Colorado River Delta Geomorphology

Remote sensing of changes in delta flows from 1972 to present

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Introduction

The Colorado River stopped flowing naturally to the Sea of Cortez after the completion of the Glen Canyon Dam in 1966. It hasn't reached the sea since 1998. The river, one of the most litigated in the world, supplies seven U.S. states and northern Baja California in Mexico with the water necessary to survive their flourishing populations, modern luxuries, and ever-booming agriculture. It is agriculture, specifically Southern California's Imperial Valley farming, which uses an allocated 80% of the entire Colorado River's flow for irrigation. When the remaining 2000 cubic feet per second reaches the U.S./Mexican border, it is all diverted by the Morales Dam for irrigation to Mexicali farming. Decades of dam construction and diversions upstream have reduced the mighty river to a remnant system of small wetlands and brackish mudflats. Ecologists and geomorphologists have been monitoring the Colorado River delta to better understand implications of human activity on surface water supplies and the unsustainable demands of development in the desert southwest. In 2014, binational agreement led to the Minute 319 deal, which aims to restore parts of the Colorado River delta through 2017 with "pulse flows" from upstream dams in times of plenty. Though these pulse flows may provide ephemeral quenching for desiccated vegetation and estuary life, the geomorphology of the delta region remains a lasting testament to the effects human demand and ingenuity. In order to analyze any changes to the Colorado River delta over time, I took a look at the morphology of the region since around the time of the river's last major period of interruption. By using satellite remotely sensed images to assess the region at different time periods, I created composite views that reveal before and after glimpses at the area's history. As a result, we find a wandering and vanishing stream profile, fed scarcely by irrigation and agricultural runoff, and morphing estuary banks and gulf shores, sediment eroding in certain places and depositing in others.

Methods

My starting point was 1972, when Landsat-1 began producing imagery with its Multispectral Scanner. Since Landsat has had operational imaging satellites in orbit ever since, I could create a time-series of images for every ten years leading to the present. Although some years' images were not usable due to Landsat upgrades or scanning glitches, I was able to assess changes over 40 years with images from 1972, 1984, 1992, 2002, and 2011 (1982/83 and 2012 were not usable for my intentions). In order to demonstrate the most recent state of change and enhanced results from Landsat 8's enhanced radiometric performance, I also included imagery from 2014. I collected Landsat imagery from the USGS Global Visualization Viewer website for swaths over delta coordinates 31.7400° N, 114.6600° W. I chose dates around September 30th as representative of the "thirstiest" time of year with the highest evapotranspiration (the water year runs Oct. 1-Sept. 30, and the end of the water year is the driest after having endured summer.) Images were selected for pixel clarity and fortitude, and those with substantial cloud cover or errors were dismissed for clear images available around September 30th. In some cases, images available from satellites that had just been upgraded were used, even though the latter had improved performance, because the former had more reliable data. Ultimately, Landsat 1 MSS data was used for September 30, 1972, and Landsat 5 TM data was used for July 27, 1984, October 5, 1992, October 1, 2002, and October 10, 2011. Landsat 8 OLI data was used for the final look at October 2, 2014. These six files of spectral data were downloaded, and TIFF files of each available band were extracted. After selecting the Band 6 TIFF file image (NIR) for the 1972 image for optimal delta definition, I created a

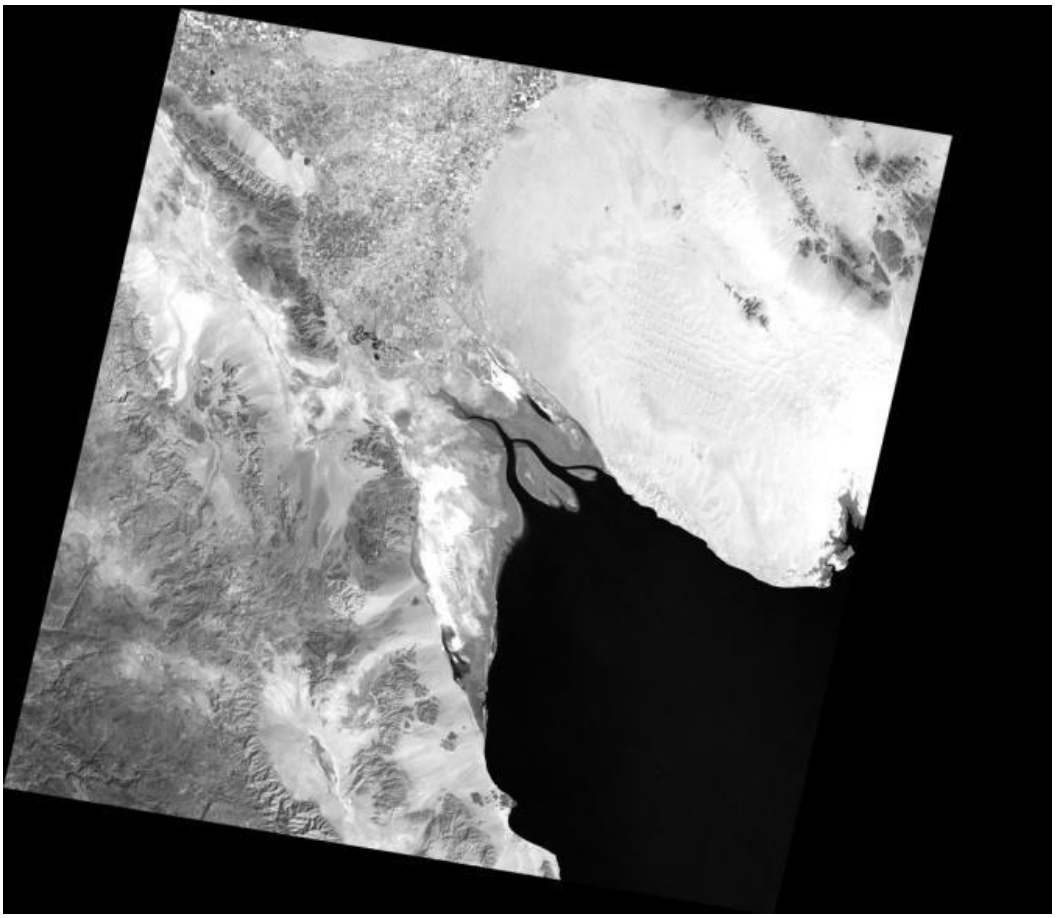

Figure 1, focus area (1972, NIR-band 6)

Region of Interest (ROI) to isolate the delta area. Because Landsat 5 data has different pixel sizes, I resampled images from 30 x 30 meters for 1984 (TM), 1992 (TM), 2002 (TM), 2012 (TM), and 2014 (OLI) to the 60 x 60 meters pixel size of the MSS image from 1972. I then subsetted the ROI for each of the other five NIR band TIFFs. This entire process was then repeated to create images from the red band TIFFs (MSS was Band 5, TM was band 4, OLI was band 5). The resulting images show a gradual range of brightness values across the gray-scale display. Toreduce the effect of light reflecting off of stream bottoms, banks, and inland depressions, and to increase the contrast of between light and dark values (land and water, respectively), I then changed the detection of water by applying a band ratio adjustment (intensifying the ratio between NIR band and red band with b1*100/b2+1) to all 5 images. By analyzing the pixel values hovering over apparent land and water differences I surmised a general threshold between land and water surfaces. I then checked statistics for each grayscale image, using a statistical histogram of the pixel values to ascertain a trough/threshold between light and dark pixel values (Figure 1, 2).

To classify all water specifically I performed a density slice redefining the range for water as – 9999 to each threshold value established from histogram for each image. I assigned different colors to the water content in each, so that it would stand out against the black of "land" and from each other as the represented varying years of data. The final step was used to create telling composites of the classified images. Opening a new composite image in RGB and assigning a time-series to each band (i.e. 1972, 1992, 2011), revealed the geomorphology over forty plus years.

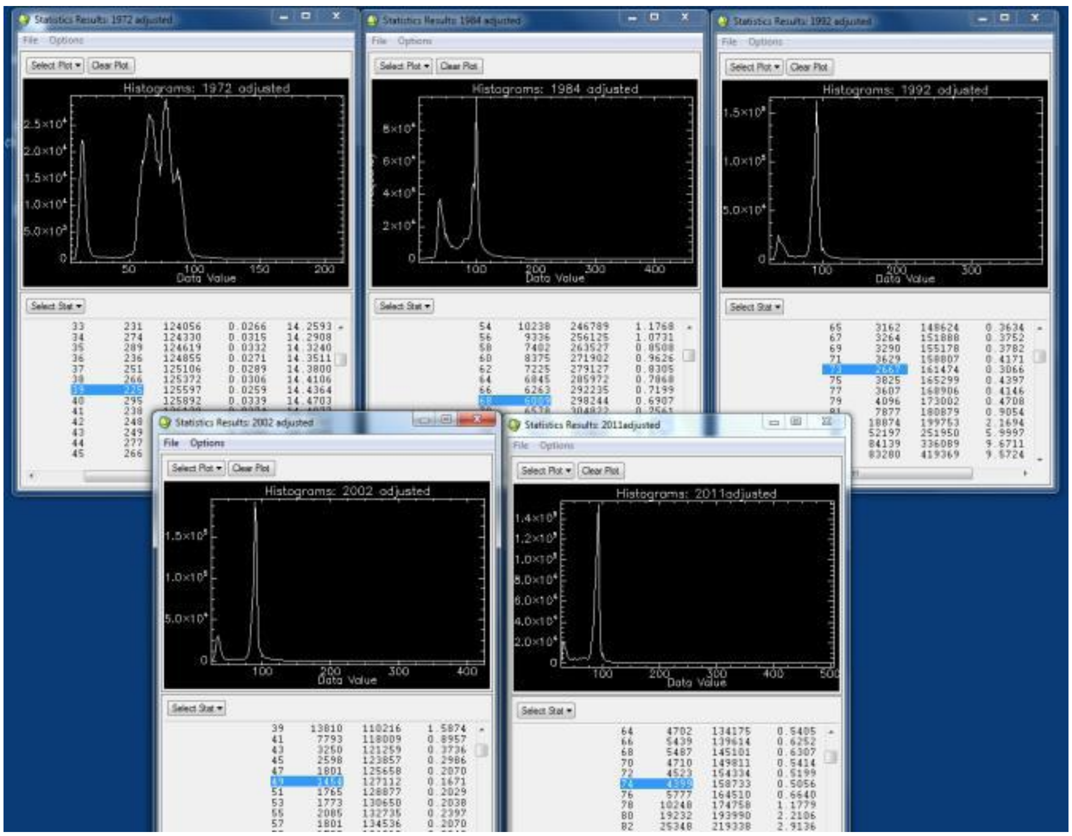

Figure 2, Histograms of pixel value statistics pre-Density Slice

Results

These new adjusted and classified images of the Colorado River delta from 1972 to 2014 help to isolate and magnify incremental changeover recent time. While this morphing in individual stop time images from each of every ten years is not all that perceptible (Figures 2-7), the evolution is stark when composites of multiple years are overlapped (Figures 7-9). (continued) Figure 2, 1972 Figure 3, 1984 (flood year) Figure 4, 1992 Figure 5, 2002 Figure 6, 2012 Figure 7, 2014 RGB= 1972, 2014, 2014 RGB= 1972, 2011, 2011 RGB= 1972, 1972, 2011


Figure 2, 1972

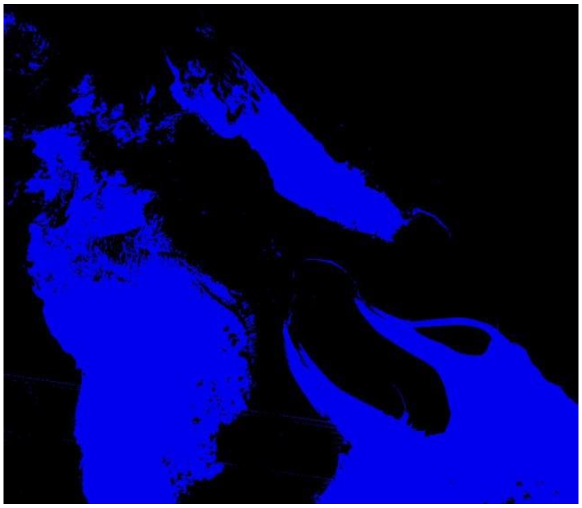
Figure 3, 1984 (flood year)


Figure 4, 1992

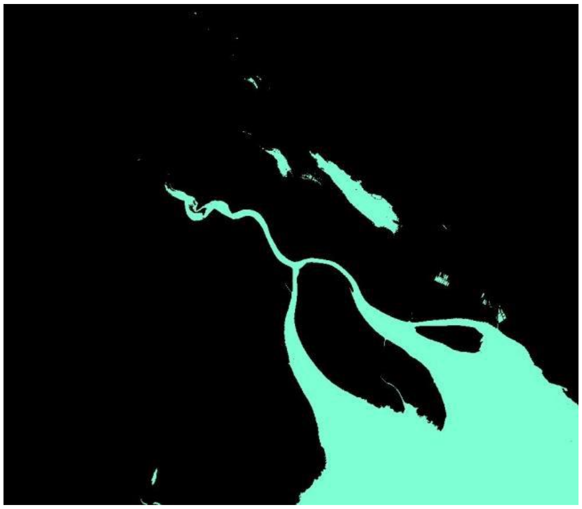
Figure 5, 2002

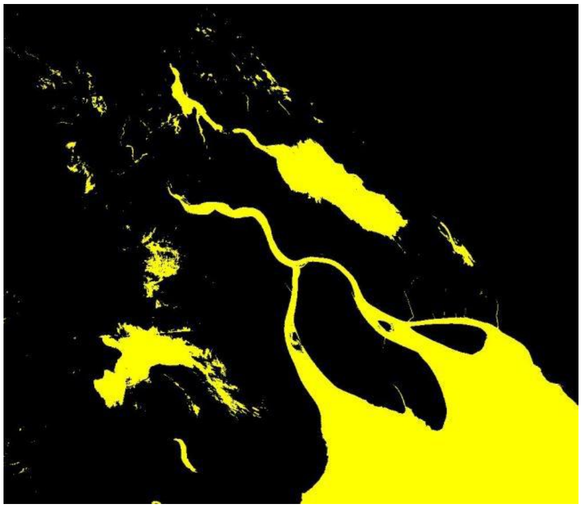
Figure 6, 2012

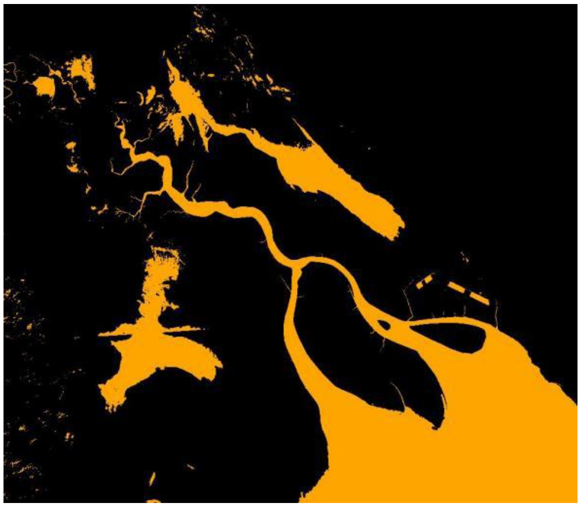
Figure 7, 2014

RGB= 1972, 1992, 2011 RGB= 1972, 1984, 1992 Results (continued) The most revealing composites, as expected, are those comparing 1972 to 2014 (and/or 2011). The red color shows the river mouth profile in 1972 while the cyan/aqua color shows the profile for 2014. The white is simply area of water that was present in 1972 and 2014. (An RGB additive color wheel

has been added beneath each composite to aid in translation of the overlay.) This shows us how the mouth channel has migrated in a northeasterly direction over 40 years on both sides of Isla Montague (the sediment body built up over millennia at the river mouth). The channels surrounding Isla Montague have also narrowed substantially over the years. The composite image shows cyan/aqua in the landlocked wetland areas to the east and west of the mouth where "pulse flows" from 2014's Minute 319 deal began to restore the habitat somewhat during that season. The image also reveals that shorelines that didn't exist in 1972 (red) have been exposed, either by sediment deposits or bower water levels. Perhaps related, areas that were once land have been covered in water (cyan around southern Isla Montague). We can also see that sandbars have been created (red spots in white) since 1972. Some other composites are provided here for the fascinating timeline that each presents.

Discussion

While the geomorphology of the region may not be of as prime human importance as how the increasing demand for water will be met in the Southwest, or as dire to ecologists as how to restore the river delta habitat, satellite remote sensing for these purposes is exceptional for studying changes to earth's surface by man over recent time. Even in a short span of 40 years, one can assess the differences in the natural world brought on by unsustainable development and agriculture. Other parts of the world can be mapped and data provided from remote sensing can be used to discover how the Earth is responding in natural reaction to man's endeavors. We can monitor things like the Minute 319 deal between the U.S. and Mexico by monitoring water flow into landlocked depressions or wetlands. As we can see from these changes taking place at the Sea of Cortez (Gulf of California), land is being created and destroyed, and where a great fertile river delta is now relegated to a brackish estuary where tides encroach on the carved out mouth.

External References

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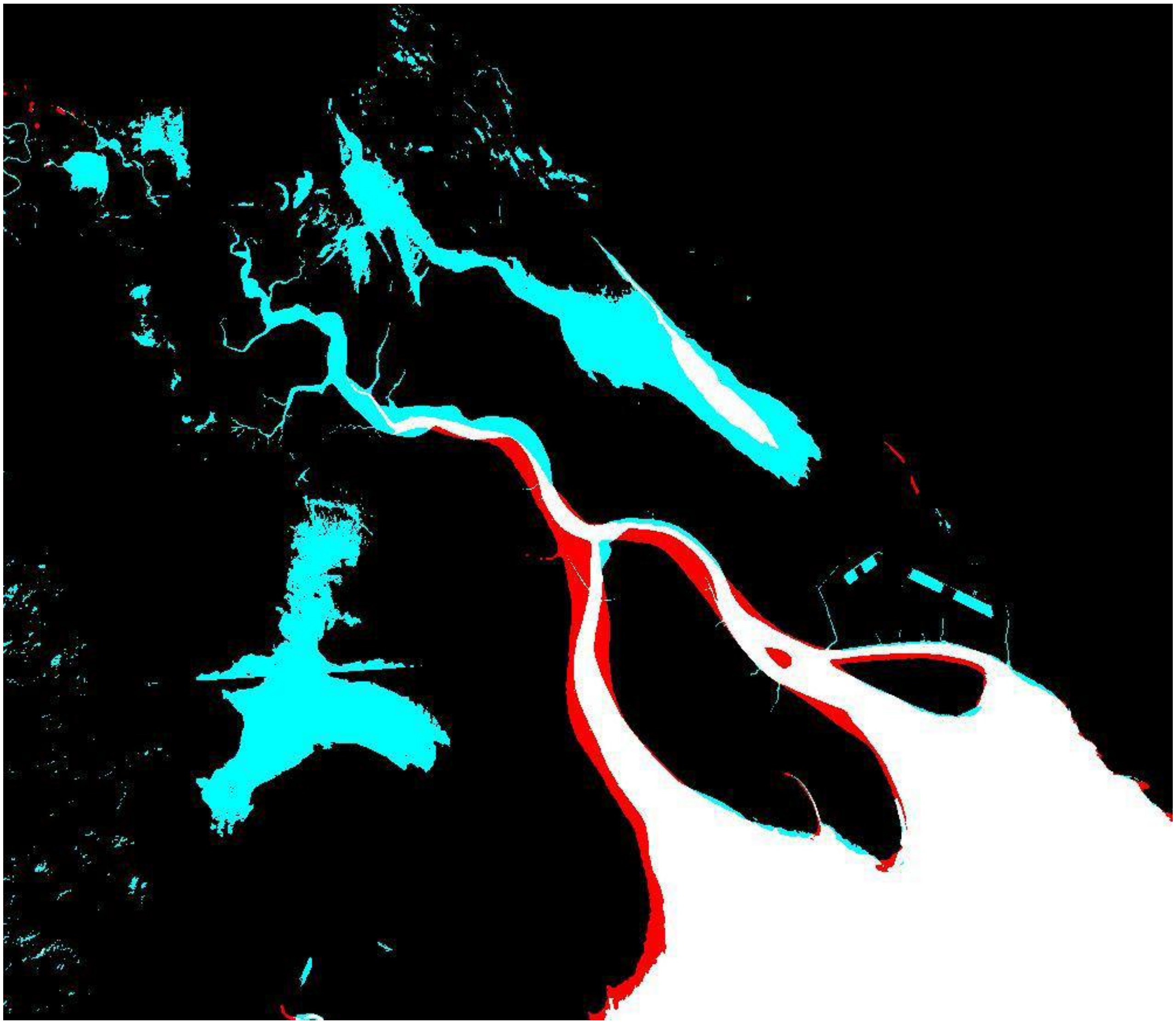
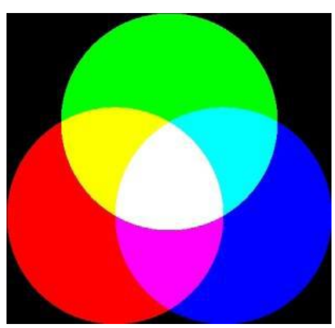
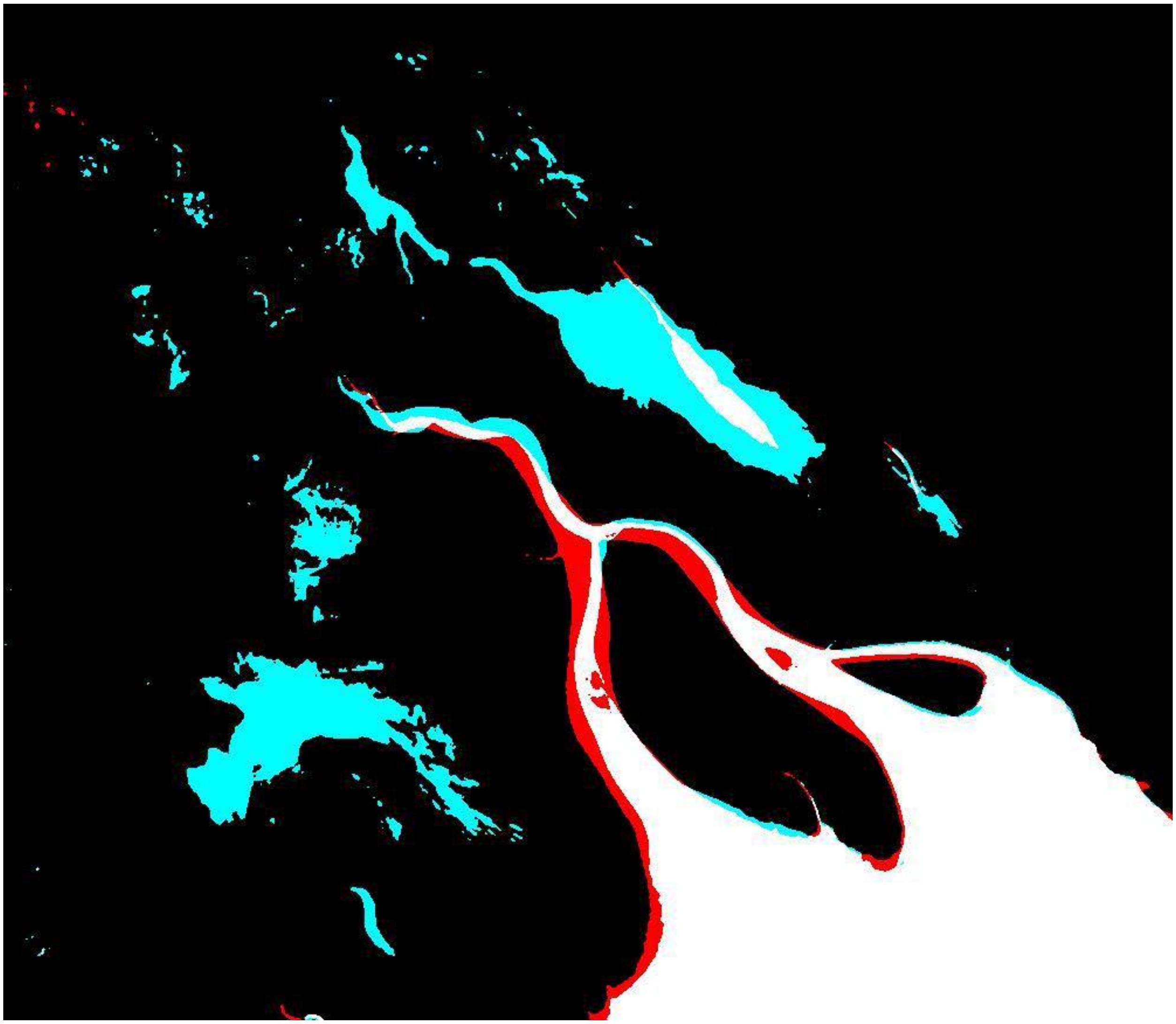
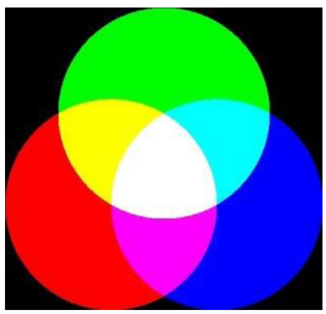


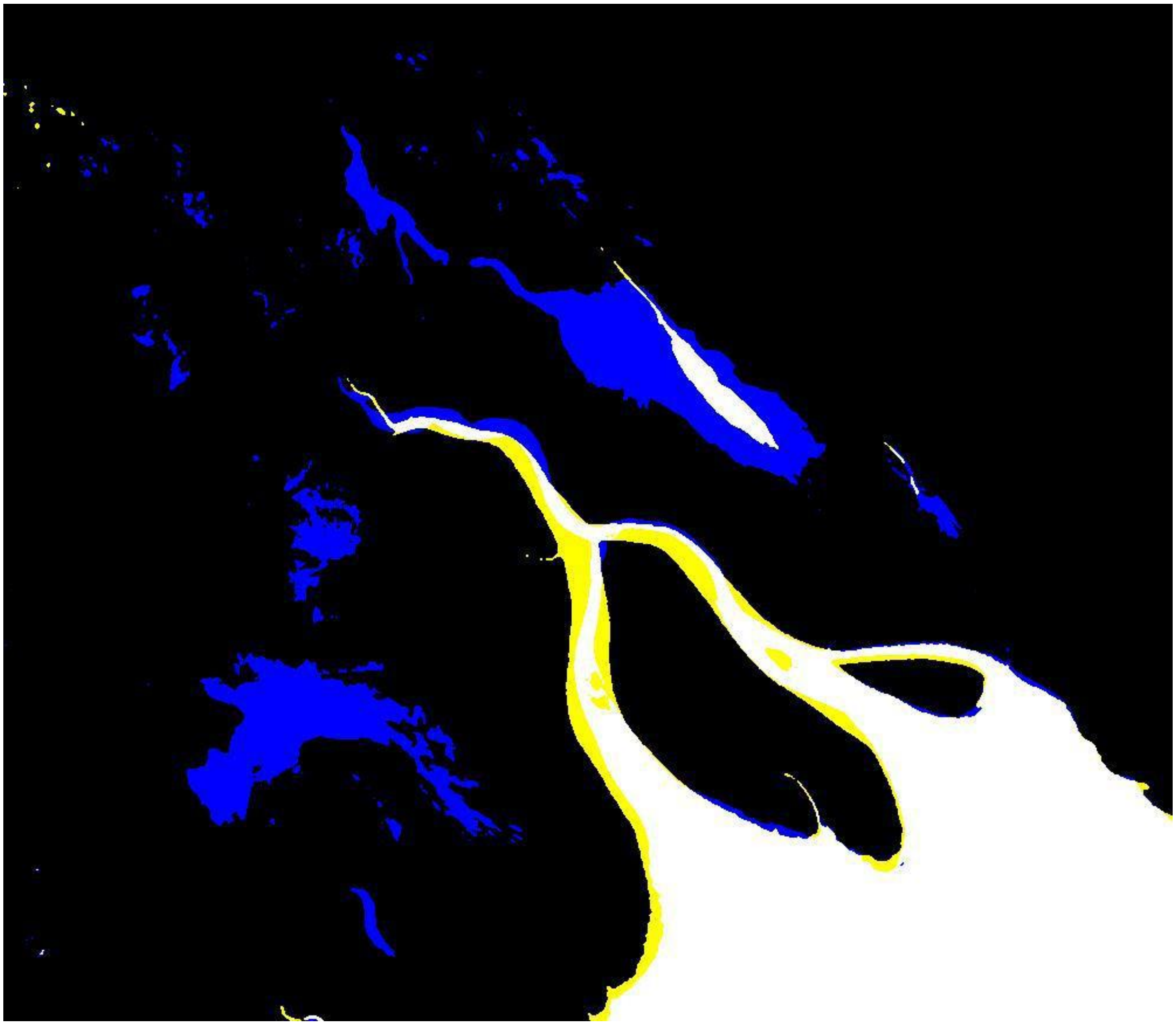
RGB= 1972, 2014, 2014



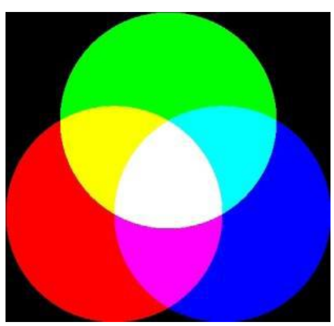


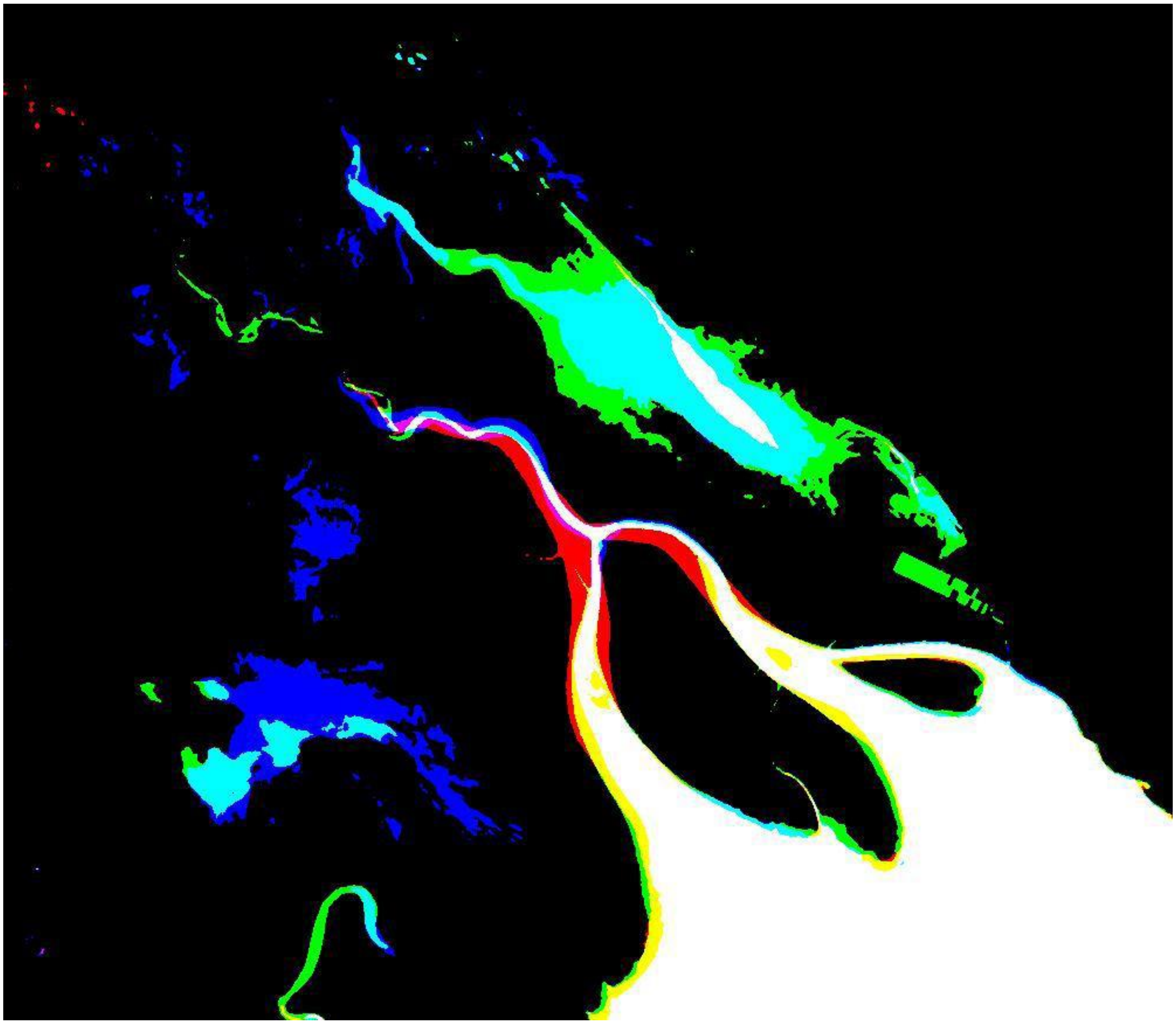
RGB= 1972, 2011, 2011



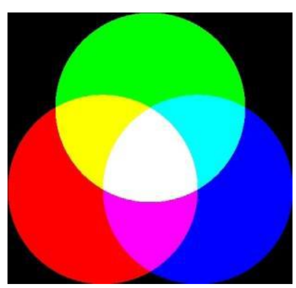


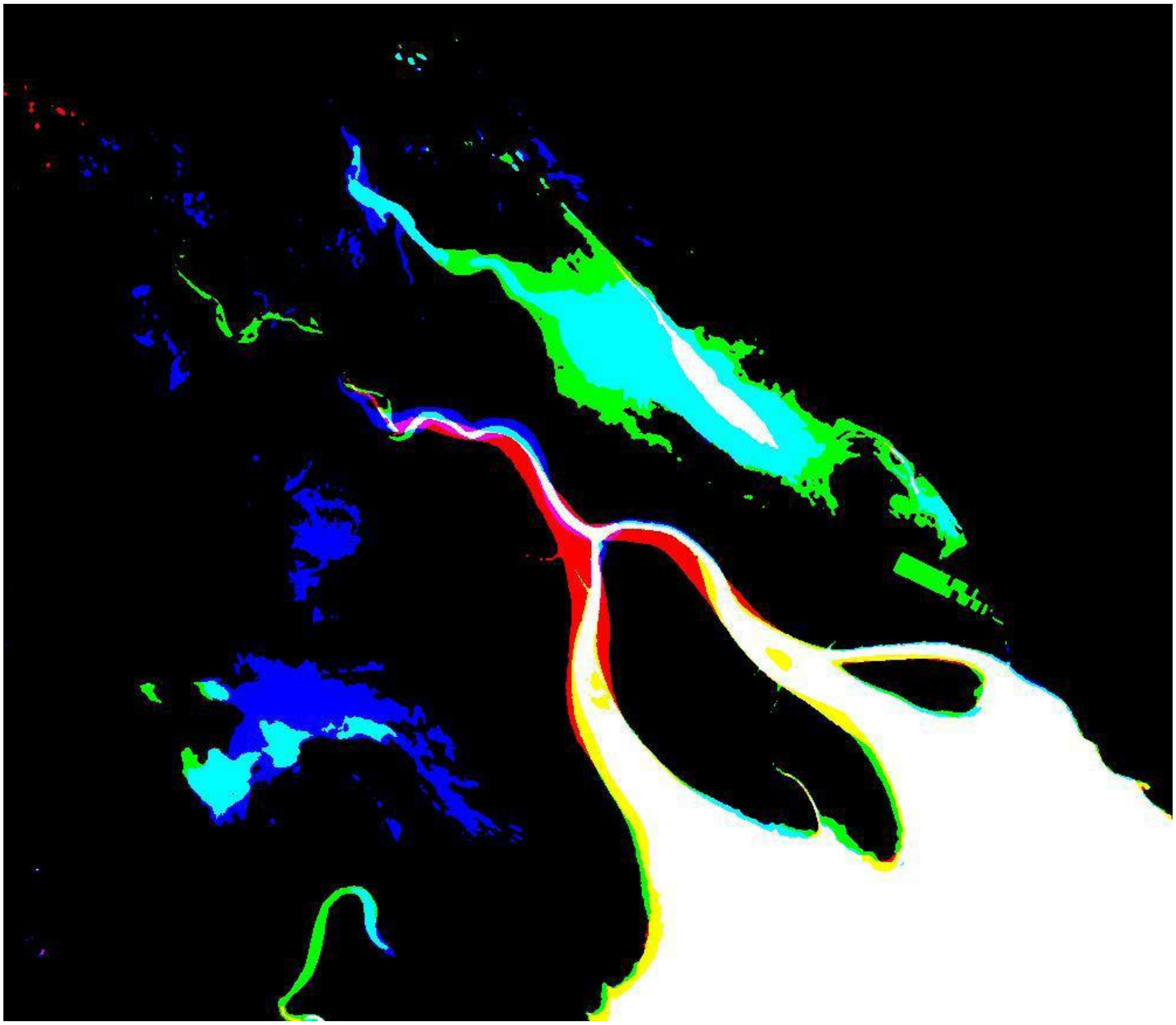
RGB= 1972, 1972, 2011





RGB= 1972, 1992, 2011





RGB= 1972, 1984, 1992