 2015 population of 170 million (over ½ of the U.S. population) residing in a 'land' area of 148,000 square miles of land (or roughly 1.5% of the U.S. land area) [CIA 2015], it is one of the most populous nations on earth. An article published by the New York Times on March 28, 2014 entitled "*Borrowed Time on Disappearing Land - Facing Rising Seas, Bangladesh Confronts the Consequences of Climate Change*" envisages a future wherein as many as 50 million Bangladeshis would be forced to flee their homelands due to rising seas by 2050. Interestingly, the article also provides a "model" showing the inundation that would occur upon 13 feet of sea-level rise entitled *"Disappearing Land"*. As of the date of this analysis such New York Times article was publicly available at:

http://www.nytimes.com/2014/03/29/world/asia/facing-rising-seas-bangladesh-confronts-the-consequences-of-climate-change.html?_r=0

However, rising Mean Sea-Level ("MSL") is not the only driver of a prospective rise of RSL in coastal Bangladesh. A conclusive study and 'scientific consensus' on the matter appears to be currently unavailable, but some evidence has been presented to suggest that subsidence (the fall of the land surface level) may also be a significant contributor. Specifically, (1) the extensive pumping of groundwater from shallow and deep confined aquifers required to irrigate high-yield rice crops during dry winters [Kumar 2015] and (2) the embankment of delta islands under the Coastal Embankment Project ("CEP") [deDie 2013] and consequent disruption of the delta's natural sedimentation cycles have been identified as likely causes of local subsidence [Biswas et.al.2015] – thus contributing to a rise in RSL.

In the course of this analysis I plan to use ArcMap 10.3 software available from Esri Information and Technology Services to evaluate the impact of a rise in RSL using a Digital Elevation Model ("DEM") and contrast those findings with results generated reflecting an adjusted rise in RSL accounting for changes to subsidence which may be achieved by alternative water management and/or land use practices. A description of the methods and data used and results generated follows.

## II.   DATA COLLECTION & PREPROCESSING (Part 1 - DEM)

To begin, I established a baseline area of interest by downloading a vector file of Bangladesh political boundaries directly from the Global Administrative Areas website at www.gadm.org. Entry of this, first layer to the map file set the coordinate system to WGS 1984 but was un-projected and thus the data frame was unaltered. At this time I saved the map file as an ArcMap (.mxd) file named "Bangladesh".

For this analysis a valid and accurate DEM is anticipated to be the most critical data point. Consulting lecture notes regarding the availability of international DEM's, I first looked to the ASTER Global Digital Elevation Model ("GDEM") as I believed this to be the highest quality, freely available source of such data. Specifically, I downloaded six quadrangle GDEM files including North 21 and 22 degrees and East 89, 90, and 91 degrees. These files were originally downloaded in compressed (.zip) format and were unpacked by use of the free WinRAR application to an appropriate file folder and subsequently loaded into the newly created map file.

III.   ARC PROCESSING (Part 1 – Assembly & Assessment)

Initial review of the GDEM files, native in the WGS 1984 spatial reference, presented immediate concerns regarding data consistency. Notably, all three GDEM files along the North 21 degree axis seemingly experienced a data/symbology failure upon import to ArcMap. While the **Identify function** reported individual raster cells with seemingly reasonable values the table of contents noted High and Low values of "0" **[FIGURE 01]**. However, in the hope that the data values were properly stored (as the Identify function led me to believe), I proceeded with combing these six GDEM files into a single raster via the **Mosaic to New Raster tool [FIGURE 02]**. The Mosaic to New Raster tool succeeded in generating a new raster from the mosaic of six GDEM files under a new file folder labeled "Mosaic" and named "ASTER_GDEM".
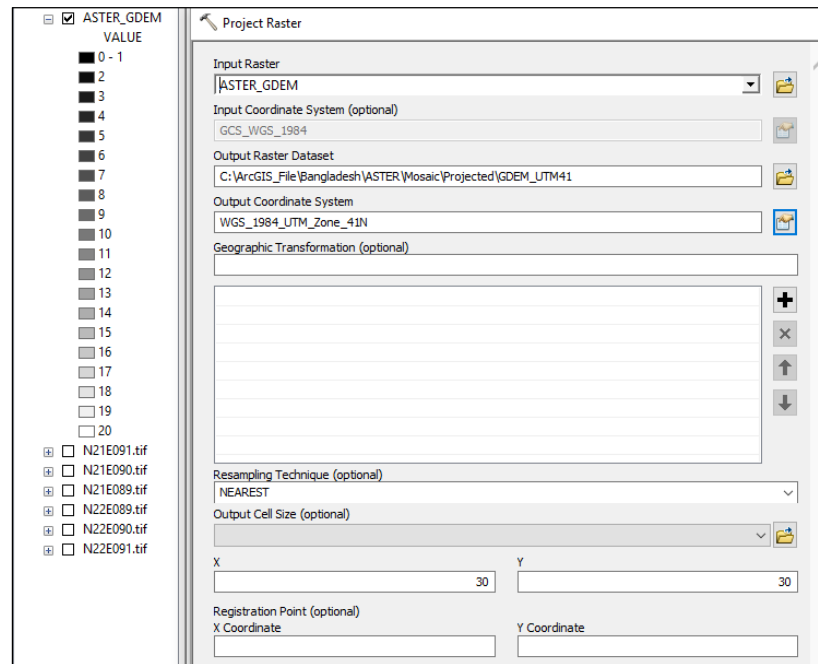
[FIGURE 01]
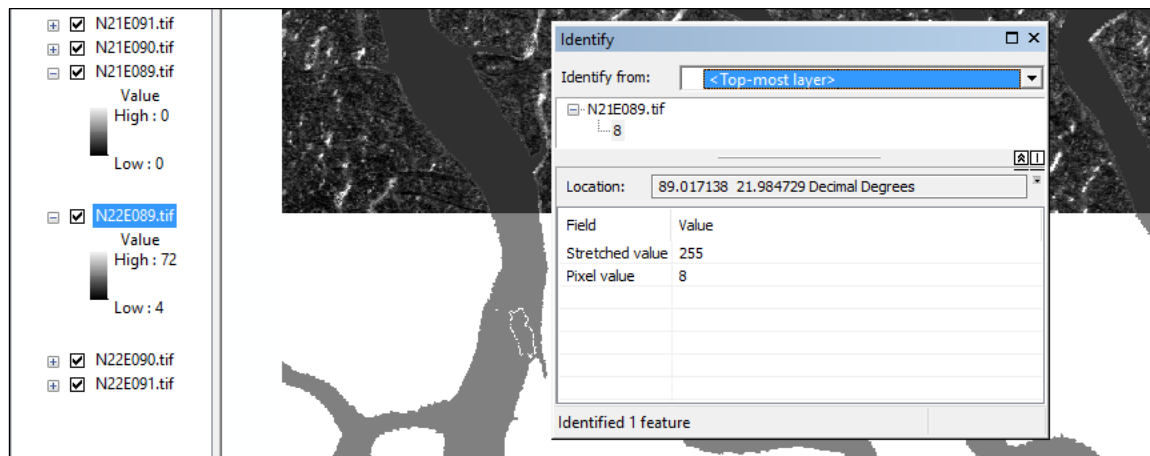
[FIGURE 02]
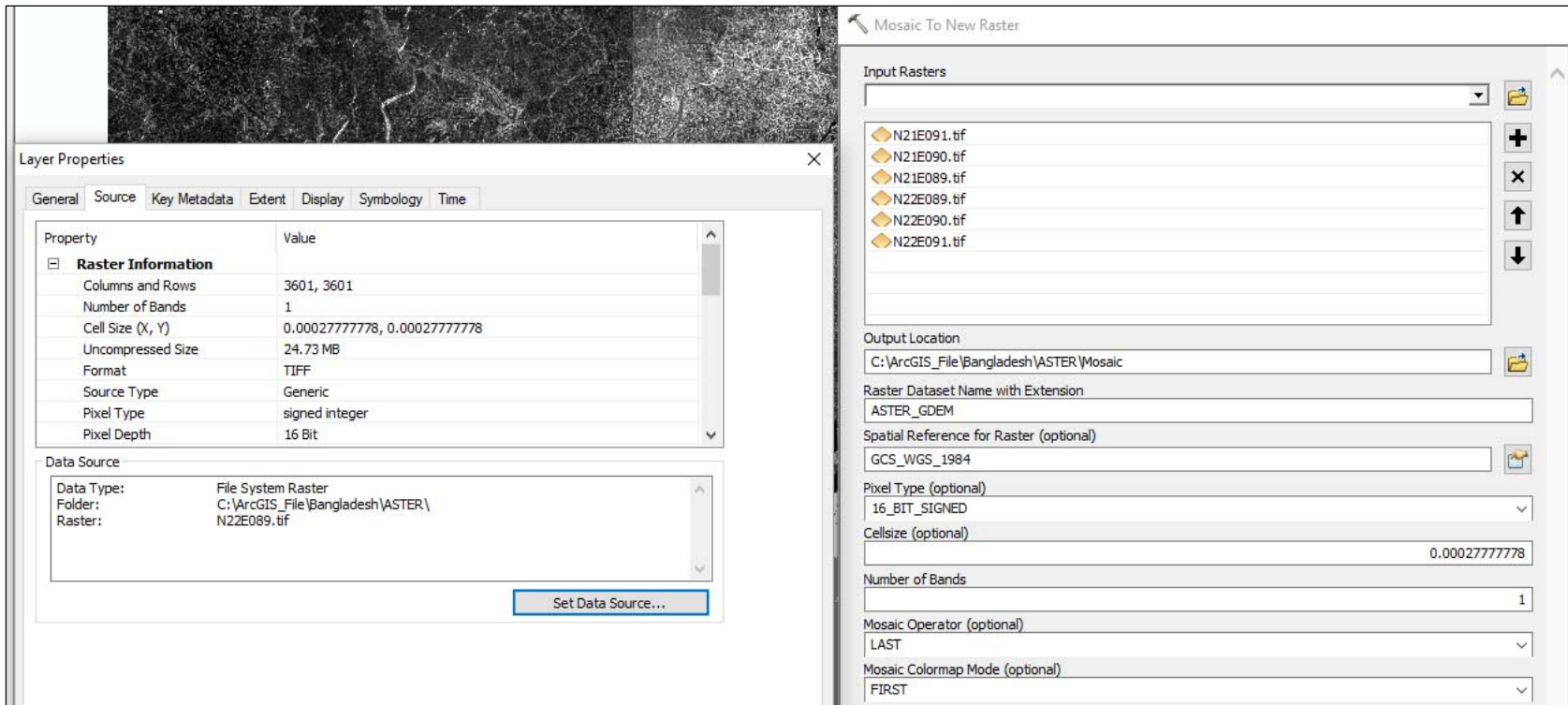
Before moving further, I projected the raster using the **Project Raster tool** in order to, in part, establish linear units in meters. Unfortunately, Bangladesh lies almost directly center-line of the border between Universal Transverse Mercator ("UTM") zone 41 and 42. However, as UTM zone 41 covers a greater proportion of the area of interest it was selected as the output coordinate system for the projected raster **[FIGURE 03]**. I named the file "GDEM_UTM41" and saved it to the "Mosaic" file folder.

Given that the problem addressed hereto calls for an assessment of the impact of sea-level rise upon low-elevation (less than 20 meters), coastal areas and that the GDEM selected includes higher elevation, mountainous areas to the East, I decided to **symbolize** the data under the Classified mode with the *Brown to Blue Green Diverging, Bright* color scheme (flipped – so that blue-green is 0) with an exclusion of all values above 20 meters (and ending at 551 meters - the maximum reported value for the raster) **[FIGURE 04]**.

At this point noticeable differences appeared between the extent of the GDEM above 0 meters and the extent of the Global Administrative Areas vector file **[FIGURE 05]**. Usage of base maps corroborated that the GDEM was a closer approximation to the true land surface, however, it is important to note that while superior to the vector file, the GDEM did not closely approximate land area indicated by base maps in *all* areas **[FIGURE 06]**. Therefore I elected to remove the administrative area vector file in favor of calculating a new, sea-level contour line from the GDEM.
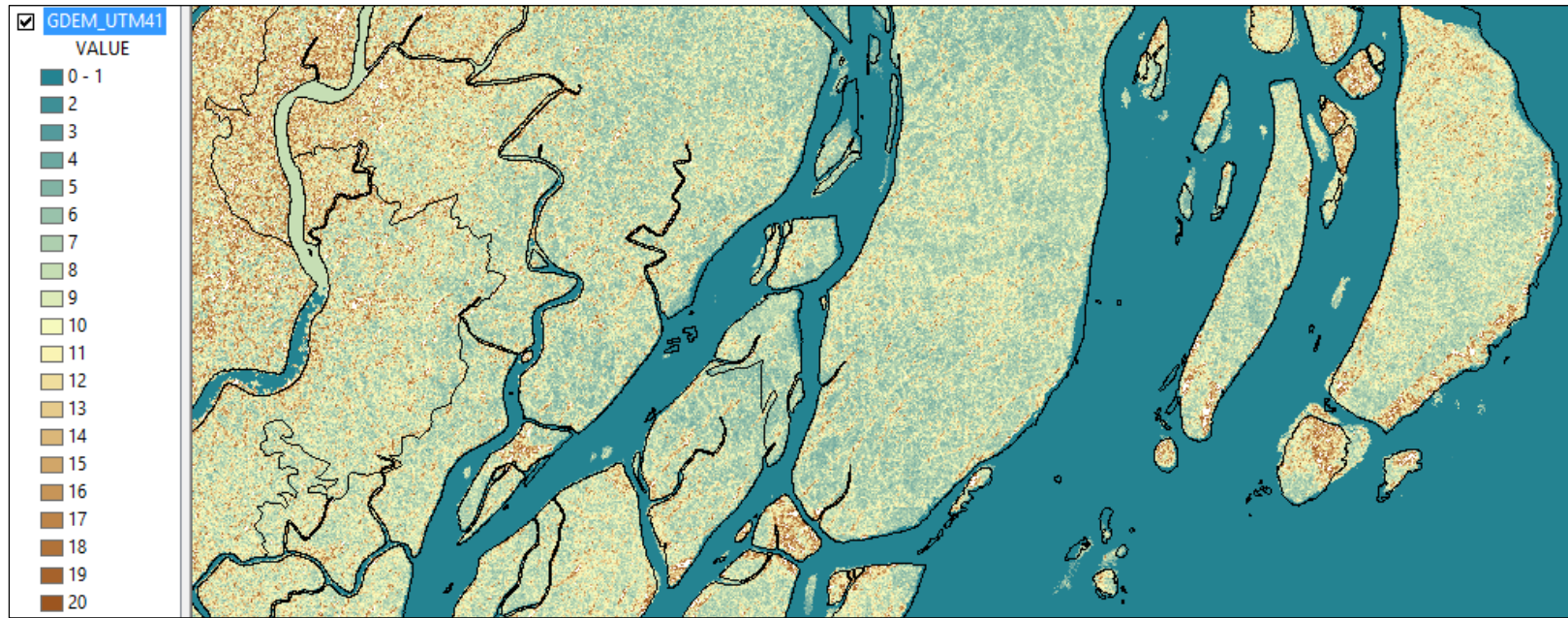
[FIGURE 03]

[FIGURE 04]
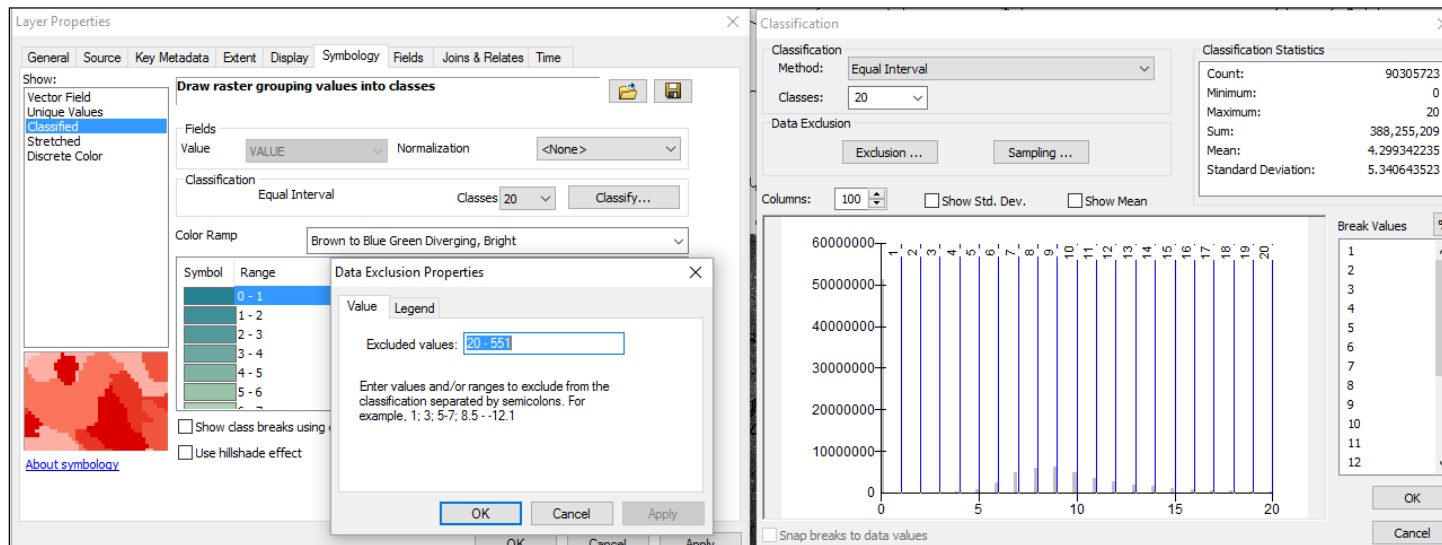
[FIGURE 05]

[FIGURE 06]

Initial review of the GDEM symbology and anticipated sea-level contouring revealed numerous locations that posed likely problems in generating such - notably several river areas were reported to suddenly increase in elevation by as much as 10 meters for what the base map satellite imagery indicated was for no explained reason **[FIGURE 07]**. As this analysis is particularly concerned with delta islands spatially defined and provided sedimentation by these waterways, these errors needed to be corrected before proceeding further in generating a sea-level contour line.

[FIGURE 07]

In order to minimize the required error processing and focus the analysis, I decided it was time to select an appropriate area of study. In order to achieve this, I opened ArcCatalog from within ArcMap and in the "Bangladesh" file folder I created a new **Personal Geodatabase** (.mdb) for the analysis and saved it as "Bangladesh". Then, from within ArcCatalog, I created a new **polygon feature**

class and named it "Map_Area". Then, within ArcMap, I launched the **Editor** function and created a new, rectangle polygon vector file to serve as the bounding line for the study. I saved edits, closed the Editor function, and symbolized the polygon with no color fill and a 1 point black outline. The area chosen was selected, somewhat arbitrarily, for the presence embanked delta islands at low elevations and, so established, I then proceeded to use the **Raster Clip** tool to present GDEM data exclusively within the Map Area polygon and named the file "GDEM".

[FIGURE 08]
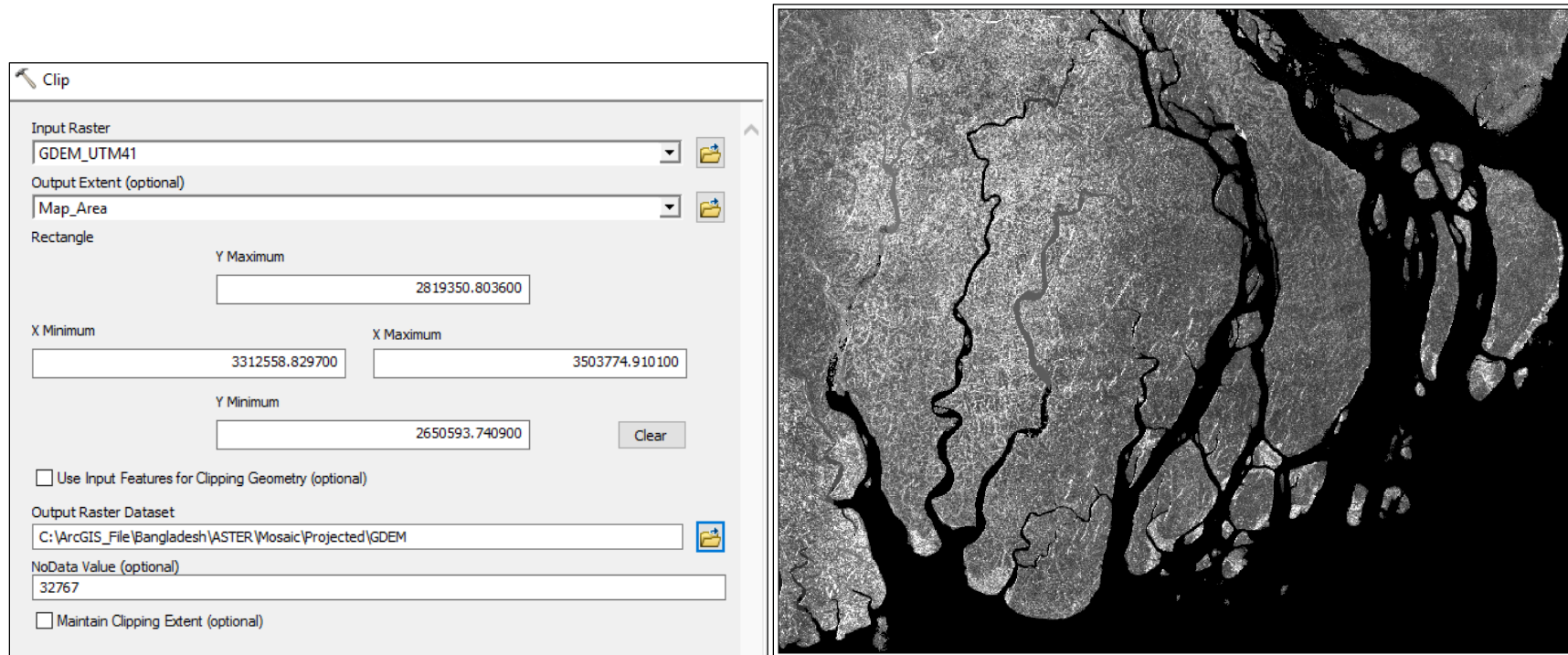
At this time I symbolized the GDEM as previously only this time values between 20 meters and the maximum reported value of 113 meters were not excluded but rather grouped as a single symbology classification category. So prepared, I then ran a series of map algebra, conditional statement, and region group tools to attempt to correct perceived errors in the newly clipped and symbolized GDEM elevation values – particularly along river channels. However, I will not detail this process here as these efforts entirely failed to remove the errors in question and the steps will be wholly repeated and detailed later in the analysis. In summation, the delineation of elevation differences in the GDEM were too distinct to be corrected. Therefore, an alternative method of correcting for these errors was required before proceeding further in the analysis.

IV.   DATA COLLECTION & PREPROCESSING (Part 2 – GLS 2010)

As arc processing of the GDEM alone was insufficient to remove elevation errors, additional data sets were required to validate the extent of water courses. As the only other freely available DEM for the area was the Shuttle Radar Topography Mission data set (likely representing a reduction in data quality from the ASTER GDEM), I elected to seek satellite imagery for needed validation.

Specifically, I downloaded Global Land Survey 2010 ("GLS2010") images WRS Path: 137 / WRS Row: 44 and 45 directly from the U.S. Geological Survey ("USGS") by way of the Earth Explorer service provided at www.earthexplorer.usgs.gov. These two downloads were in the "standard file format" (.TIFF) which was uncompressed (from .tar format) to a new file folder labeled "GLS2010". Each such image contained ten black and white bands and a single, multi-spectral band. By loading all bands and comparing them manually, one-by-one with the assistance of the Identify function, I was able to select the bands representing the finest quality images with the highest color contrast between land and water. For the northerly image quadrangle I selected the "B50" band (named "NW_B50") and the "B30" band (named "SW_B30") for the southerly quadrangle. All images were presented with a zero value collar and overlapped in field **[FIGURE 09]**.
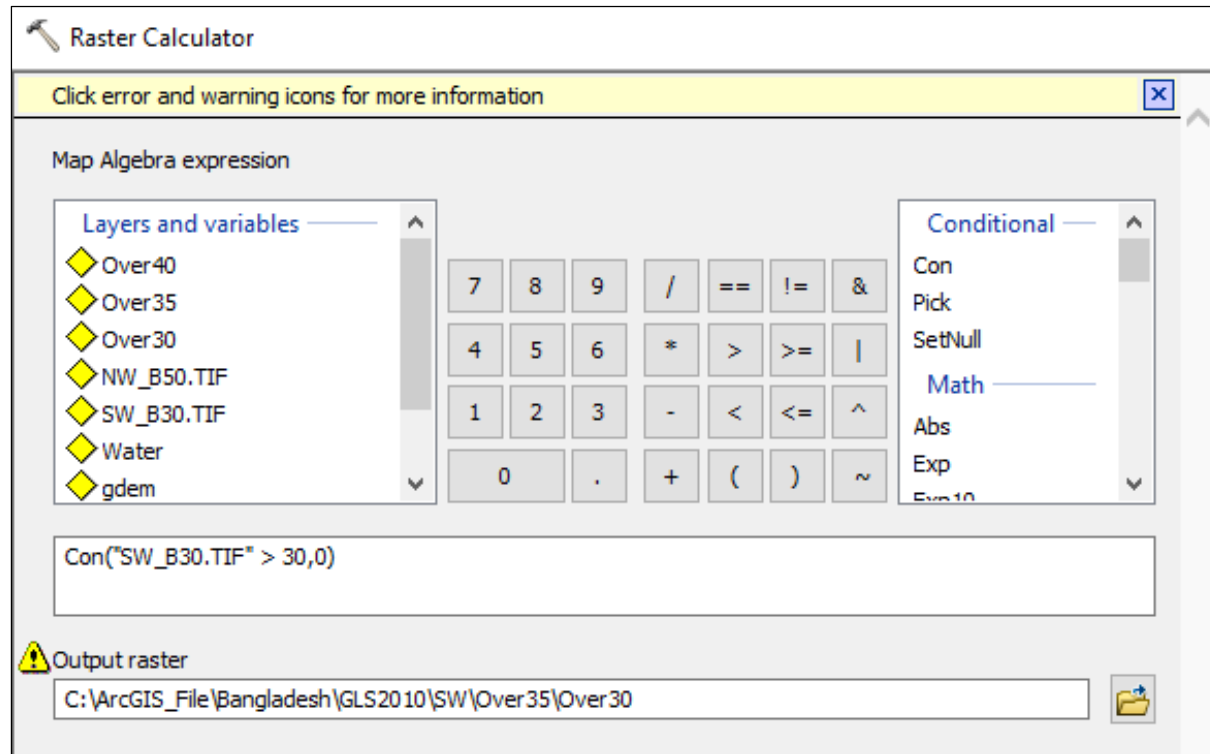
[FIGURE 09]
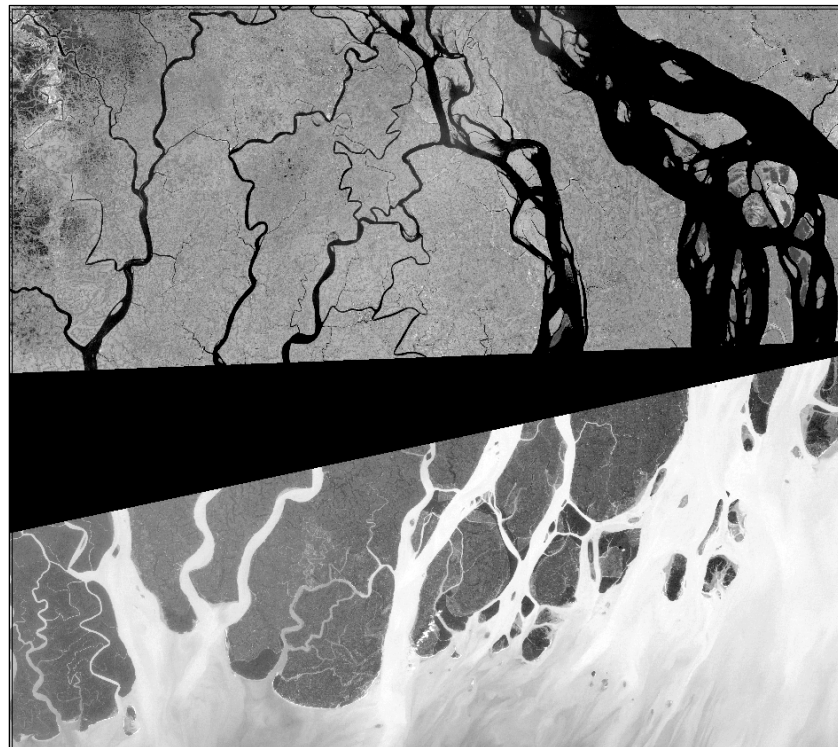
V.   ARC PROCESSING (Part 2 – River Correction)

With the GLS2010 image bands selected and loaded, I first employed the **Raster Calculator** tool with a conditional SQL statement to generate a new raster for each image **[FIGURE 10]** which would exclude the zero pixel value collar data. I named these new rasters NW and SW Collar respectively.

[FIGURE 10]

I then examined selected banks of waterways using the Identify function and base map imagery to determine a pixel value demarcation between land and water. Once a reasonable pixel value range was determined, I generate three new rasters for each NW and SW Collar rasters from pixel values in the selected range in five unit increments as a value of zero with all other values excluded as "no data" **[FIGURE 10]** and named them accordingly. I then superimposed these newly generated rasters in ascending order and compared the differences in coverage to the base map satellite imagery to determine which value was the closest approximation to the represented river bank **[FIGURE 11]**.
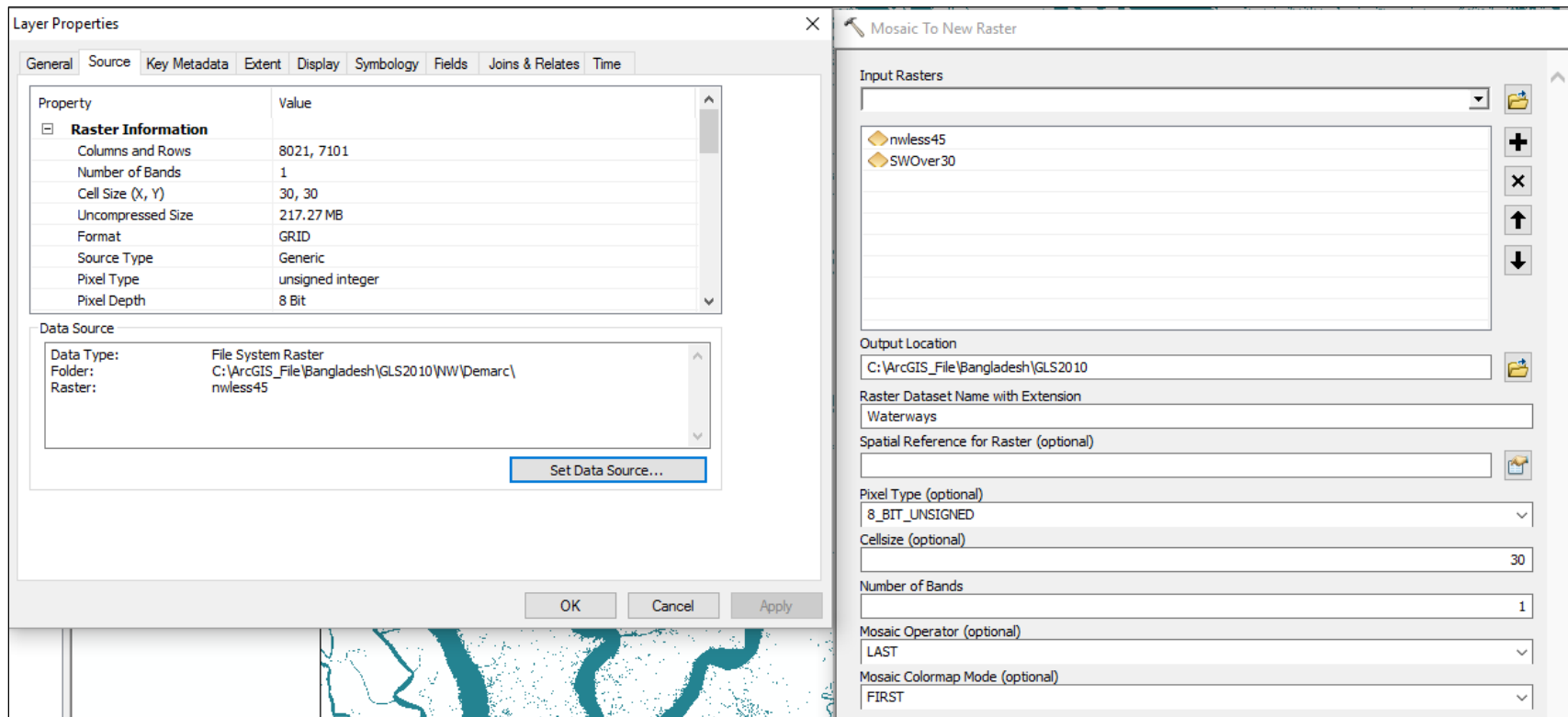
[FIGURE 11]

Pixel value thresholds were selected as "over 30" for the southerly raster and "less than 45" for the northerly raster. From these two rasters, I again employed the Mosaic to New Raster tool to generate a single raster with zero values for prescribed waterways and "no data" in all other cells and named it "Waterways" **[FIGURE 11]**. I then used the **Region Group** results with the **Con** tool to remove as many of the extraneous, qualifying pixel values as possible (keeping only the highest count group) and outputting the results as a value of one with a file named "One_River" **[FIGURE 12].** I then utilized the **Reclassify** tool to create a new raster wherein the river channels would be represented as "no data" while all other values would be valued at one named "River_Mask" **[FIGURE 13]**.

Finally, with this new "River_Mask" raster sufficiently generated, I used the **Extract by Mask** tool **[FIGURE 14]** to extract the GDEM using the "River_Mask" raster as a mask. I then used the Reclassify tool on the resulting "GDEM_correct" raster to revert "no data" cells to zero values and named the final output raster "GDEM_Mod". A comparison of the GDEM with errors present and the newly created GDEM_Mod **[FIGURE 15]** reflects satisfactory correction of elevation errors along waterways. I symbolized the GDEM_Mod with the same color ramp as before, only this time I did not run an exclusion, but rather combined all values above 20 meters into a single symbology category – for the sake of final presentation.
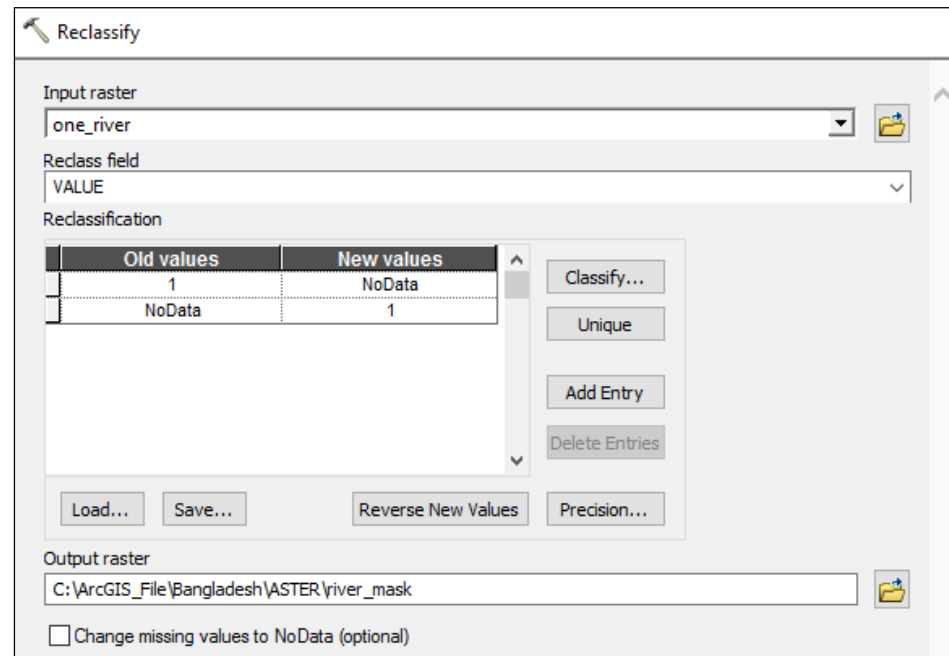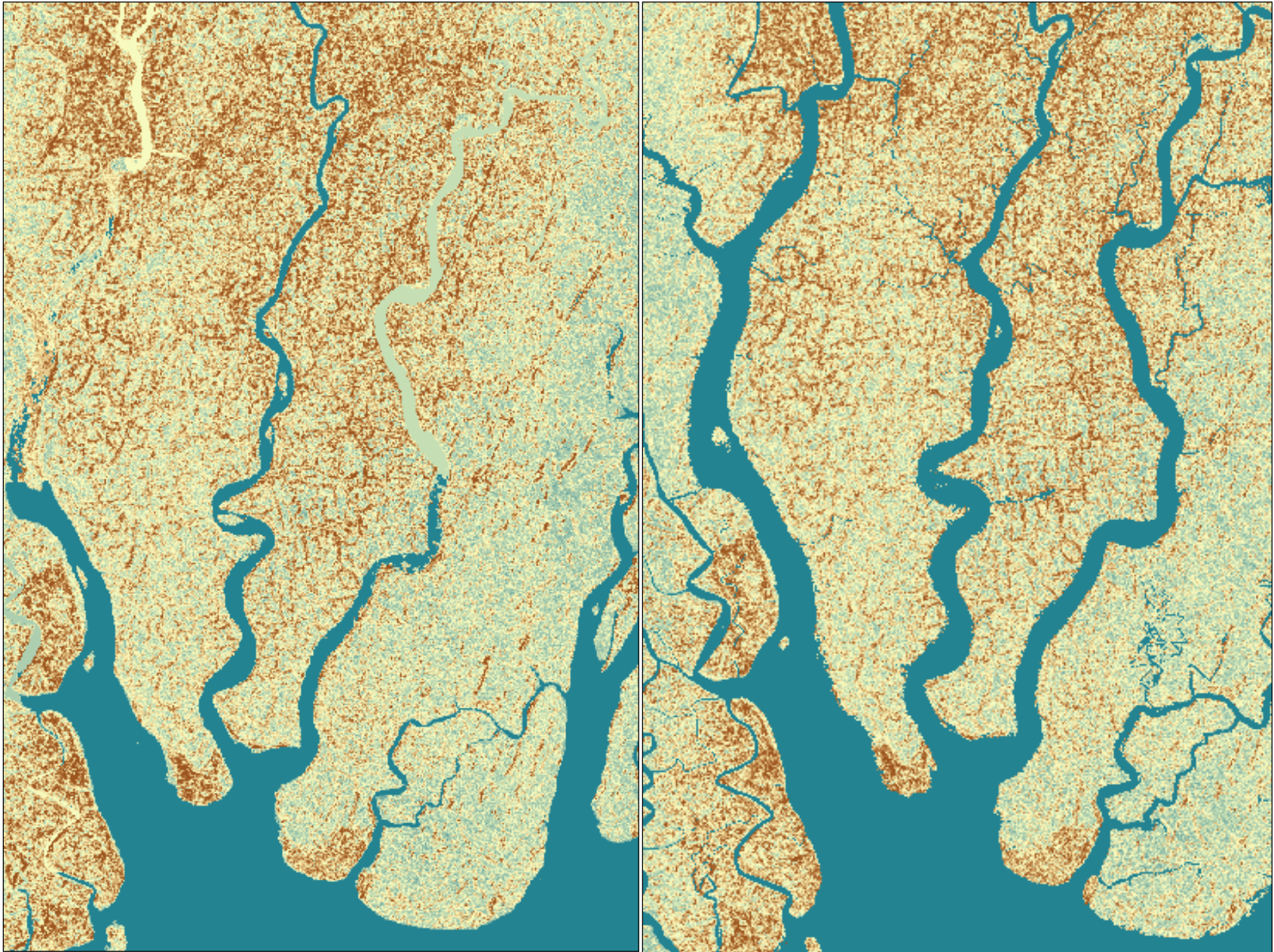
[FIGURE 11]

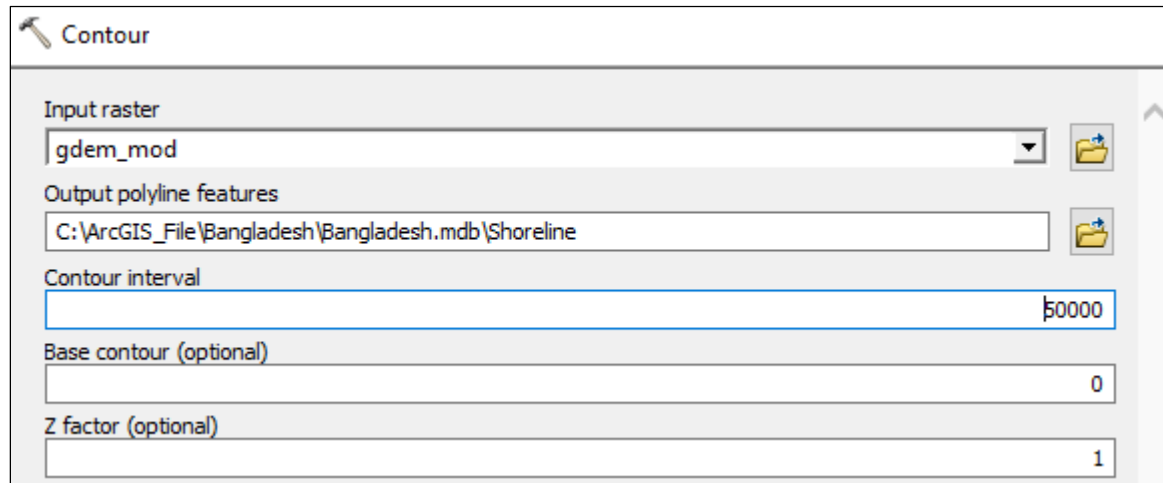**[FIGURE 12]**

[FIGURE 13]


[FIGURE 14]

[FIGURE 15]

VI.   ARC PROCESSING (Part 3 – Sea-Level Rise)

With a sea-level (zero elevation value) well established, I then utilized the **Contour** tool to generate a shoreline vector file, which I named "Shoreline" and saved to the existing "Bangladesh" personal geodatabase **[FIGURE 16]**. I symbolized the new "Shoreline" vector file with a black line of 0.5 points in weight and 50% display transparency **[FIGURE 17]**.
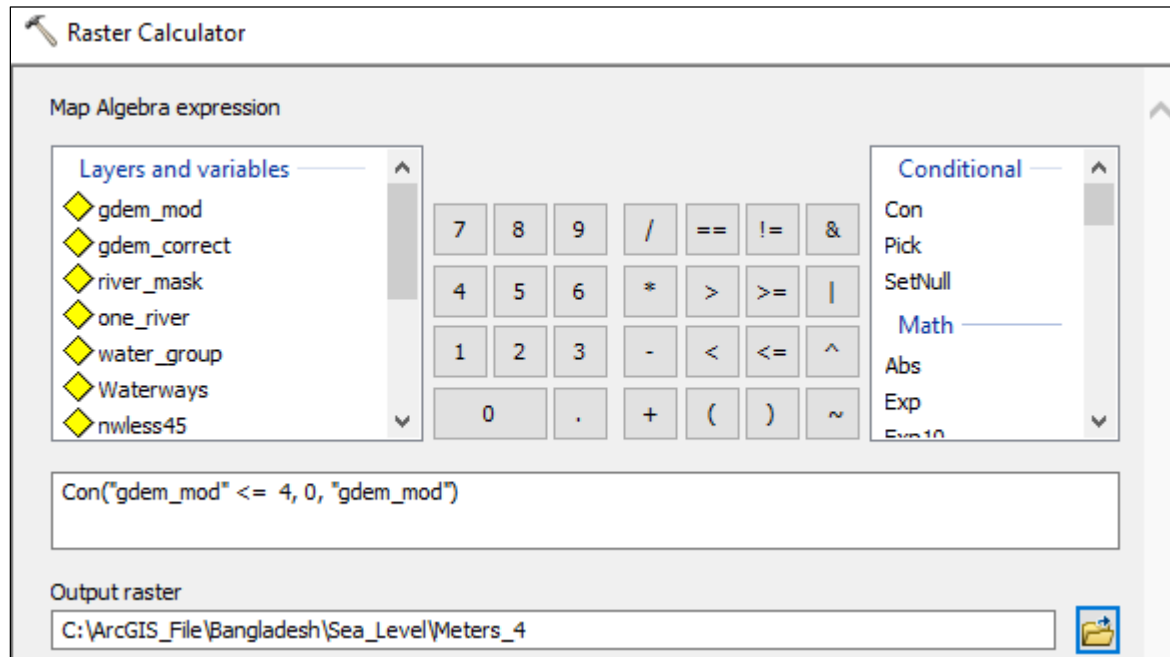
[FIGURE 16]

[FIGURE 17]
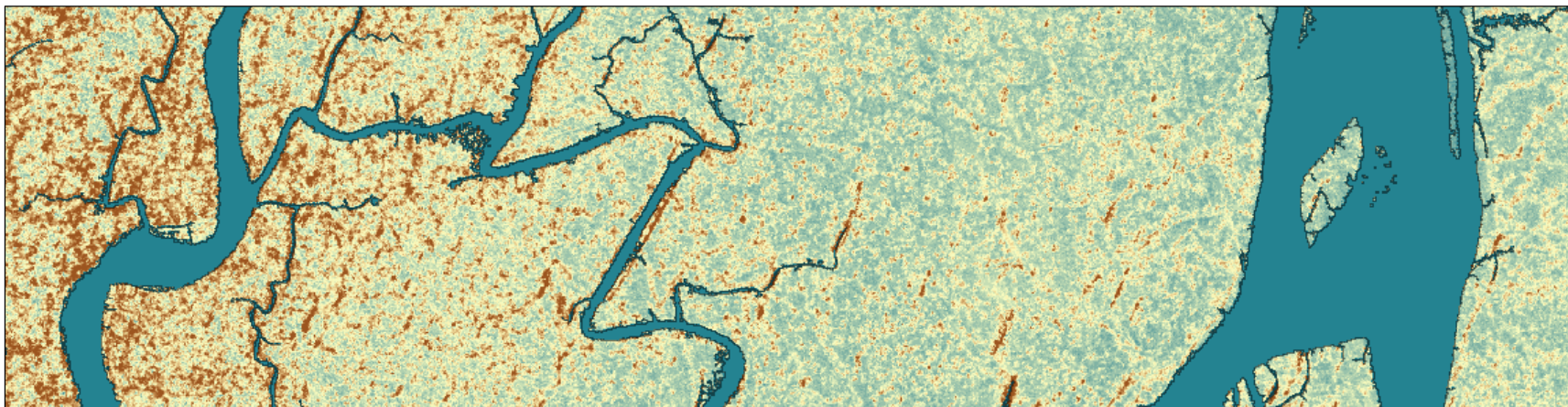
At last ready to perform calculations for sea-level rise, I again utilized the Raster Calculator to show the effect of 13 feet (or, represented in this analysis, 4 meters) of RSL as discussed by the New York Times to generate a new raster I named "Meters_4" and saved to a newly created file folder titled "Sea_Level" [FIGURE 18].

[FIGURE 18]

Interestingly, the "Meters_4" raster did not reflect the vast areas of inundation shown by the New York Times model. Indeed, only the very lowest lying areas were reduced to an elevation of zero **[FIGURE 19].** This is fairly well represented by the GDEM_Mod itself and could have been just as easily verified by simply changing the symbology of the GDEM_Mod for all values of four or less to the same category as zero. Through repeated iteration of the above the raster calculation at increasing meters, I found that roughly 10 meters (or nearly 33 feet, named "Meters_10") of RSL rise was required to produce approximate flooding (demonstrated by the respective contour line and symbology) as presented by the New York Times model **[FIGURE 20].**
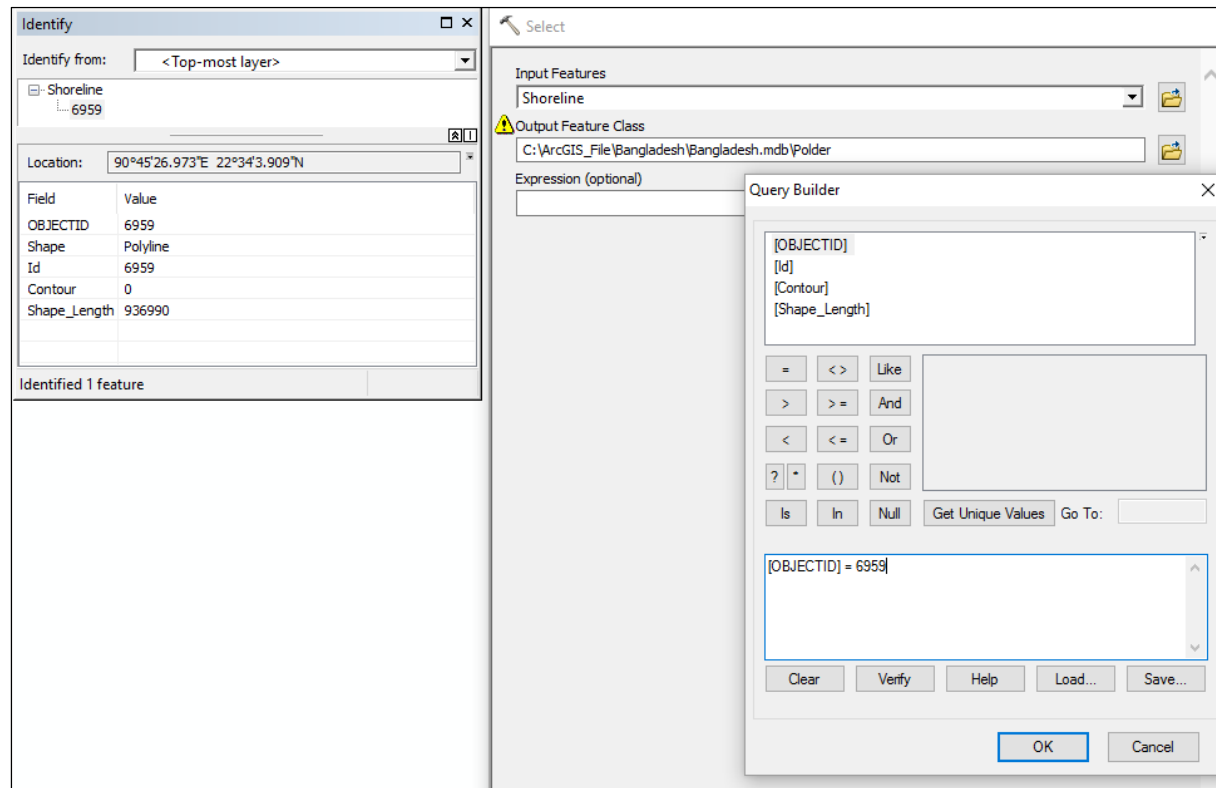
[FIGURE 19]

[FIGURE 20]
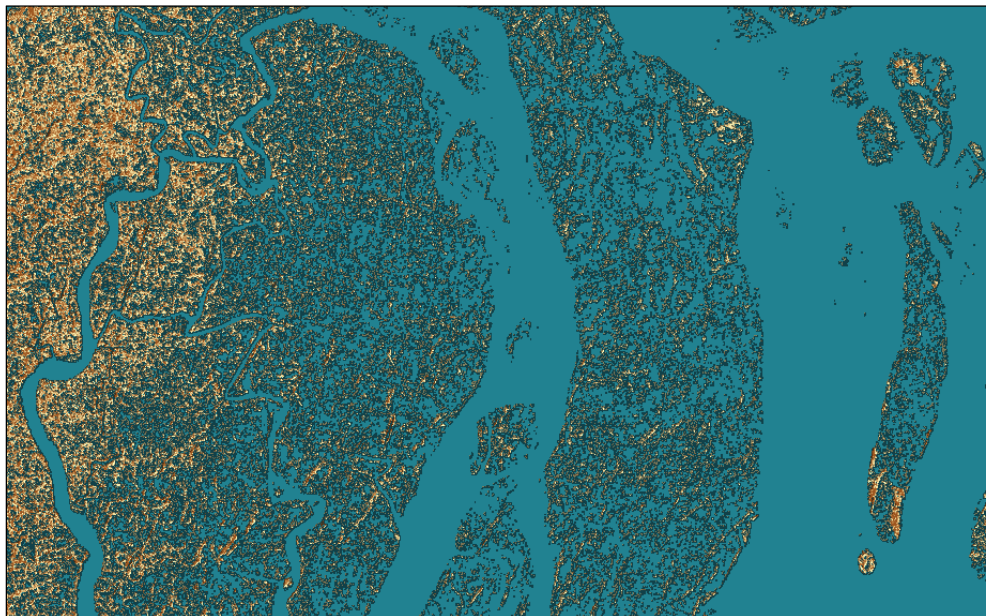
**VII.   ARC PROCESSING (Part 4 – Managed Land)**

The final phase of this analysis was to evaluate the impact of prospective RSL rise in light of managed subsidence via the cessation of groundwater pumping and enhanced sedimentation from de-poldering of CEP developed areas. Specifically, polder 56/57 was chosen for this case study as it experienced significant inundation under the GDEM_Mod reflecting 10 meters of RSL rise.

To achieve this, I utilized the Identify feature to locate the Object ID for the "Shoreline" line-file representing the current sea-level of polder 56/57 and named the resultant feature class "Polder" **[FIGURE 21]**. The result was indeed a line-file (as opposed to a closed polygon) and thusly I needed to enter the editor to add a line closing the feature class and then apply the **Feature to Polygon** tool **[FIGURE 22]** to properly reflect the polder as a closed polygon. The successfully generated polygon was named "Polder_Poly", saved to the existing "Bangladesh" personal geodatabase, and was symbolized with a 0.5 black outline, lilac fill, and 50% transparency display **[FIGURE 23]**.
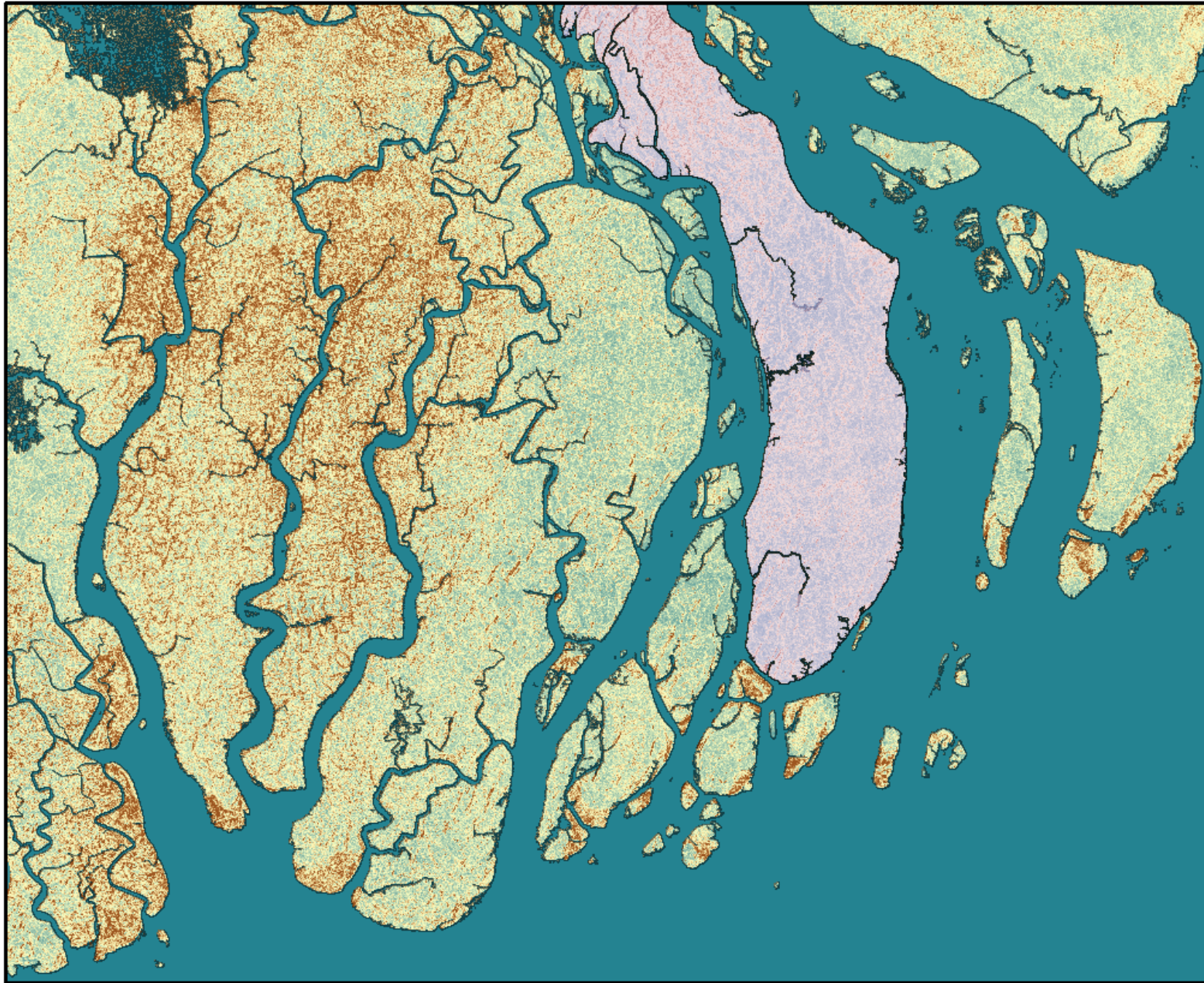
[FIGURE 21]
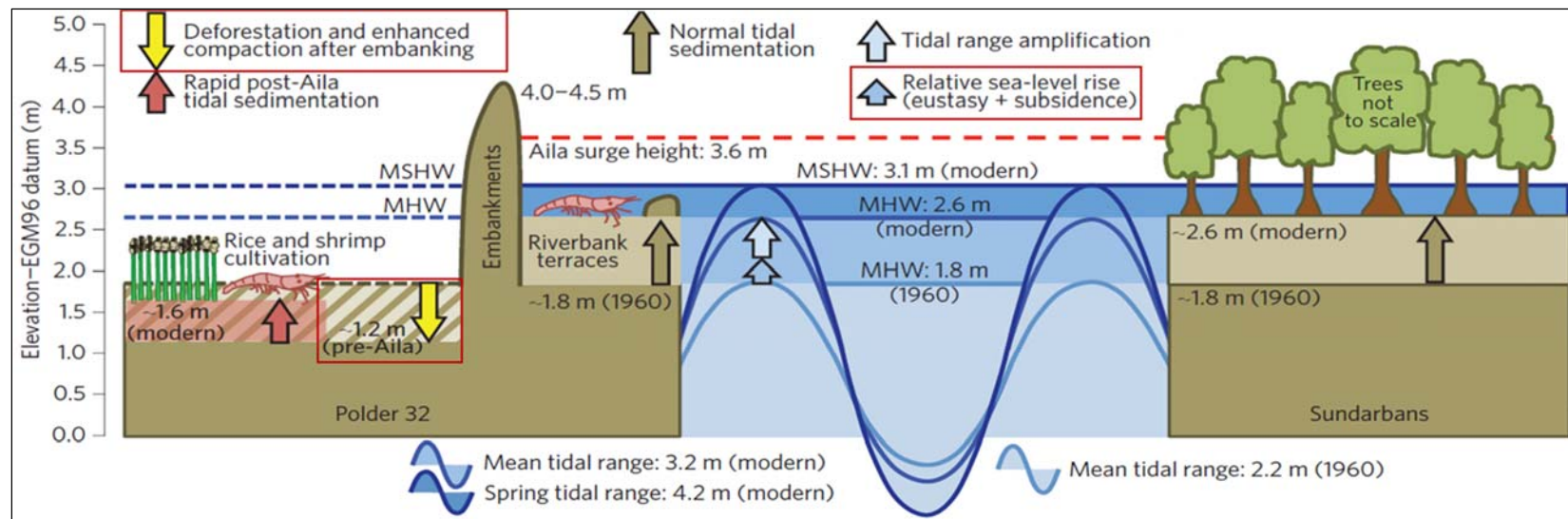
[FIGURE 22]
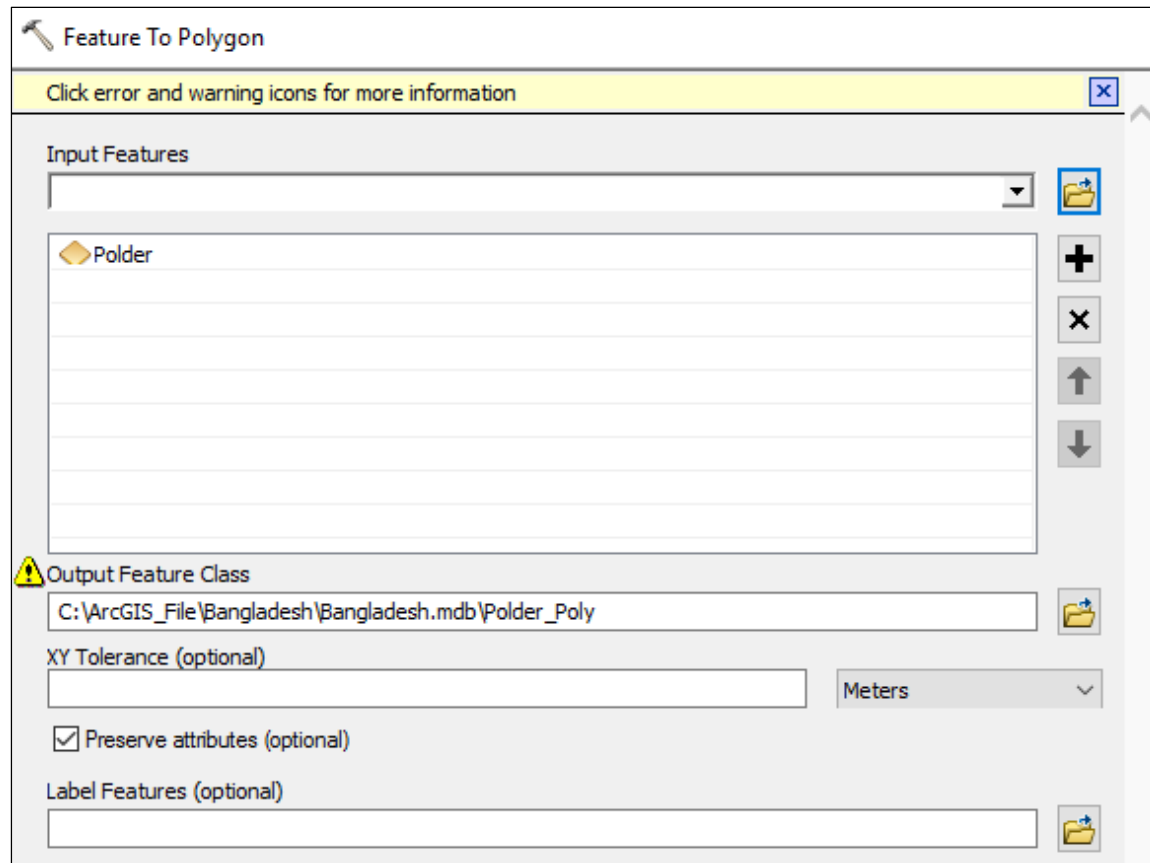
[FIGURE 23]

In preparation for the comparative raster calculations, I created a new rasters using the Extract by Mask tool. Specifically, I extracted the GDEM_Mod with a mask of the Poly_Polder, naming it "Select_10m" and symbolizing it in the same fashion as the GDEM_Mod.

If then we accept an extreme MSL rise event (in the amount of 10 meters) for all areas *except* Polder 56/57 we are now free to apply a *different* MSL rise event to Polder 56/57 to reflect the prospective impact of the cessation of groundwater pumping and resumed deposition under tidal river management and similar policies. One recent study, citing polders inundated by tropical cyclone Aila for two years, has suggested that areas *below* RSL seem to experience enhanced sedimentation resulting in an increase of deposition of roughly 0.8 meters per year **[FIGURE 24]** [Auerbach et.al. 2015].

Therefore, if we consider a timeline for this RSL rise to be 34 years (2016 – 2050, as in the New York Times Model reflecting only 4 meters of RSL rise) then the annual RSL rise is only 0.2941 meters per year. As such, for the purpose of this analysis, we see that RSL rise of 0.2941 meters per year is overcome by 0.8 meters per year of enhanced sedimentation to areas below RSL and therefore we may reasonably model the impact to Polder 56/57 by adjusting the "Meters_10" raster to reflect elevations equal to or below zero as one meter of elevation (but no more as enhanced sedimentation has only been suggested for areas *below* RSL at the time of inundation) **[FIGURE 25]**.
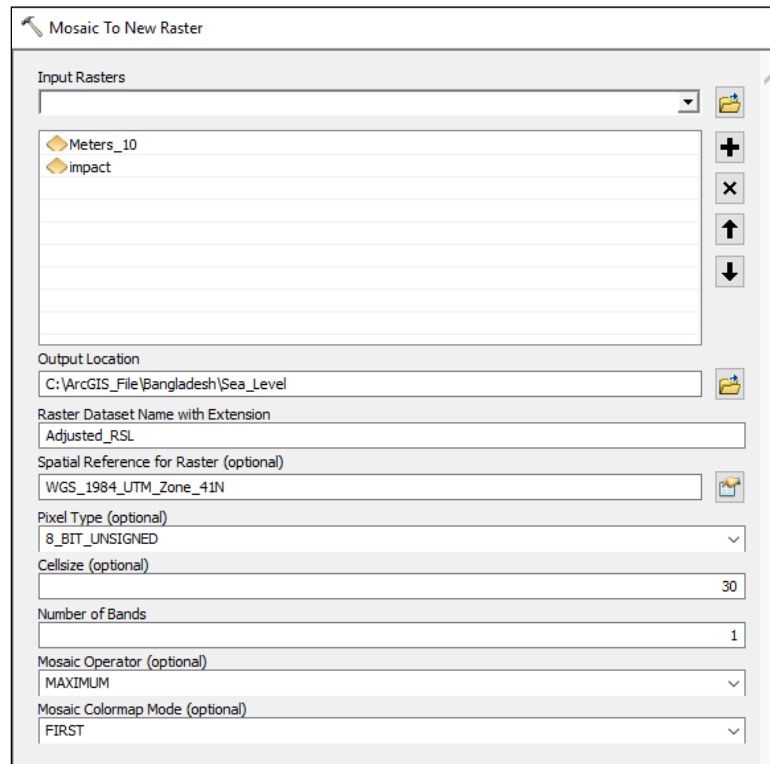
[FIGURE 24]

[FIGURE 25]
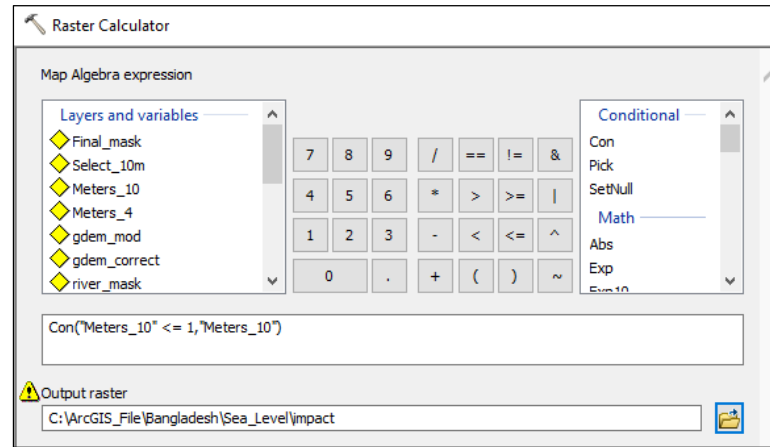
[FIGURE 26]

VIII.   CONCLUSIONS & PRESENTATION

To complete the analysis, I employed the Mosaic to Raster tool one final time, notably utilizing the "maximum" mosaic operator [FIGURE 26], and symbolized the resulting raster (named "Adjusted RSL") as before. A shoreline was added via the Contour tool and symbolized as before.

The results, while admittedly pre-determined, are nonetheless compelling – the study area (Polder 56/57) was spared inundation from RSL rise. Importantly, while the model used in this analysis did not project an increase to the land surface above 1 meter in elevation (which is arguably not very helpful in the context of tropical cyclones and continuously rising MSL) the impact of this analysis may have very useful implications with respect to the required heights of embankments and the management of sedimentation from tidal inundation.

The final three pages of this analysis, following a reference page, are exported directly from Arc Map in PDF format and present 1) modeled DEM and corresponding shoreline for the area of study as it exists at the time of data capture, 2) modeled DEM and corresponding shoreline reflecting 10 meters of RSL rise, and 2) modeled DEM and corresponding shoreline reflecting 10 meters of RSL rise but with elevations falling below one meter within Polder 56/57 held constant at one meter in elevation. All are symbolized in the same way, present the same study area, and all reflect the same reference scale of 1:600,000 meters.

Kind thanks for your time and attention.

SELECTED REFERENCES (in alphabetical order by notation)**:**

[Amir et.al. 2013] Md. Sharif Imam Ibne Amir, M. Shah Alam Khan, Mohammad Masud Kamal Khan, Mohammad Golam Rasul and Fatema Akram (2013), "Tidal River Sediment Management–A Case Study in Southwestern Bangladesh", World Academy of Science, Engineering and Technology, International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering Vol:7, No:3, 2013

[Auerbach et.al. 2015] L.W. Auerbach, S. L. Goodbred Jr., D. R. Mondal, C. A. Wilson, K. R. Ahmed, K. Roy, M. S. Steckler, C. Small, J. M. Gilligan and B. A. Ackerly (2015), "Flood Risk of Natural and Embanked Landscapes on the Ganges–Brahmaputra Tidal Delta Plain", Nature – Climate Change, Vol.5, February 2015

[Biswas et.al. 2015] B.S. Pushpendue Biswas, Aseya Khatun, Md. Tauhid-Ur-Rahman, Bijit and Kumar Banik (2015), "Measurement of Tidal Fluctuation Using MATLAB-Based Program and Development of Salinity Intrusion Model for Coastal Region of Bangladesh Using VISUAL MODFLOW", Department of Civil and Environmental Engineering, Shahjalal University of Science and Technology, Sylhet, Bangladesh
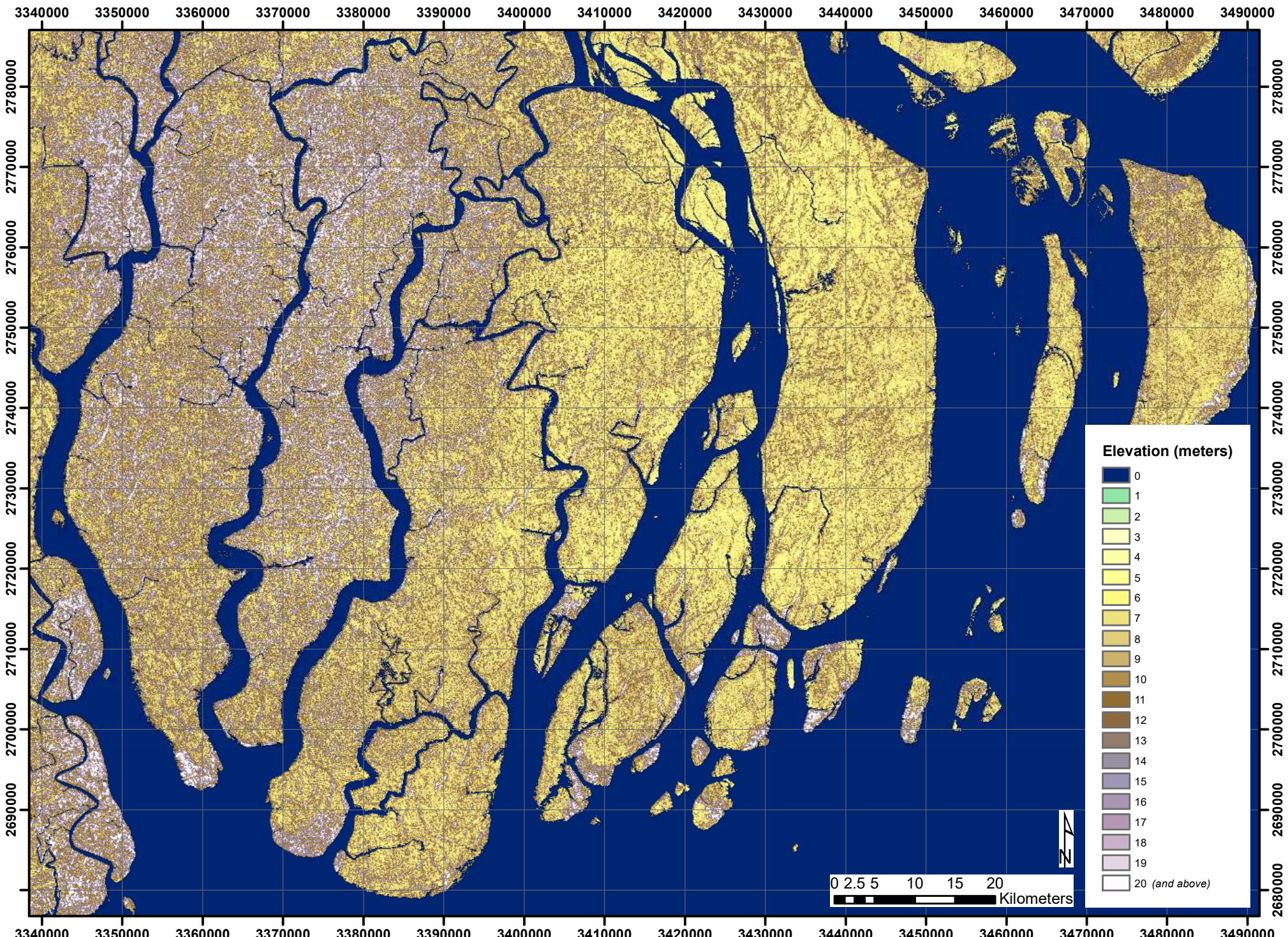
[CIA 2015] Central Intelligence Agency (2015), "Bangladesh", World Fact-Book
Accessed on 04/20/2016 from: https://www.cia.gov/library/publications/the-world-factbook/geos/bg.html

[deDie 2013] Leendert de Die (2013), "Tidal River Management - Temporary Depoldering to Mitigate Drainage Congestion in the Southwest Delta of Bangladesh", M.Sc. Minor Thesis, Water Resources Management Group, Wageningen University, The Netherlands

[Kumar 2015] Dr. Amartya Kumar Bhattacharya (2015), "Saline Water Intrusion in Coastal Aquifers of Bangladesh", Chairman, MultiSpectra Consultants, 23, Biplabi Ambika Chakraborty Sarani, Kolkata – 700029, West Bengal, INDIA

Modeled DEM for Coastal Bangladesh - Current

1:600,000 Reference Scale
WGS 1984 UTM Zone 41N (meters)

Elevation (meters)

■	0
■	1
■	2
■	3
■	4
■	5
■	6
■	7
■	8
■	9
■	10
■	11
■	12
■	13
■	14
■	15
■	16
■	17
■	18
■	19
■	20 *(and above)*

0 2.5 5   10   15   20
Kilometers

Modeled DEM for Coastal Bangladesh - 10 meters of RSL rise

1:600,000 Reference Scale
WGS 1984 UTM Zone 41N (meters)

Elevation (meters)

- 0
- 11
- 12
- 13
- 14
- 15
- 16
- 17
- 18
- 19
- 20 *(and over)*

0 2.5 5   10   15   20
Kilometers

Modeled DEM for Coastal Bangladesh - 10 meters of RSL rise

1:600,000 Reference Scale
WGS 1984 UTM Zone 41N (meters)

Elevation (meters)

- 0
- 1
- 11
- 12
- 13
- 14
- 15
- 16
- 17
- 18
- 19
- 20 *(and over)*

0 2.5 5 10 15 20
Kilometers