University of Puerto Rico
Mayagüez Campus,
P.O. BOX 9000 Mayagüez PR 00681-9000
Tel: (787) 832-4040

Two-dimensional temporal-spatial analysis of the "Río Bayamón" river mouth's suspended sediment area and its relation to anthropological and atmospheric processes.

Kelly M. Núñez Ocasio[12], Rosa Vargas Martes[12]

Physics Department[1]

University of Puerto Rico at Mayaguez[2]

Abstract

Suspended Sediments (SS) are normally expulsed by river mouths and are seen as plumes in many costal regions. These river discharges can have implications in aquatic ecosystems and human health, depending on their chemical composition. Previous studies have been undergone in the remote sensing field to better understand the river plumes and the effect of SS on ecosystems. This work is tailored to address these topics specifically, since there is not much knowledge or awareness of the matter in the northern coasts of Puerto Rico. The research focuses on studying the "Río Bayamón" river discharges and reflectivity as a function of time. This investigation also studies the implications of anthropological development areas near the river streams and river mouths and the effect the atmospheric events and conditions had on the specific discharge. Seven images were analyzed from the year 1999 to 2015 (with the exception of some of the years for which the data was inaccessible). After the seven images were analyzed using the ENVI platform and the area and reflectance values were recorded conclusions were reached. The study of reflectance over time showed a negative relationship behavior but had a weak linear regression. Finally, it was seen that the atmospheric events where the ones that influenced the most the river discharges in comparison to the actual anthropological development.

Keywords: ENVI, ROI, River Plume, Reflectance, Suspended Sediments (SS)

Introduction

Remote sensing has contributed to the study of suspended sediments (SS) and river plumes, specifically in the west coast of Puerto Rico. The study of the distribution of SS can provide a better insight on its connection with climate and anthropogenic sources. According to Feng et al. a lot of the changes seen in the past decades concerning coastal oceans and estuaries are due to climatic and human impacts (Feng et al., 2012). River mouths are an adequate scenario of where these changes take place. Although previous studies on the west bays of the island have been carried out, river discharge activity along the northern coast of the island are yet to be understood.

The Río Bayamon River has a longitude of 25 kilometers (km) and extends from San Juan Bay all the way through Cidra, Guaynabo, Toa Baja, Bayamón and Cataño municipalities. This river is located in a dense populated area where anthropogenic development is more evident and greater than in the west coast. Figure 1. shows the designated area of interest for this study which intends to find relationship between the increase/ decrease of the river plume area and the anthropological development adjacent to the river stream and river mouth. Also, to analyze the reflectance of the river plume area as a function of time to find a possible trend. The study of the distribution of SS can provide a better insight on its connection with climate and anthropogenic sources. It can also create awareness on how anthropological day to day activities can have negative repercussions on human and coastal ecosystems' health.

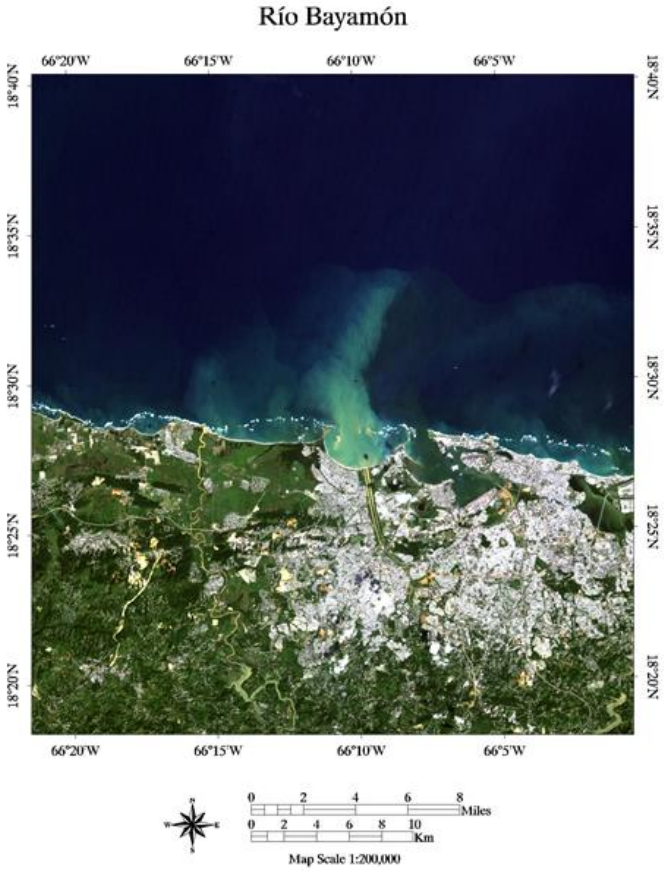

Figure 1. Map of the Río Bayamon river area

Objectives

This study focuses on finding the area coverage of the SS over time as the river releases them. The human and natural influence on the SS area coverage over time was also studied through an observational analysis and the use of collateral information such as the specific atmospheric events that occurred near the studied period. The turbidity of the water over time was also studied as this may have an impact on aquatic ecosystems and human health. According to the Surfrider Foundation contaminants found in

sediments have led to human health problems such as: increased cancer risks from people who ate fish of the Fox River in Wisconsin, disabled children from pregnant women fish contaminated form sediments in Lake Michigan, and it has also been found to disrupt human reproductive functions. These impacts on human health provide evidence and support to pursue his study in the Río Bayamon river area where human population and anthropogenic development is higher compared to the other coasts of the island.

Methodology

The selected area for the study was the "Río Bayamón" river mouth and adjacent areas to its river stream. Since the purpose of the research was to study the SS and anthropological development areas, and the turbidity of the water as functions of time, images ranging from 1999 to 2015 were selected. For the purposes of the study the images were obtained from the *Earth Explorer* United States Geological Survey (USGS) platform. All the studied images were taken by sensors onboard of the Landsat Platform. There were three sensors used: Thematic Mapper, Enhanced Thematic Mapper Plus (ETM+) and Operational Land Imager (OLI) (see Table 1 for sensor details). The study's time period was limited due to the availability of the images on the Earth Explorer platform and the temporal resolution of the sensors. Regarding the availability of the images, for several years from 2003 until 2013 the sensor on board of the Landsat platform was not working correctly and the images were damaged and unusable for the study purposes.

After the time period for the study was established seven images were selected for further analysis. The images were level 1b because they were geo-referenced by the time of the image acquisition. There were several preprocessing methods that were applied to the images. Equal 1500x1500 image subsets were created enclosing the river mouth, the anthropogenic development area and part of the Atlantic Ocean adjacent to the river mouth. After the subsets were created a dark object subtraction atmospheric correction was applied to all images. Since the area measurements are highly dependent on the spatial resolution a data fusion (panchromatic sharpening) was applied to the images using the NNDifusse Pan Sharpening tool in ENVI, which combines the spatial resolution of the panchromatic band with the "multispectral content of a multiband image at coarser resolution" (as studied and discussed in class). After the data fusion the areas of interest within the subsets were studied.

Since the anthropogenic development areas that may contribute to the river discharges are those in the proximity of the river stream and river mouth a subset within the 1500x1500 subset was created. All the measurements for the anthropological development were done within this smaller subset.

After all the preprocessing techniques were applied, area calculations were made using the ROI tool in ENVI both for the river plume area and the anthropogenic development area. Examples of how the ROIs looked appear in Figure 2 and 3 (it is important to highlight that these are just explanatory examples and do not represent one of the actual calculated areas). The same process was applied to each of the seven images and the area magnitude in kilometers squared was recorded.

In order to study the turbidity as a function of time, reflectance values were calculated on the seven images. To perform the reflectance calculations both Classic and 5.3 ENVI platforms were used. For the years: 1999, 2000, 2001, and, 2003 ENVI Classic Landsat Calibration tool was utilized specifically with the red band for each image to calculate the reflectance values. Correlation between sediment and reflectance has shown that high concentration of sediments produces more reflection in green and red bands than the other bands (Kaliraj et al., 2014). For years the years: 2013, 2014 and 2015, radiometric calibration was performed to the images to produce the reflectance values. After calculating the reflectance values for each image a specific location close to the river mouth was located for each year using the cursor value tool. The values for each year were then recorded at this location and plotted as a function of time.

Table 1. Shows detailed features of the sensors of the Landsat satellite used throughout the research project, including

	Thematic Mapper (TM)	Enhanced Thematic Mapper Plus (ETM+)	Operational Land Imager (OLI)
Sensor Type	Opto-mechanical	Opto-mechanical	Pushbroom
Spatial Resolution	30m (120m – thermal)	30m (60m-thermal, 15m-pan)	30m (15 m pan, 100 m thermal)
Spectral Range	0.45µm – 12.5µm	0.45µm - 12.5µm	0.43µm – 12.51µm
Number of Bands	7	8	11
Temporal Resolution	16 days	16 days	16 days
Image Size	185km – 172km	183km x 170km	185km x 185km
Swath	185km	183km	185km

Figure 2. Depiction of the area calculations for the river plume as determined by the ROI tool in the ENVI platform.

Figure 3. Depicts the area for the anthropological development as calculated with the ROI tool available in ENVI.

Results

Figures 4 through 10 show the image subsets of the river area for each year utilized in the study. The river plume area varies from year to year showing more active

years like 1999 and more passive years such as 2013. Although the image resolution vary due to different sensors, each image was pre processed in the same manner (with the preprocessing technique mentioned previously).

Figure 4. Río Bayamon subset 1999

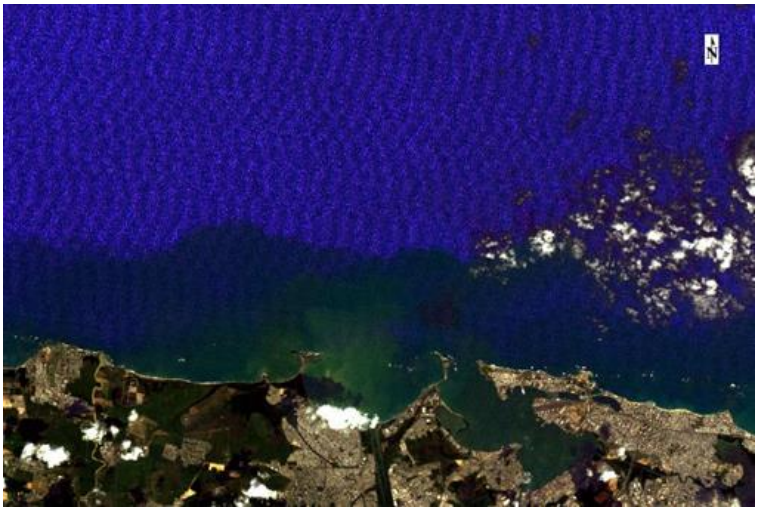

Figure 5. Río Bayamon subset 2000

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Figure 6. Río Bayamon subset 2001

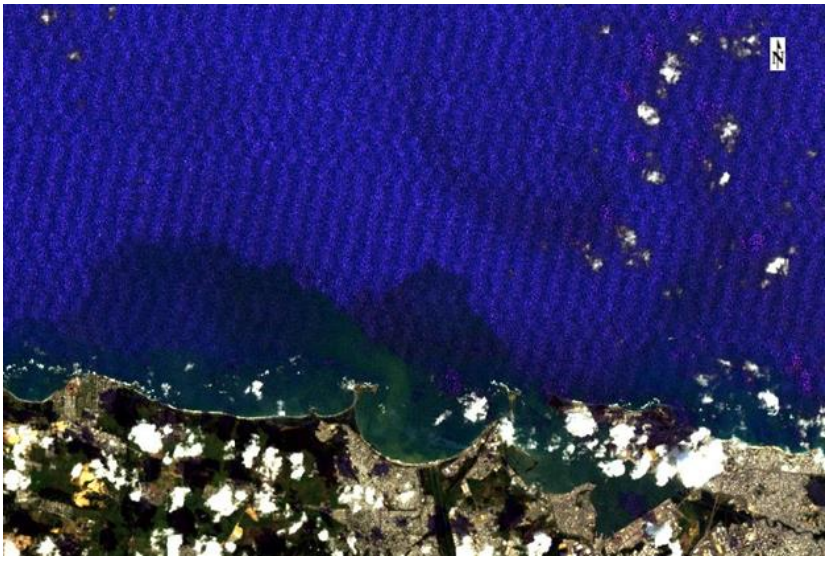

Figure 7. Río Bayamon subset 2003

Figure 8. Río Bayamon subset 2013

Figure 9. Río Bayamon subset 2014

Figure 10. Río Bayamon subset 2015

After the river plume and anthropogenic development area for each river was measured (in km^2), a table was constructed and yielded the following results shown in Graph 1. The plot shows the relationship that was found to exist between the anthropological development and the river plume area. Even if the linear regression was not high (R^2=0.5687) the value is closer to 1 rather than to zero. This results, while showing that the river plume area changes are not entirely dependent on anthropological development these cannot be separated from one another. There is in fact a simple negative relationship between both of the studied variables.

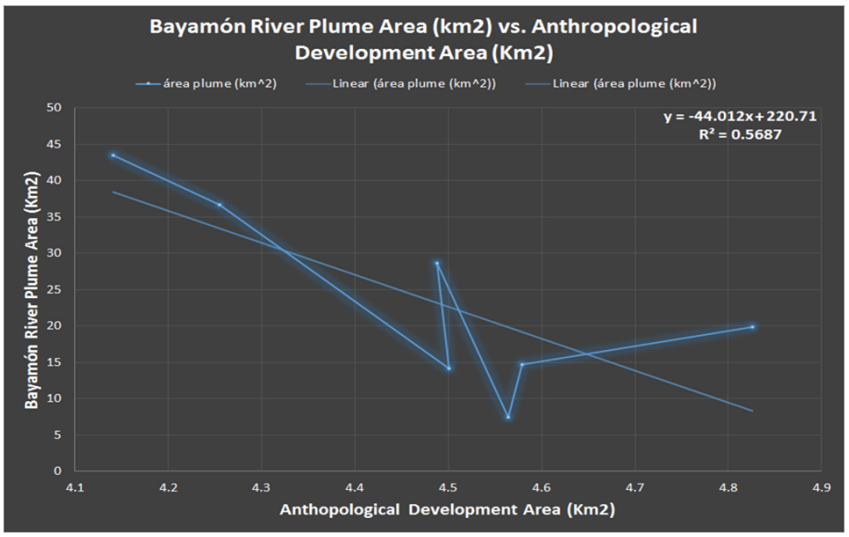

Figure 11. Bayamon River Plume Area as a function of the development area. The figure shows a weak negative relationship between the two studied variables. The linear regression is R^2=0.5687 and the trendline is shown in blue.

Since the study does not only focus on the anthropogenic impacts to the river discharge over time, careful consideration was taken to study collateral information. The specific information used for investigation purposes was the water vapor images acquired through the NOAA *Global ISCCP B1 Browse System* web platform and weather forecasts offered by the National Weather Service (NWS) Office at San Juan Puerto Rico. The satellite water vapor images were selected either in the early morning hours the same day or the day before the Río Bayamon river image subset was taken. For the first event on November 27, 1999 the satellite image shows a low-pressure system just north of Dominican Republic and Puerto Rico. The bands associated with the center of low pressure are the ones that possibly provided the instability to produce the river plume discharge. On November 13th 2000 there was some humidity in the forecast region,

although no major atmospheric event was over the area. Given the time period it is also possible that the river plume activity was a result of local effects such as daily convection. For the event on 2001 there was water vapor present throughout the area that could have propelled the river mouth activity. For the event on 2003, the NWS reported a swell event on their forecast discussion, which mean that the rain activity that caused the river discharge was possibly due to a cold front in the vicinity (the satellite images agreed with this forecast). For the event on 2013, an upper level trough brought instability to the local area, which might have influenced the development of showers and river discharges. For the event on 2014, Both the NWS and the satellite images agree that the conditions were stable and there was no severe weather in the proximity of the Island, therefore, the plume activity was possibly due to local effects and the thermal convection. For the last year, 2015, there was an upper level trough and trade winds that may have influenced the development of the plume activity for this specific case.

Fig 12 shows the graph of reflectance values of each year as function of time. Year 2001 shows a very distinct peak reflectance value, that should be related to the cold front seen in the satellite water vapor image. However, the graph did not show any particular behavior or trend. Because of this, year 2001 was eliminated and the results were plotted together on figure 13. The result show a coefficient determination of R^2=0.3637 closer to zero than to one which means that the dependent variable, in this case the reflectance values are not essentially related to the independent variable which is the years. These results suggest that suspended sediments in the Bayamon River area were not altered or affected by the passing of time.

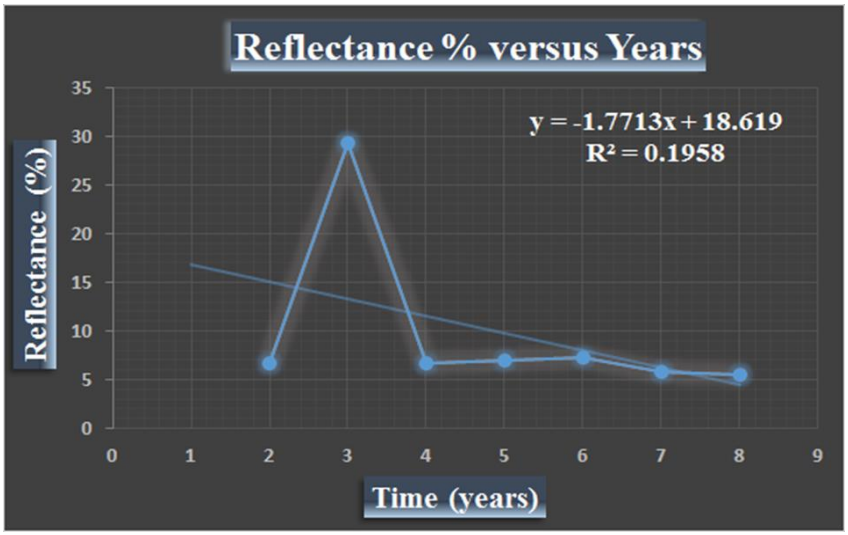

Figure 12. Reflectance values as function of time for the seven years.

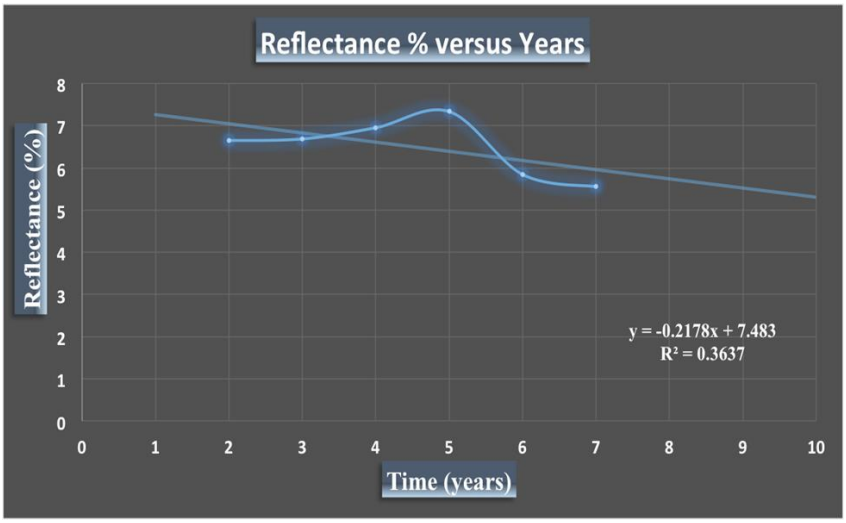

Figure 13.Reflectance values as function of time without year 2001.

Conclusions

A quantitative analysis was performed to the river plume area of the "Río Bayamon". Calculations of both river plume suspended sediments and anthropogenic areas close to the river were calculated as well as reflectance values. Reflectance showed almost no relation and/or dependence with time (R^2=0.3637). Comparison of historical data with river plume area demonstrates a direct relation between river plume active period and atmospheric conditions.

Although anthropogenic area did not show a positive relation with the river plume area, statistics demonstrate a somewhat relation (R^2=0.5687). This research presents the few if not first studies done for a river plume area over the northern coast of Puerto Rico and evidences statistical information of the relationship between suspended sediment with time and anthropogenic area increase with river plume discharge. This study can provide insight on the river plume activity and if continued can contribute to understand how this river is affected by human influences, especially since located close to the metropolitan area of the island which is highly urbanized and industrially developed.

Recommendations

To study a larger set of data can provide a broader period of time to study. To use a specific and detailed algorithm tailored for the sensor in order to calculate reflectance values can improve the reflectance measurements technique. The use of several sensors may have altered the final results, utilizing a single sensor with better resolution can give more precise results. For the anthropogenic area location a supervised classification can

be performed to better identify the anthropogenic development. Rain gauge data would aid on the support of the forecast discussion collateral information.

Acknowledgment

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