University of Puerto Rico

Mayaguez Campus

Department of Geology

Undergraduate Research Report

Report Submitted to Department of Geology

Spectral Effect of Minerals in Sediments of Mayagüez Bay

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Abstract

This project is focus on the spectral response of minerals in suspended sediments of Mayaguez Bay. Rio Añasco, Yagüez and Guanajibo are the three major rivers that affect the sedimentation of Mayaguez Bay. Each river has three stations (Dentro, Boca and Playa) to obtain sediments and compare the spectral response of total suspended sediments (TSS) and withour organic matter. Water samples were collected in September 21 and September 26, 2008. In the project, a laboratory procedure was developing to obtain pure minerals from the sediments and take out the organic material, which can affect the Remote Sensing Reflectance (Rrs). Rrs was obtained from data obtained using the GER-1500 radiospectrometer.In general, in the samples with minerals only, the value of Rrs is higher than in samples with TSS. The higher value of Rrs, in general, is related with high concentration of minerals. These results will help to develop other studies in Mayaguez Bay and will provide recommendations in remote sensing studies.

Key Words: suspended sediments, minerals, remote sensing reflectance, GER-1500 radiospectrometer, concentration, Mayaguez Bay

Outline

I. Introduction

Puerto Rico has two major seasons that affect the precipitation: the rainy season (May to November) and the dry season (December to April). During these two seasons, the dynamics of suspended sediments in the Mayaguez Bay is affected (Hernandez, 2008). Mayaguez Bay is located in the west part of Puerto Rico at 18° 10' N and 18° 16' N of latitude and 67° 10' W and 67° 14' W of longitude (Figure 1). Mayagüez Bay has been studied for several years. Studies of the bay have included the dynamics of suspended sediments, optical properties, conditions of coral reefs, and others (Hernández, 2008, Quiñones, 2005, Rosado, 2000). During the rainy season, the Añasco, Yagüez and Guanajibo rivers have the highest discharge over the Mayaguez Bay, and therefore that affect the concentration and dynamics of the sediments transported by these rivers and introduced into the bay (Gilbes et al., 1996).

In September 21-24 of 2008, Puerto Rico was affected by a tropical wave that caused flood and mass wasting over the island. This was classified as an event of 200 years rainfall (R. Mojica, National Weather Service, San Juan, personal communication, October 2008). This event caused precipitation over 30 inches and large discharge in these rivers. Water samples from Rio Yagüez were collected in September 21, before the event, and water samples from Guanajibo and Añasco were collected in September 26, after the event. In each river the samples were collected in three stations: Dentro, Boca, and Playa. This project aimed to better understand the spectral effect of minerals in suspended sediments of Mayaguez Bay.

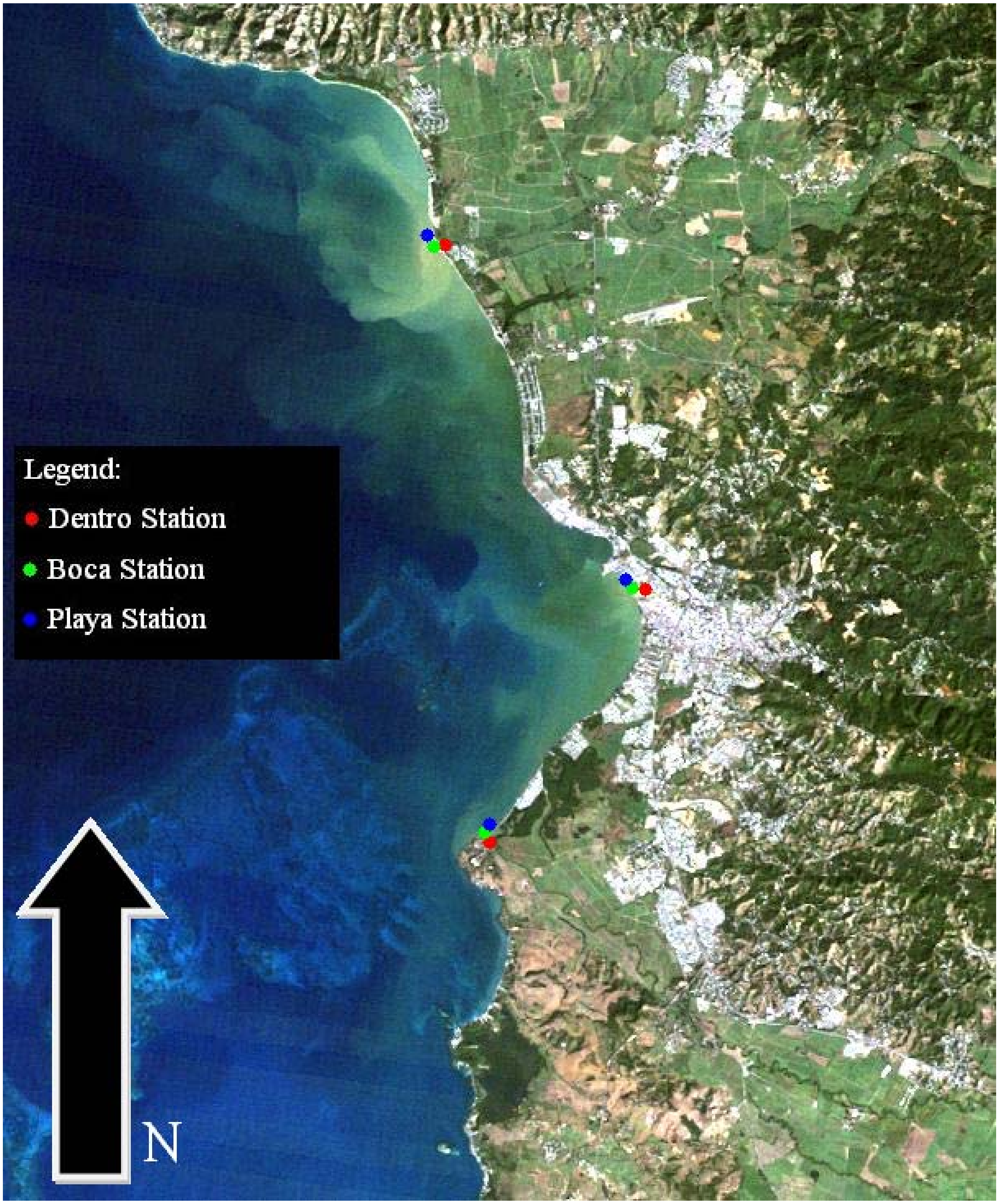


Figure 1. Thematic Mapper Image of area of study with location of stations.

The geology of the Mayaguez Bay is composed by Alluvium of the Quaternary (Curet, 1986). The composition of rocks in Rio Guanajibo are from Cabo Rojo, where is more abundant in serpentinite. The composition of rocks of Rio Yagüez is mostly composed by Yauco Fm., which is composes of volcanic sandstone, siltstone, mudstone and claystone. In terms of minerals, Yauco Fm., is mostly composed of calcite, chlorite, quartz and epidote. However, Rio Yagüez cut trough prophyritc augite basalts, which have scrapolite, plagioclase, magnetite and olivine. Mayaguez Bay has a coral reef system, which can also affect the concentration and composition of the sediments (Morelock, et al, 1983). In general, Añasco Beach sediments are composed of carbonate, quartz and igneous rock fragments with minor amount of light minerals, and Mayaguez Beach is composed of igneous rock fragments, magnetite and other dark minerals grains (Chiqués, 2005).

A more recent study has found that minerals in suspended sediments of Mayagüez Bay can affect the spectral signal (Marcos Rosado, Ph.D. student of the Department of Marine Science, personal communication). Observations on Lake Erie (Great Lakes, between USA and Canada), suggest that some selective sorption of dissolved organic matter may varies the absorption coefficients (Binding et al., 2007), and can affect the spectral signal. The total spectral absorption can be applied for inorganic matter, from samples of the rivers mentioned above. The complexity of natural sea water as an optical medium obscures the optical signal (Stramski et al., 2004). On French Guiana it was observed that a high concentration of minerals induced a high remote sensing reflectance (Froidefon et al., 2001). The spectral response depends on color, type, size and mineral composition of the sediments (Choubey et al., 1991). Based on these and other previous works, the major hypothesis of this research is that minerals can affect the spectral response of suspended sediments and therefore the detected remote signal of the water in Mayaguez Bay.

II. Objective

The main objective of this project was to determine the effect of total minerals in the spectral response of suspended sediments in Mayaguez Bay. This project is an effort for identifying the optical properties of minerals in suspended sediments, which will provide improvements and recommendations for remote sensing studies in coastal areas. In order to reach the main objective, the secondary objective of this work was to develop a laboratory procedure for determining the spectral response of total minerals in suspended sediments.

III. Methodology

A. **Field Work**: The first part of this research was the collection of water samples from Añasco, Yagüez, and Guanajibo rivers. The samples were collected at the surface in the mouth of the rivers using plastic containers at three different (random selected) representative locations. The specific sites were registered using a Garmin Handheld GPS System, model GPSMAP 76CS. Table 1 and Figure 1 show the study sites.

B. **Laboratory Work**: Water samples were filtered using pre-weighted Milipore HA 0.45 μm cellulose acetate membrane filters. Three replicates from each study site were obtained for comparison. All filters were heated at 70-80 ^{o}C during at least 6 hours to reduce water content before weighting.

After pre-weighting, the filters were placed on the filtration system and using a vacuum machine, between 100 and 300 ml of water samples were filters. The filtrated volume depended on how much sediments were in the water. Filters were washed with plenty distilled water to remove salts from the filters. After this, the filters were removed and place in a dry chamber. The filters were heated again at 70-80 ^{o}C during at least 6 hours to remove residuals of water. After dry, the filters were placed in the dry chamber and weighted again. The concentration of total suspended sediments (TSS) was determined by the difference of weight between pre and post filtration. This concentration has two major potential errors: settling of the sediments in the plastic containers and contamination by salts. For that reason, the plastic containers were shaken very well and rinsed with plenty of distilled water. The non-mineral particles were removed using a standard commercial bleach. All filters were heated again at 70-80 ^{o}C during at least 4 hours to remove the bleach and get them ready for weighting again. A second set of reflectance measurements was taken. In this case it was expected to have in the filter only minerals.

Reflectance of TSS was determined by measuring the sediments retained on the filters using the GER-1500 spectroradiometer. The measurements collected by the GER-1500 spectroradiometer were used to calculate the Remote Sensing Reflectance (Rrs) using the following equation:

$$Rrs = \frac{Lw}{Ed} \quad \text{Equation 1}$$

Lw=upwelling radiance, Ed=downwelling irradiance. The unit is *steradians*$^{-1}$.

C. **Computer Work**: The measures were from a reference card, which reflect only a half of the total radiation that receive. The other measure was from the filters with sediments. The measured contains wavelength, reflectance from reference and reflectance from the filters with sediments, and % of reflectance. The format of the data was in ASCII format, and read it in Excel. From data, Irradiance Rrs were calculated. To obtain Irradiance, the reflectance from reference was multiplied by two (because the reference only reflect the half of the total radiation that receive) and by π (because the circumference of the Earth). To calculate Rrs (equation 1) the reflectance from target (Lw) was dived by irradiance (Ed).

IV. Samples

Sample Station Name	Latitude	Longitude	Description
Añasco Dentro	N 18° 16.01'	W 67° 11.28'	A lot of leafs and organic matter
Añasco Boca	N 18° 16.005'	W 67° 11.30'	A lot of leafs and organic matter
Añasco Playa	N 18° 16.097'	W 67° 11.34'	A lot of leafs and organic matter
Yagüez Dentro	N 18° 12.493'	W 67° 9.29'	Is not have too much leafs.
Yagüez Boca	N 18° 12.494'	W 67° 9.317'	Is not have too much leafs.
Yagüez Playa	N 18° 12.522'	W 67° 9.319'	Is not have too much leafs.
Guanajibo Dentro	N 18° 10.090'	W 67° 10.813	A lot of sediments. Not too much leafs.
Guanajibo Boca	N 18° 10.095'	W 67° 10.818	A lot of sediments. Not too much leafs.
Guanajibo Playa	N 18° 10.111'	W 67° 10.818	A lot of sediments. Not too much leafs.

Table 1. Location of the stations and their characteristics.

V. Results

Figure 2 and Figure 3 show the mean precipitation of September from 1983 to 2003. It is important to notice that the high mean precipitation in 1998 was extremely affected by Hurricane Georges. One of the meteorological stations is located at Central Coloso, near Rio Añasco, and the other close to Mayaguez City. No data were reported for Mayaguez City during years 1989, 2000 and 2003. During September 21-24, 2008, a tropical wave passed over Puerto Rico. In some places, the precipitation was 30 inches in 24 hours. In Cabo Rojo the precipitation was 14 inches in 24 hours (report from National Weather Service, San Juan). These values of precipitation are not normal, and affect the discharge of each one of the rivers that has been studied. For both station, Central Coloso and Mayagüez City, the mean precipitation for September is about 8-10 inches.

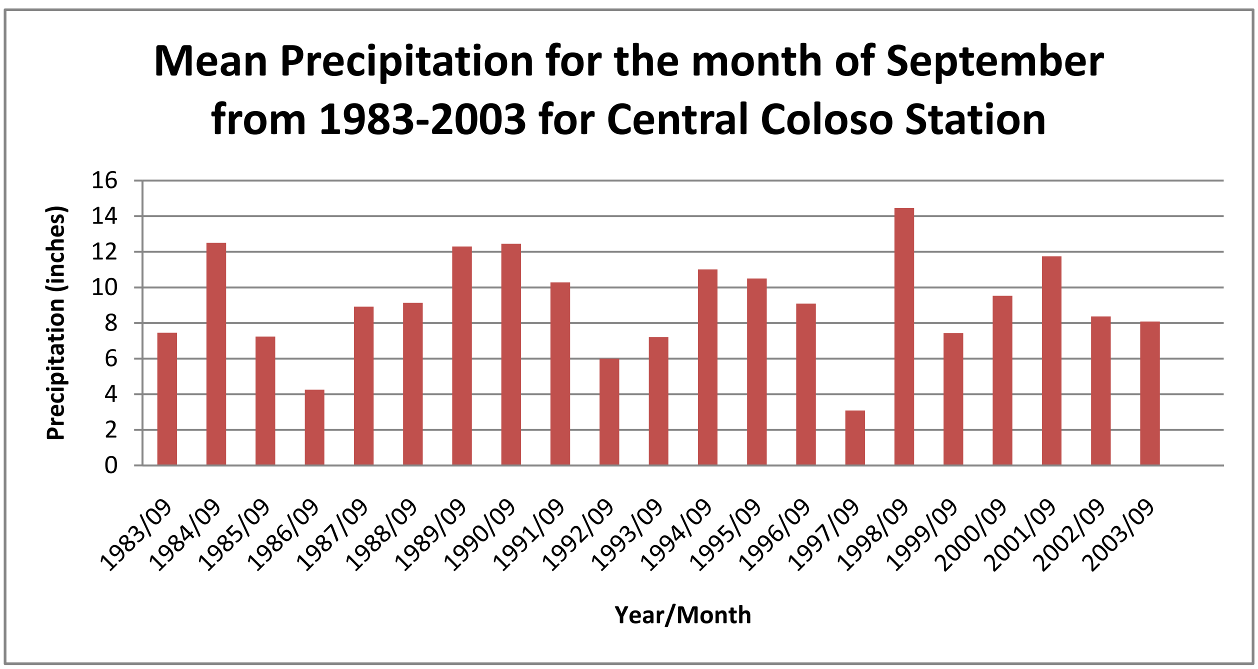


Figure 2. Mean precipitation in September during 1983-2003 for Central Coloso Station.

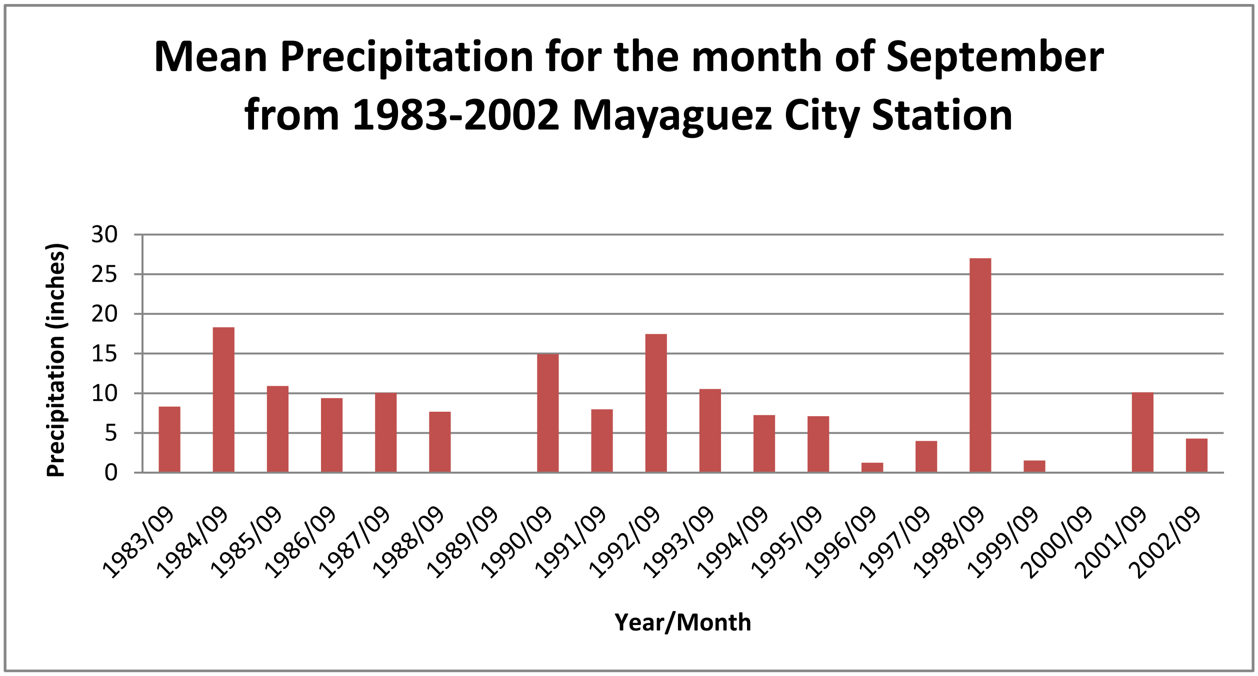


Figure 3. Mean precipitation in September during 1983-2002 for Mayaguez City Station.

Figure 4 and Figure 5 show the mean discharge for Rio Añasco and Rio Guanajibo. As in precipitation, it is important to point out that river discharge was highly influence by Hurricane Georges in 1998. No data was reported for September 2007 in Añasco and for September 2008 in Guanajibo. In Rio Añasco, the mean for September is 400 to 700 cfs. In September 22, 2008 the discharge for Rio Añasco was 3840 cfs. In Septemer 26, the discharge was 1560 cfs.

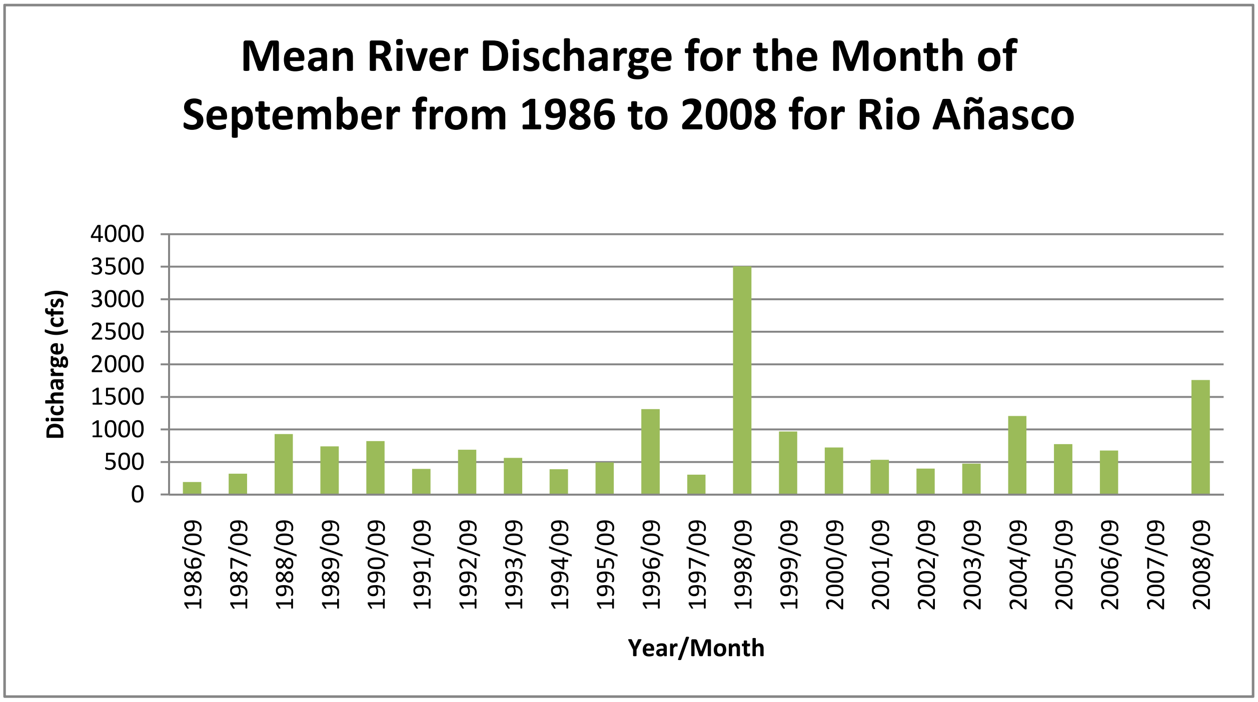


Figure 4. Mean discharge of Rio Añasco in September during 1986-2008.

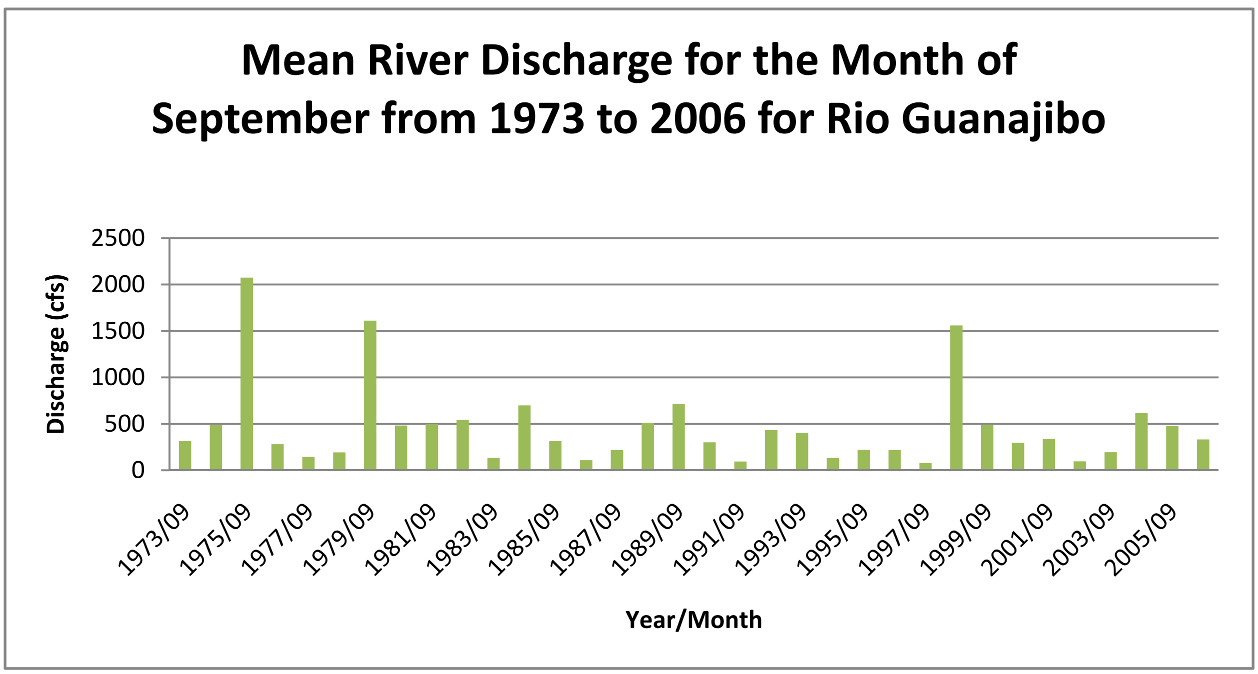


Figure 5. Mean discharge of Rio Guanajibo in September during 1973-2006.

Figure 6 shows the mean concentration of sediments in each sampled station. Data from Rio Yagüez were collected in September 21, and data from Añasco and Guanajibo were collected in September 26. Rio Añasco has the higher concentration of TSS between the three rivers. A relation can establish between the high precipitation and discharge of Rio Añasco, where in September 22, 2008, the discharge was the higher record for that month of 3840 cfs. The normal in Rio Añasco for September is 400 to 700 cfs. The discharge of the river can be one of the reasons to find higher concentration of TSS ([TSS]). Rio Guanajibo is the second. Rio Yagüez does not show high concentration, compared with Añasco and Guanajibo. The reason for this is that the water samples for Rio Yagüez were collected in September 21, the day before the event. Figure 7 shows the concentration of inorganic matter ([inorganic matter]) for each one of the rivers and station. In Añasco Playa station is an anomaly. This error could be because all the organic matter has not been removed, or by salts in the sample.

Figure 8 shows a graph of the Rrs Vs wavelength of Rio Añasco, Yagüez and Guanajibo. The Rrs was taken directly from water. In this study, the Rrs was taken directly from sediments. This figure is to compare the difference between Rrs of sediments from water, and Rrs of sediments directly.

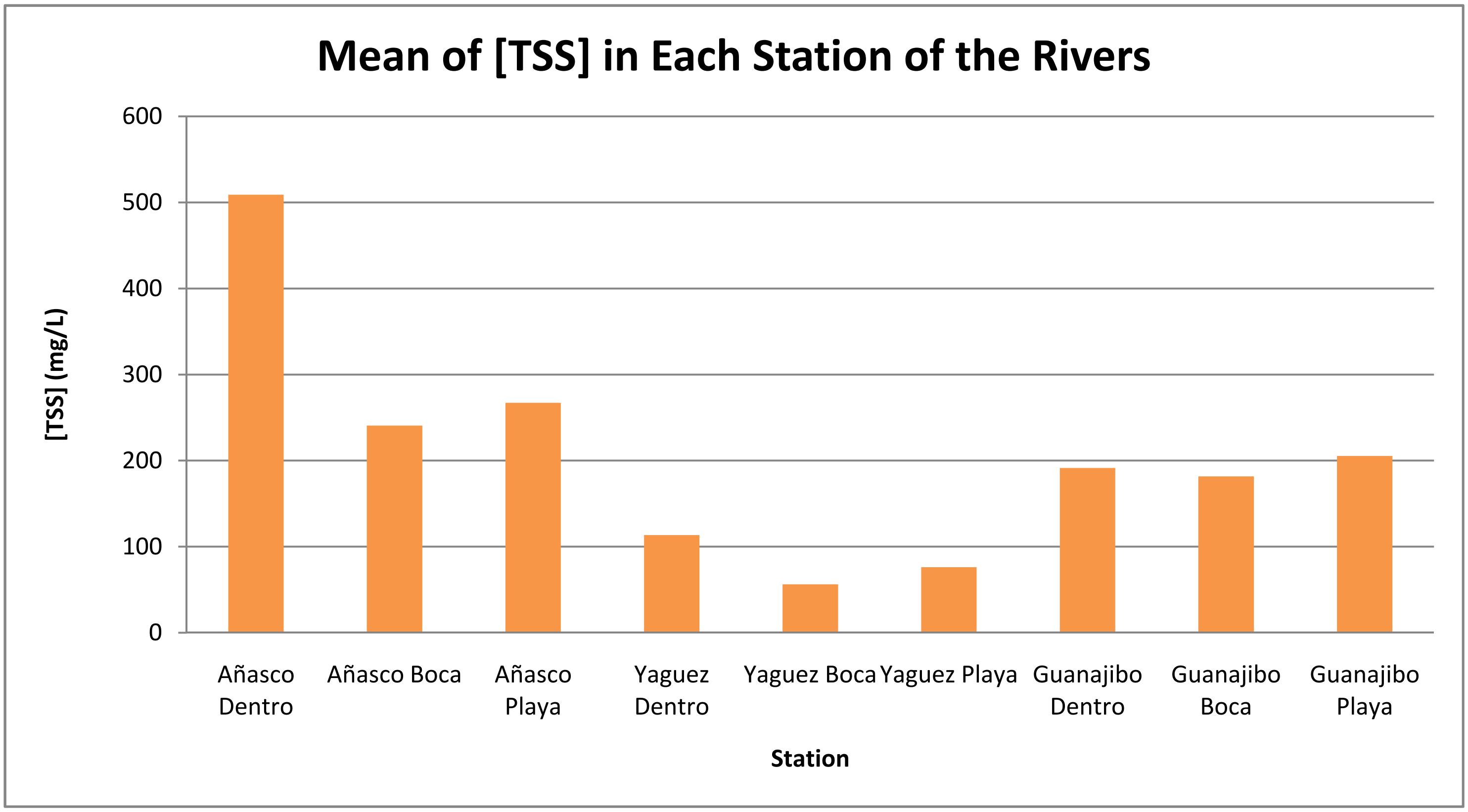


Figure 6. Mean [TSS] in each station of the rivers.

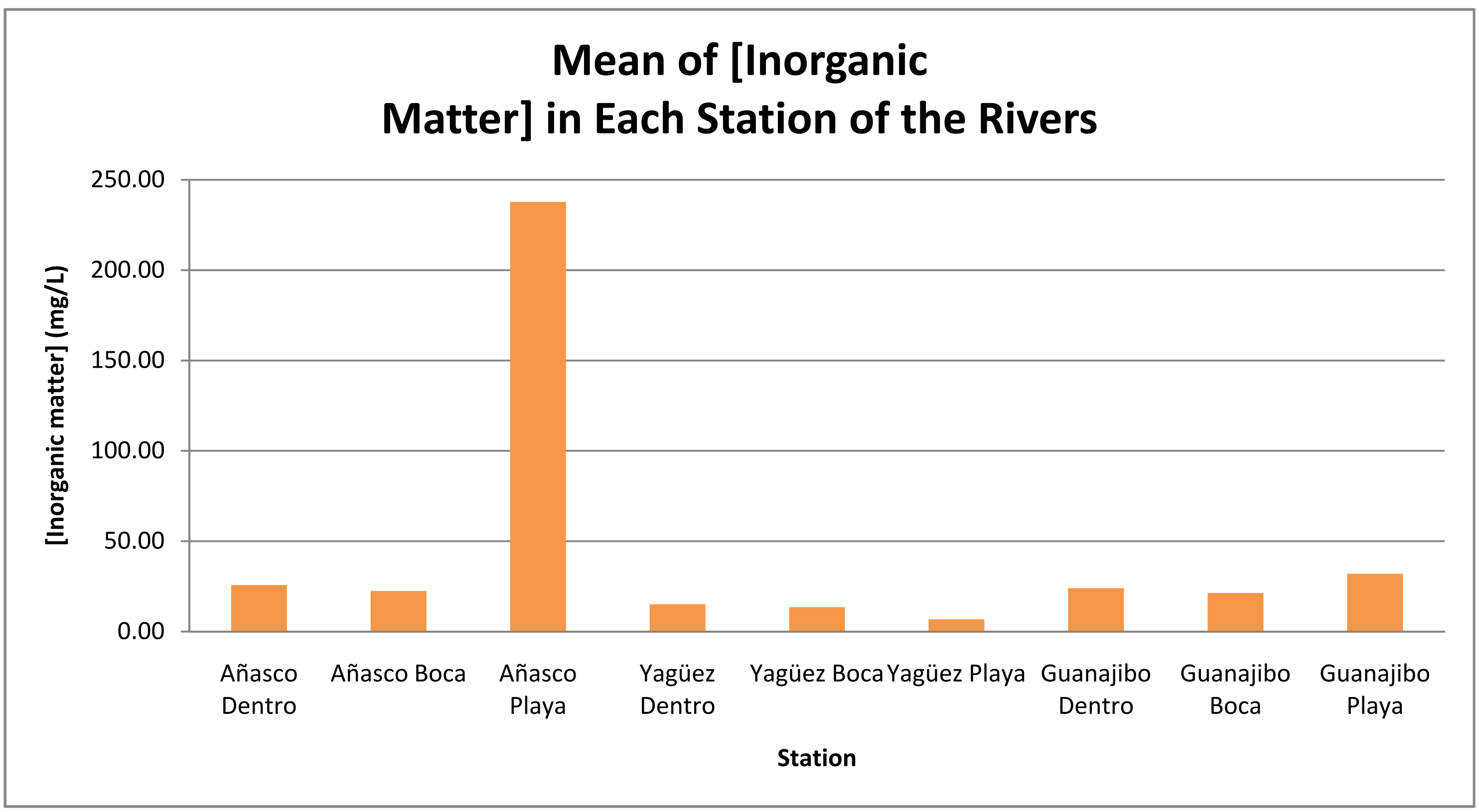


Figure 7. Mean of [inorganic matter] in each station of the rivers.

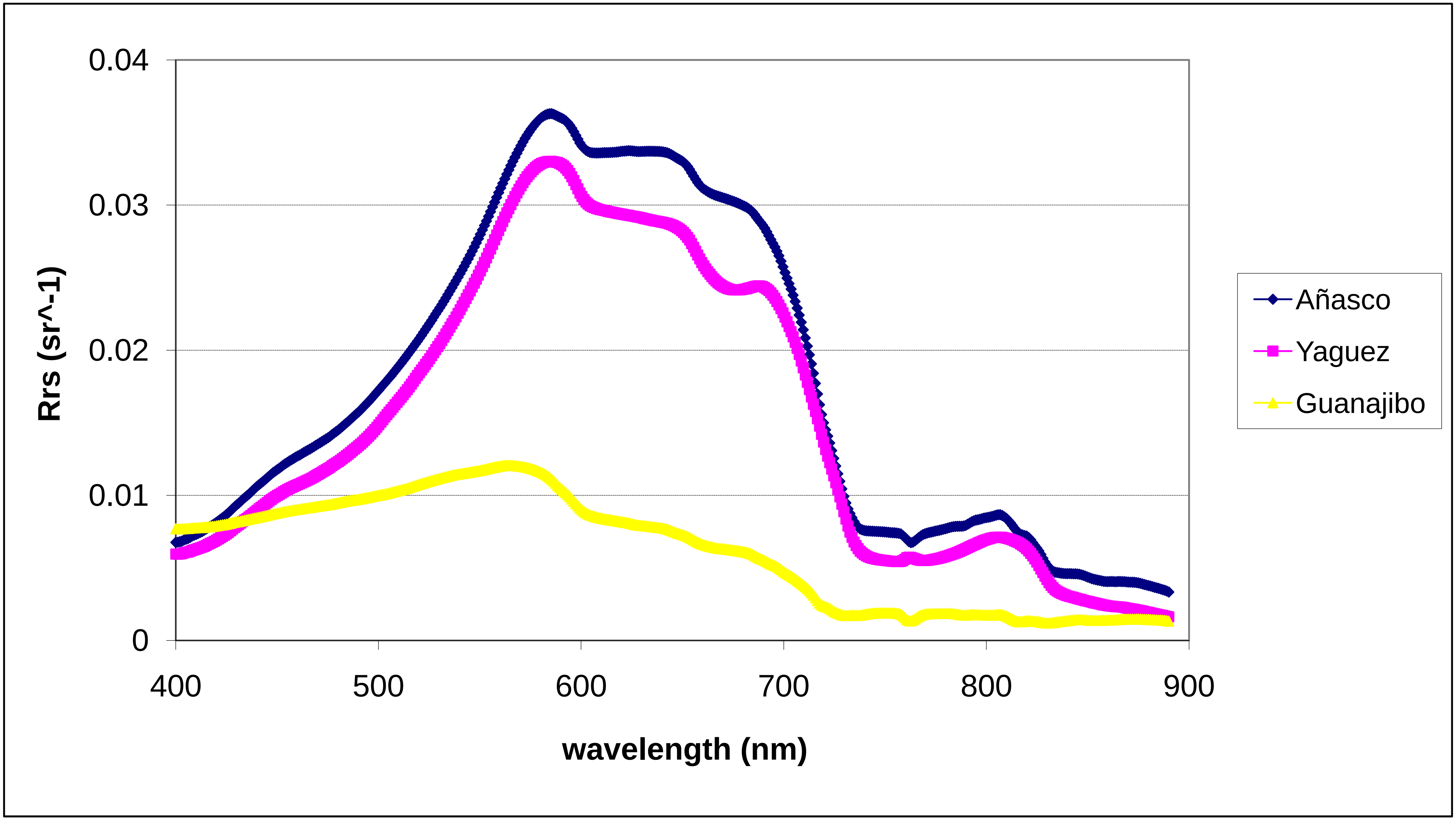


Figure 8. Graph of Rrs of Rio Añasco, Yagüez and Guanajibo Vs. Wavelength.

In the next figures, the legend has samples with TSS and without organic matter. Where the graph does not have "TSS" is that the samples are without organic matter. Each graph has the mean of Rrs of each station and the mean between the three stations as representative of the river.

Figure 9 Rrs of Rio Añasco with TSS. It is important to mention that it a peak between 650 and 700 nm, where the slope of the graph decrease. This decrease in slope in that region could be by the components and the organic matter that the TSS has. In comparison with figure 10 which is a graph without organic matter, the graph does not have this peak and continue rising. This could be because the organic matter has been eliminated from the sample. In figure 10 the values of Rrs is higher than figure 9. Figure 11 is to compare each station and the curves. In Añasco, Playa station has the higher Rrs value.

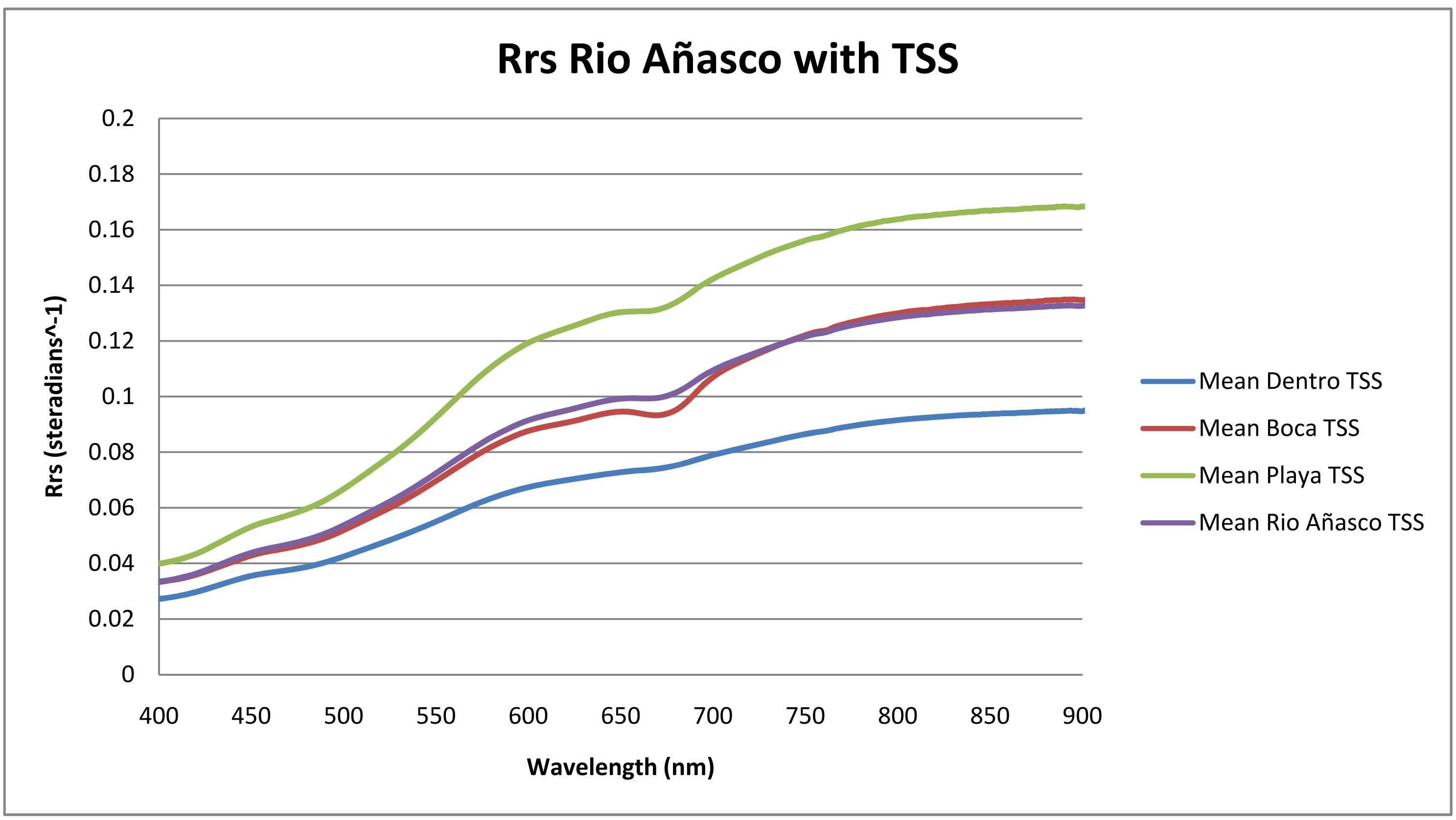


Figure 9. Graph of Rrs of Rio Añasco with TSS Vs Wavelength.

In each graph, between 400 and 550 nm, has the same values of Rrs. In that point is where the slope increases in each figure. The difference is that in the graph wit TSS the slope es lower than the graph without organic matter.

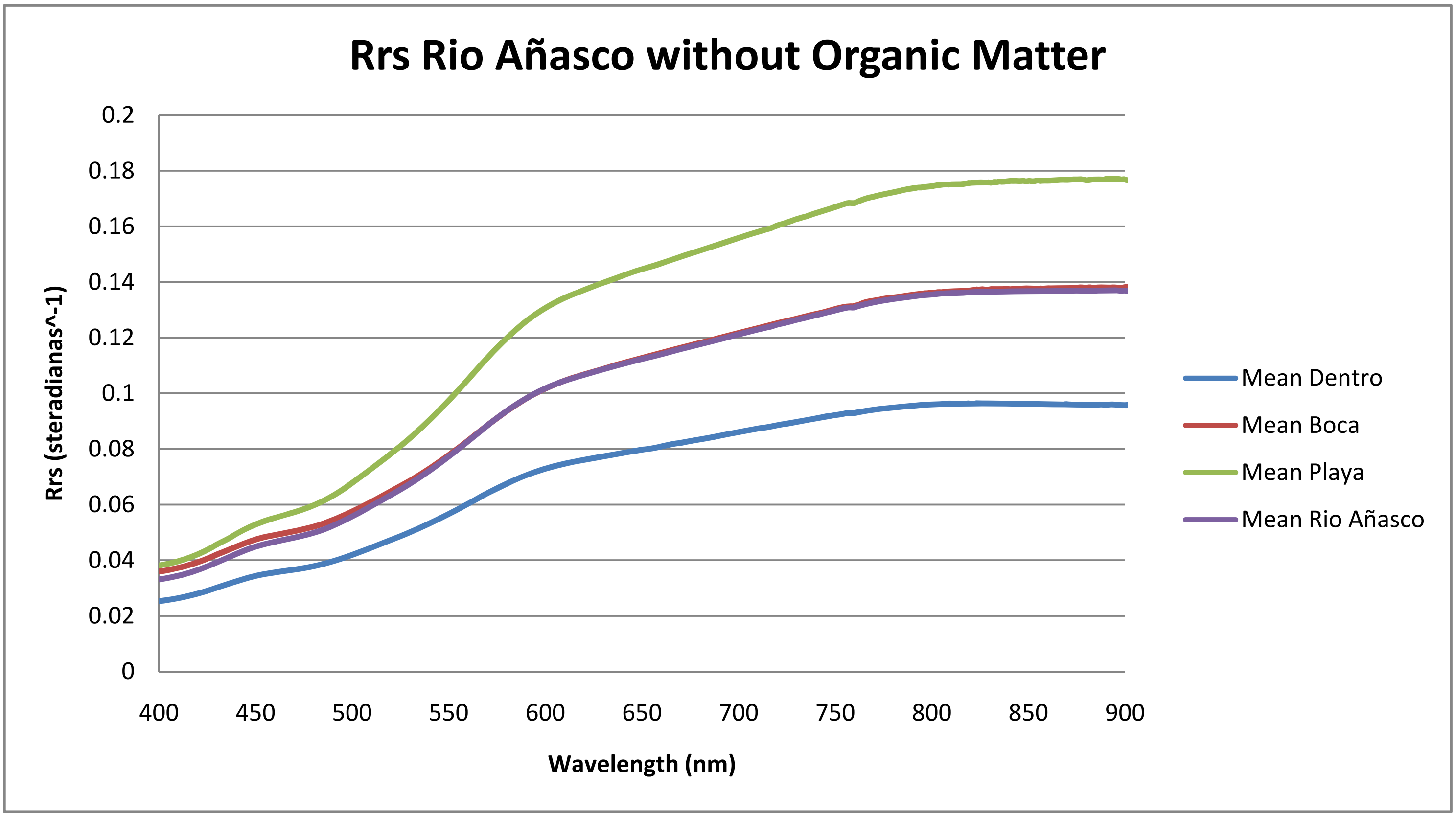


Figure 10. Graph of Rrs of Rio Añasco with TSS and without organic matter.

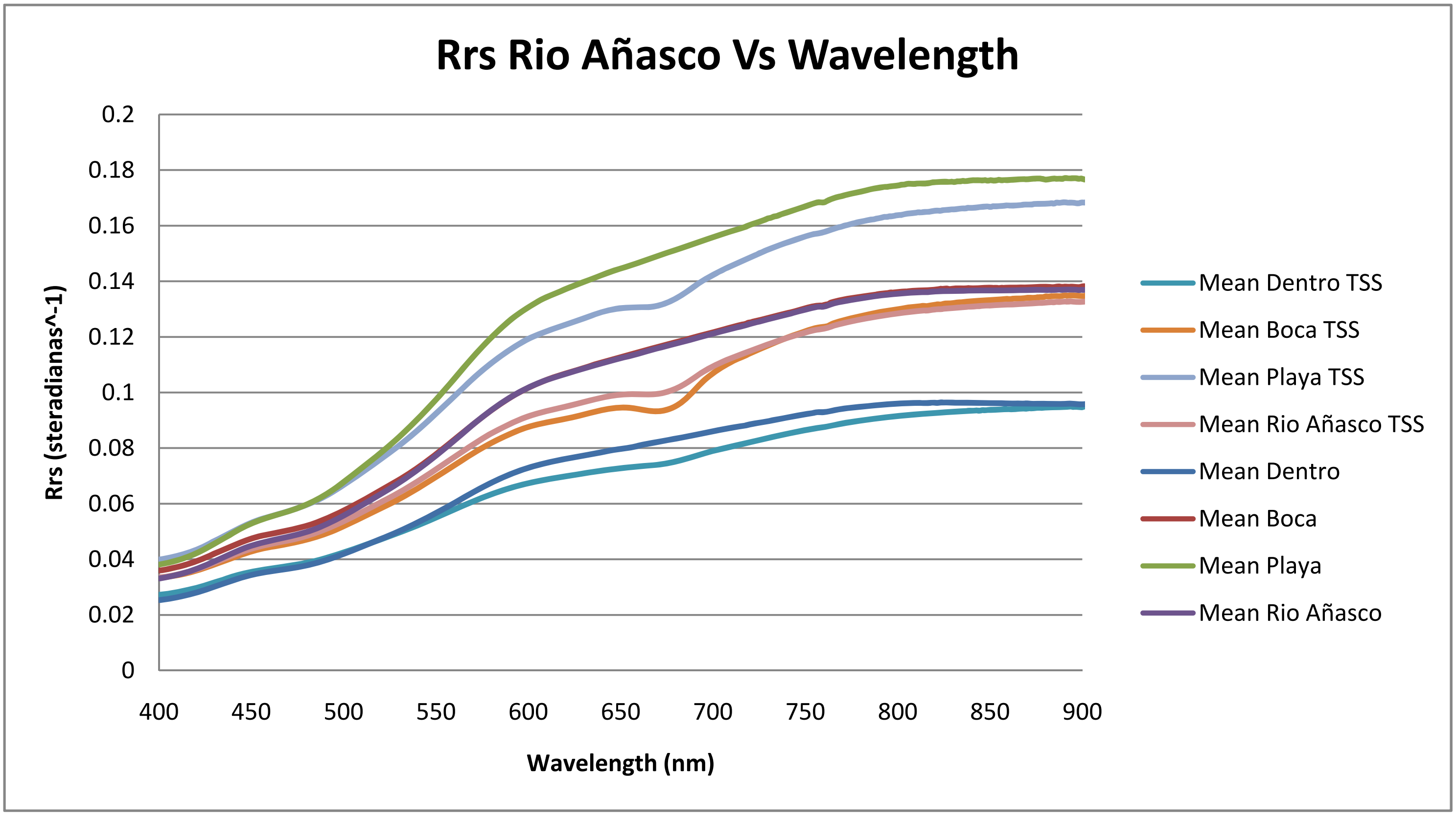


Figure 11. Graph of Rrs of Rio Añasco without organic matter.

Figure 12 is different from figure 9 because does not have this decrease in the slope between 650 and 700 nm. This could be because the samples from Rio Yagüez do not have too much quantity of organic matter. Other factor that can influence the values is that the samples of Rio Yagüez are more uniform, and this decrease in the slope is not show up. However, the values of concentration decrease. Other error that could be in these samples is that the samples have a lot of salts. Figure 13 shows that the value of Rrs is higher with TSS than without organic matter. All the error mentioned above could be responsible of the values. Figure 14 is to compare each station and the curves of Figure 12 and 13.

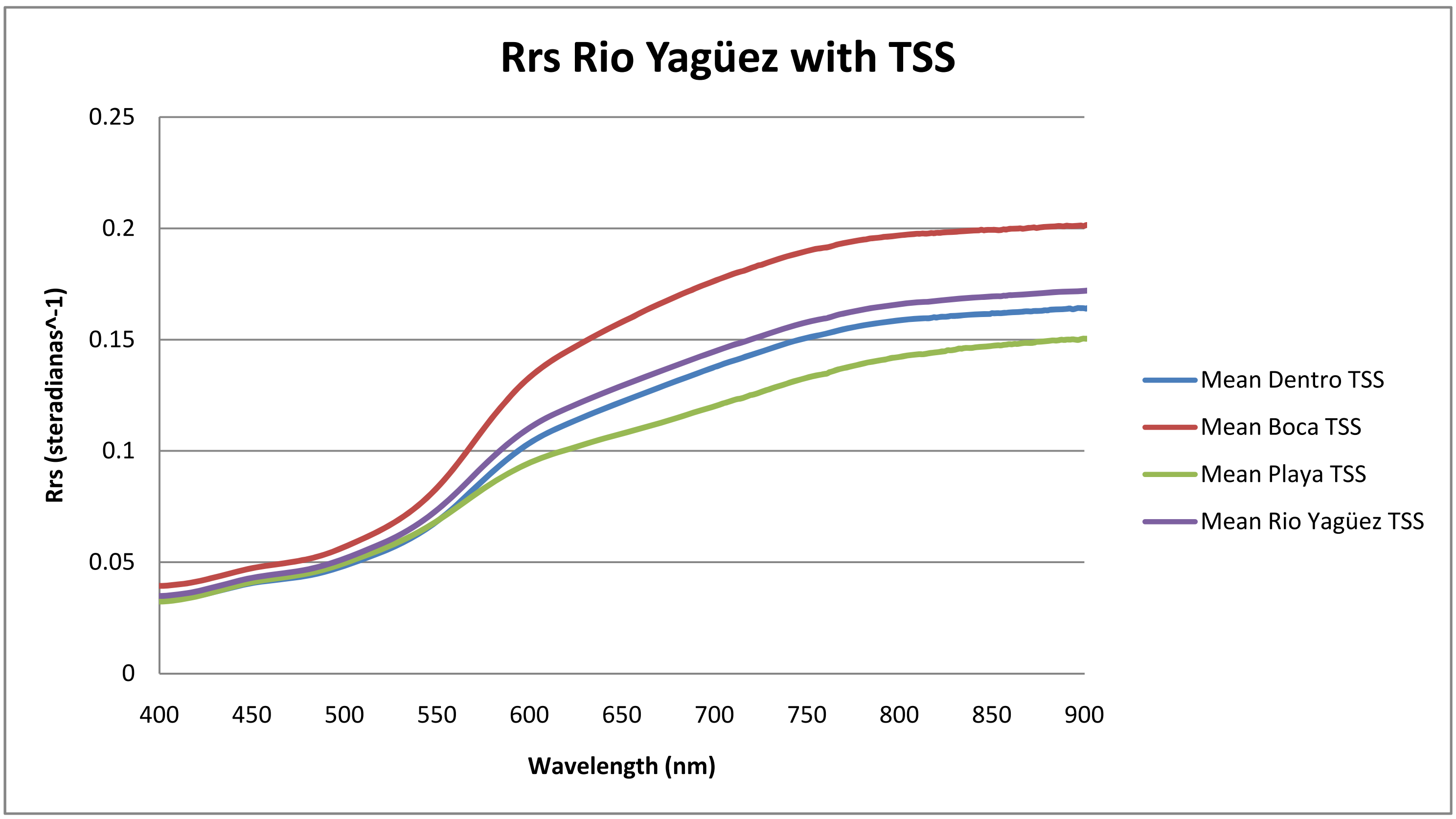


Figure 12. Graph of Rrs of Rio Yagüez with TSS Vs Wavelength.

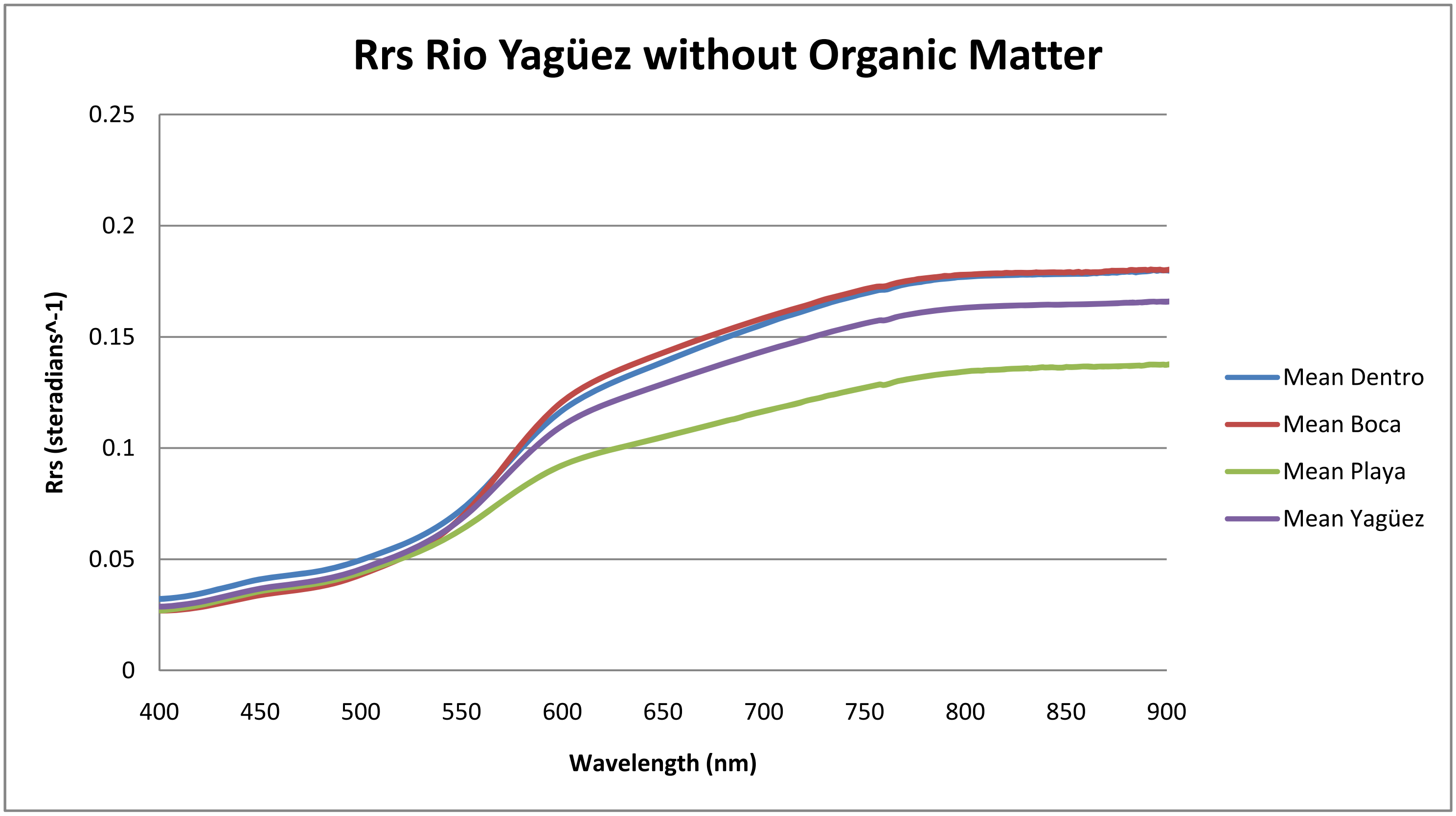


Figure 13. Graph of Rrs of Rio Yagüez without organic matter Vs Wavelength.

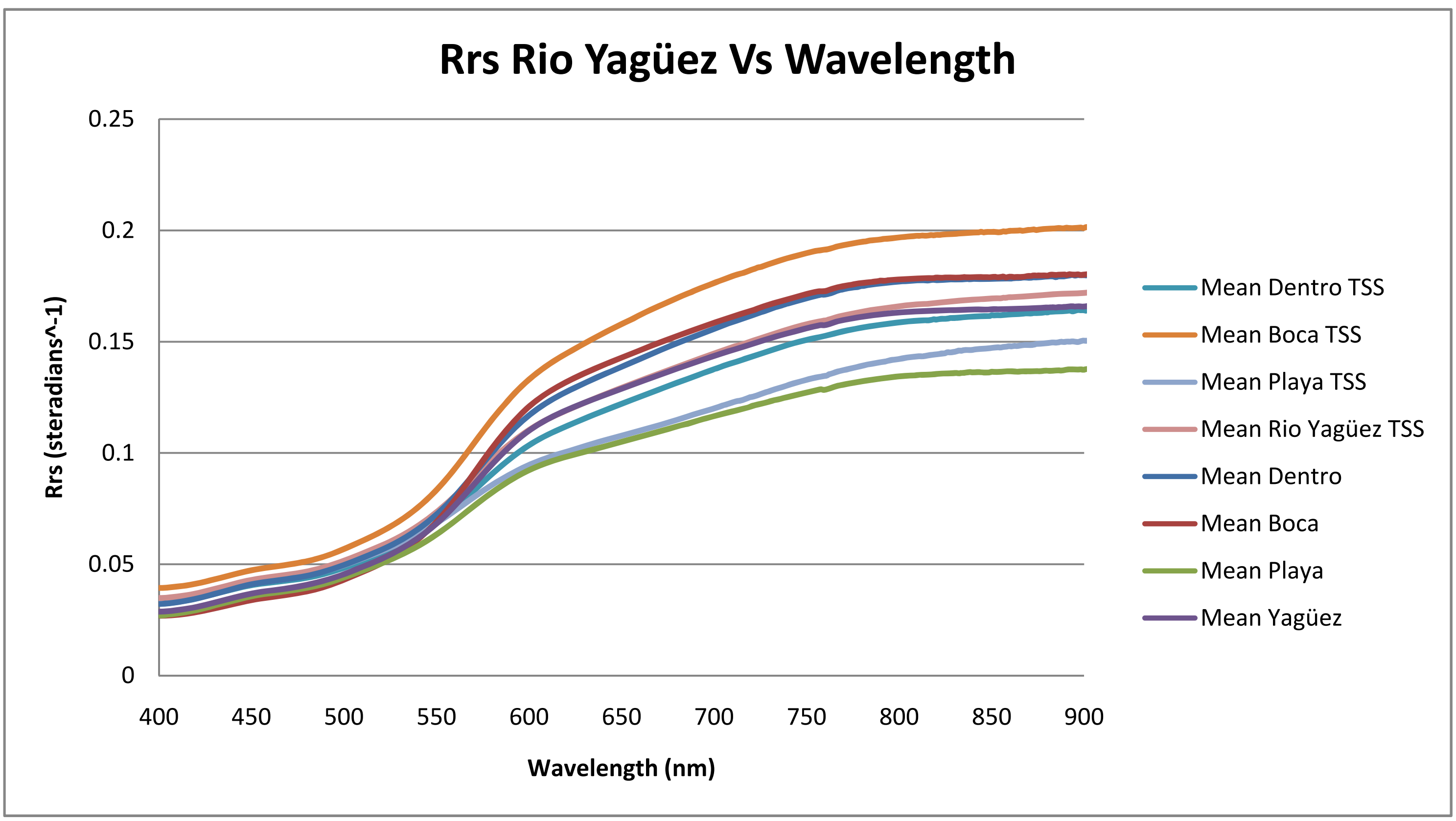


Figure 14 Graph of Rrs of Rio Yagüez with TSS and without organic matter.

Figure 15 show that at station Dentro of Rio Guanajibo has the decrease in slope between 650 and 700 nm, and the other the stations, Boca and Playa does not show it. However, between 400 and 500 nm, the slope of Playa station is similar to the slope of Dentro station. In 500 nm the slope of Playa station increase. An explanation about this two station (Playa and Dentro) is that Dentro Station has more organic matter than Playa station, and other is that the mineral composition of each sample maybe different. The concentration of Playa station is higher than the other two. Figure 16 shows that the three stations change the slope in 500 nm. However, each sample is parallel to each other. This could be by the difference in concentration and a reason for parallelism in the sample is that has the same mineral composition. Figure 17 is for compare the curves of TSS and without organic matter.

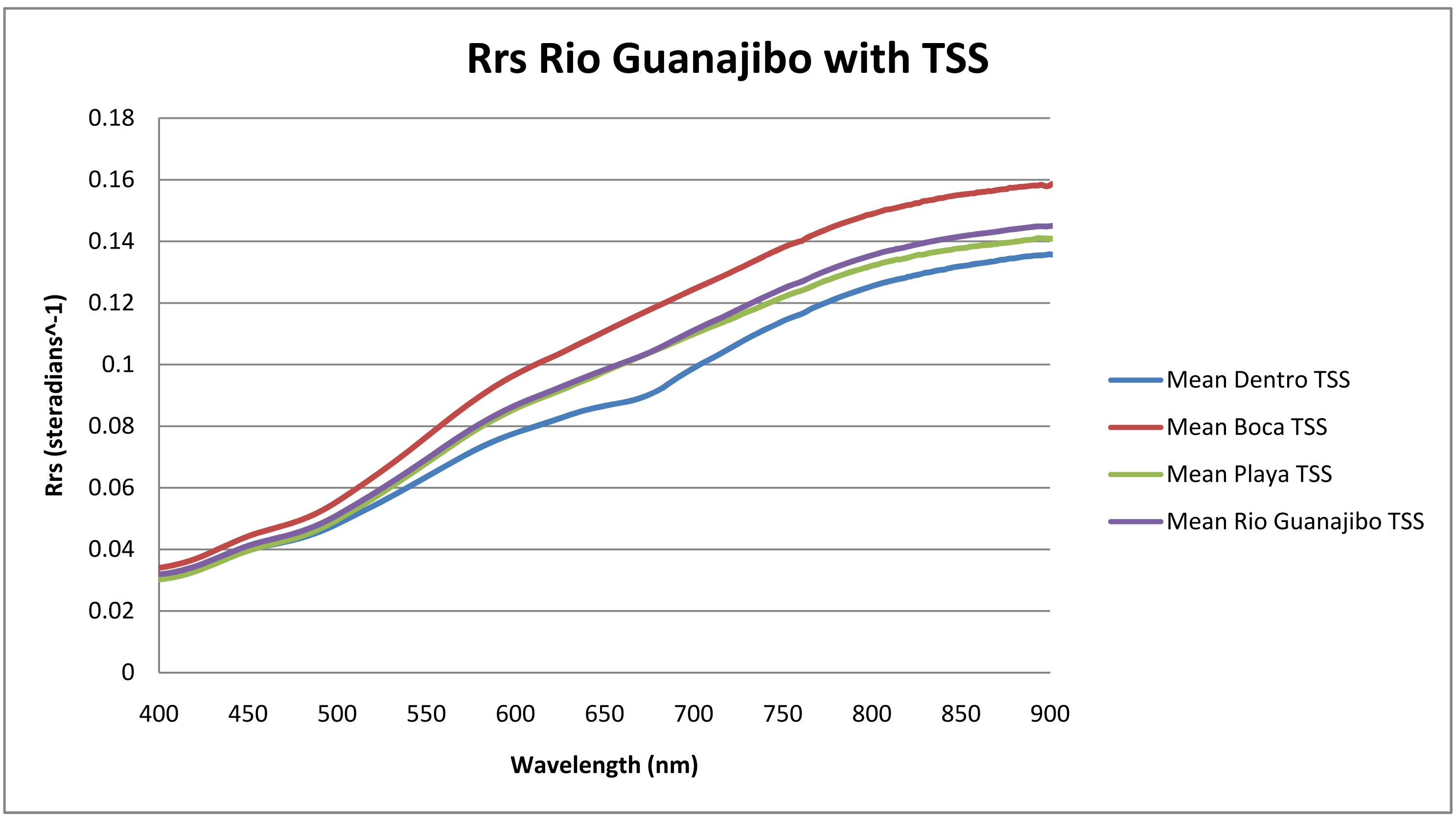


Figure 15. Graph of Rrs of Rio Guanajibo with TSS Vs Wavelength.

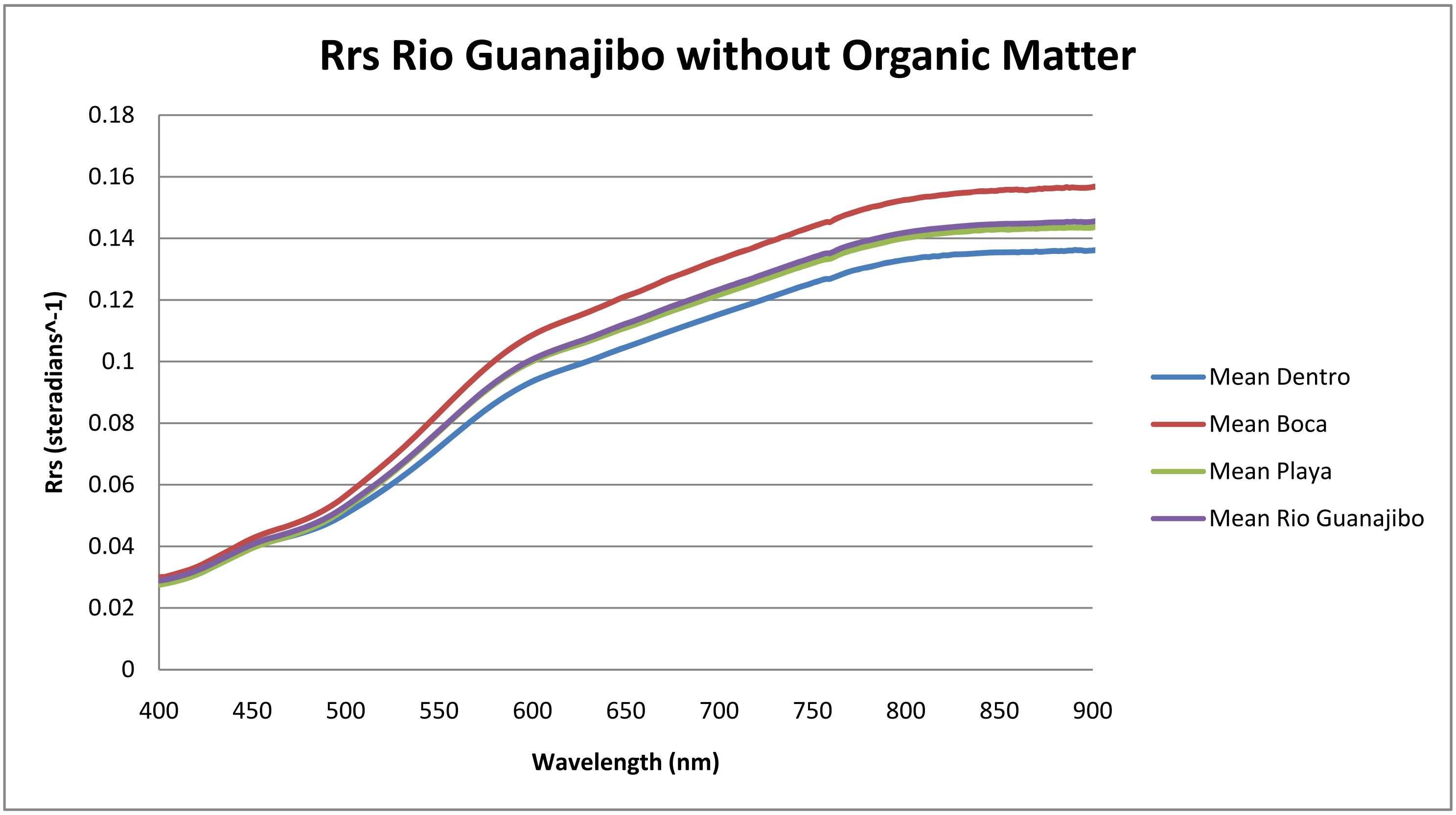


Figure 15. Graph of Rrs of Rio Guanajibo without organic matter Vs Wavelength.

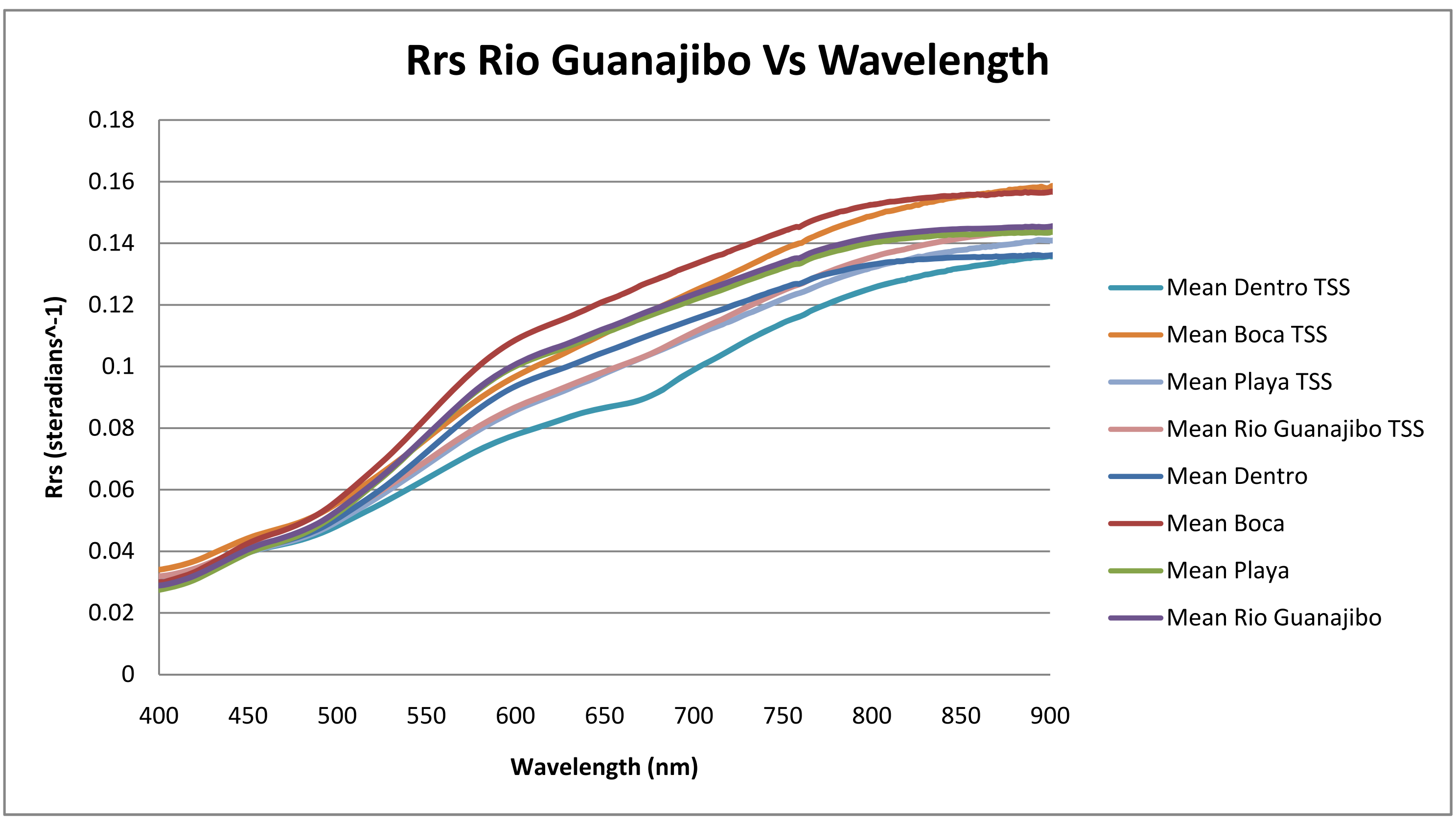


Figure 17. Graph of Rrs of Rio Guanajibo with TSS and without organic matter.

Figures 18 to 29 show a regression for Rrs Vs [TSS] and Rrs Vs [inorganic matter]. In each graph of Rrs of [TSS] of Rio Añasco, Yagüez and Guanajibo the slope is negative. This said that in the way that the concentration increase, the Rrs decrease. In the graph of Rrs of [inorganic matter] of Rio Añasco and Yagüez the slope is positive, but in Guanajibo is negative. One reason for that is the components of sediments that Rio Guanajibo transported induced this kind of curve.

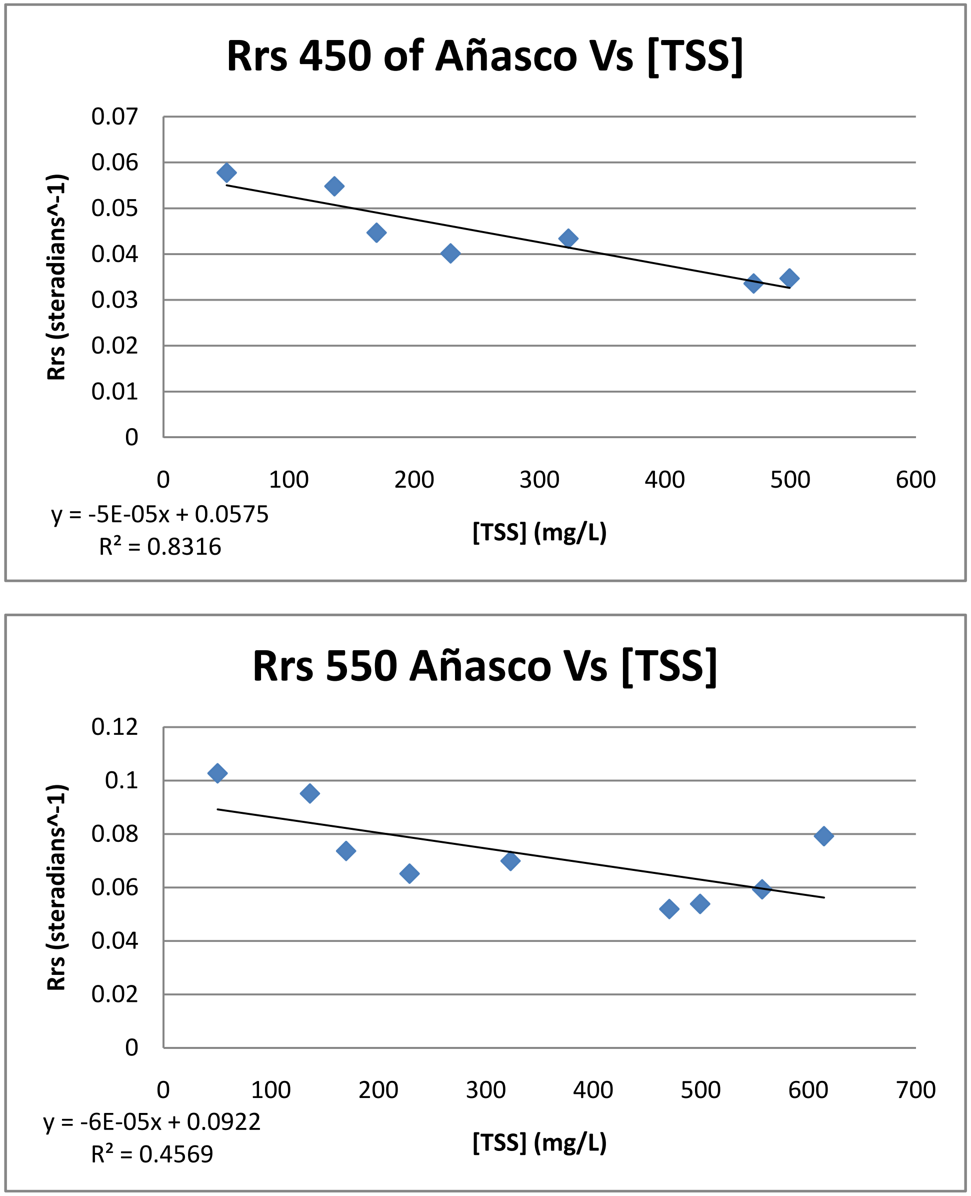


Figure 18 . Rrs Añasco Vs [TSS]

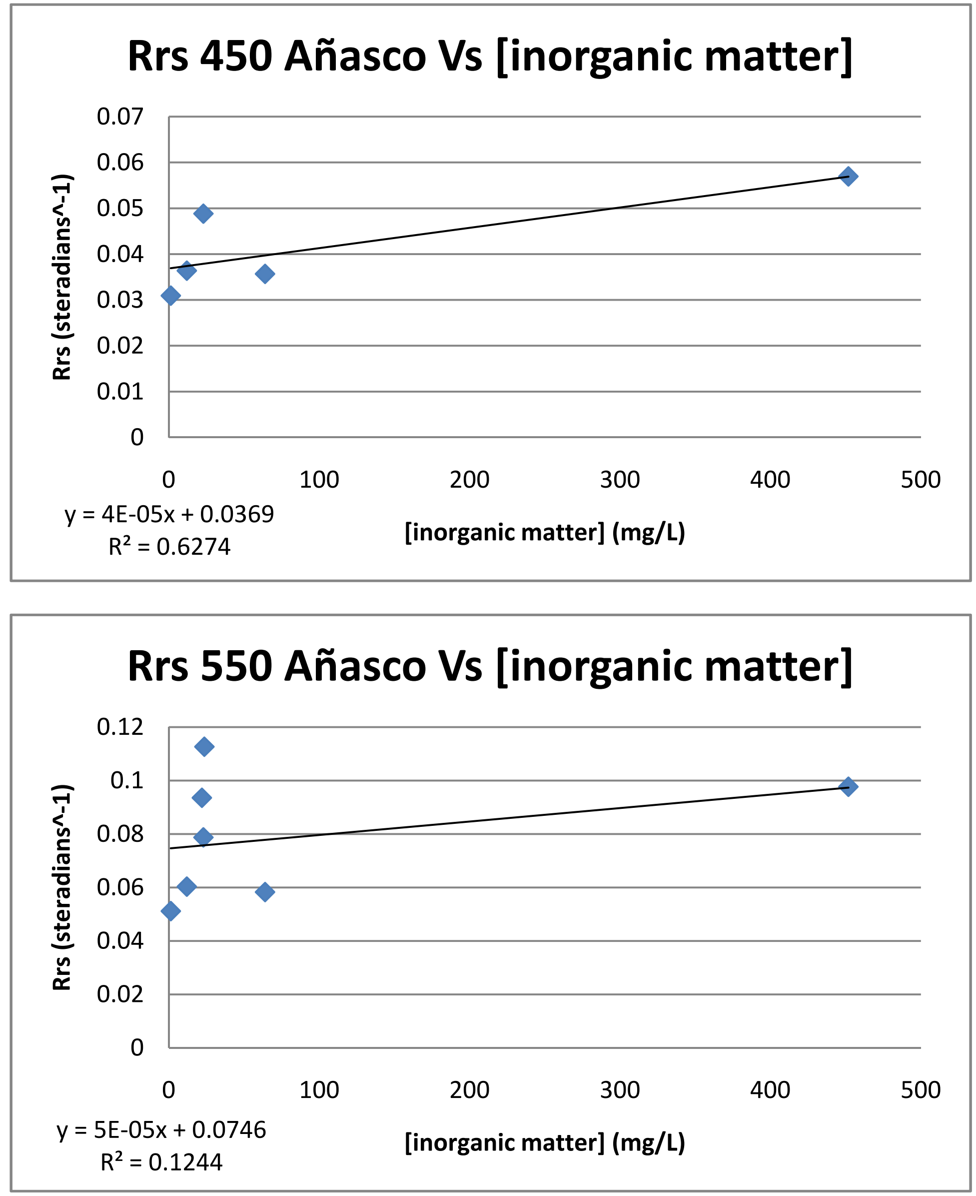


Figure 19. Rrs Añasco Vs [inorganic Matter]

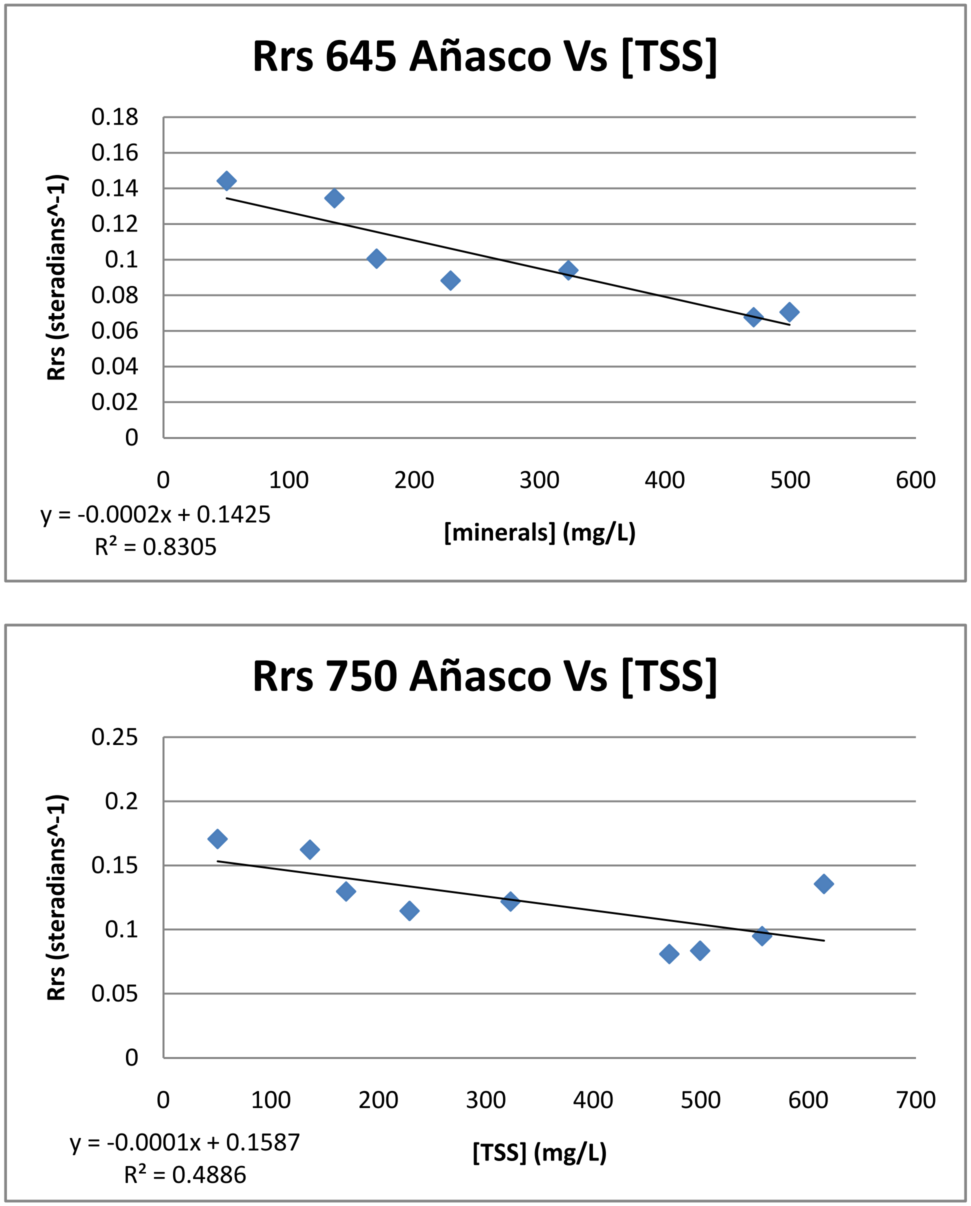


Figure 20. Rrs Añasco Vs [TSS]

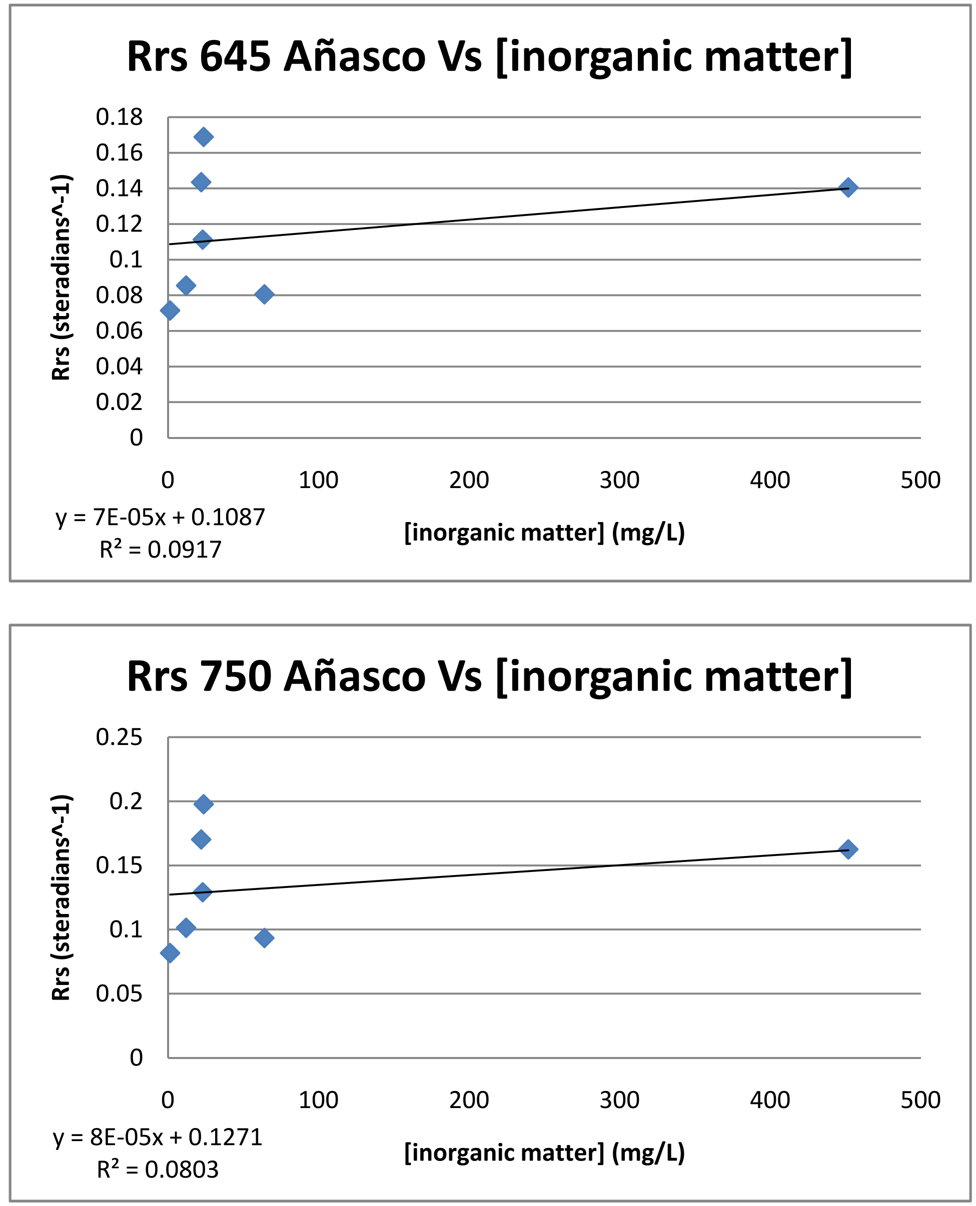


Figure 21. Rrs Añasco Vs [inorganic Matter]

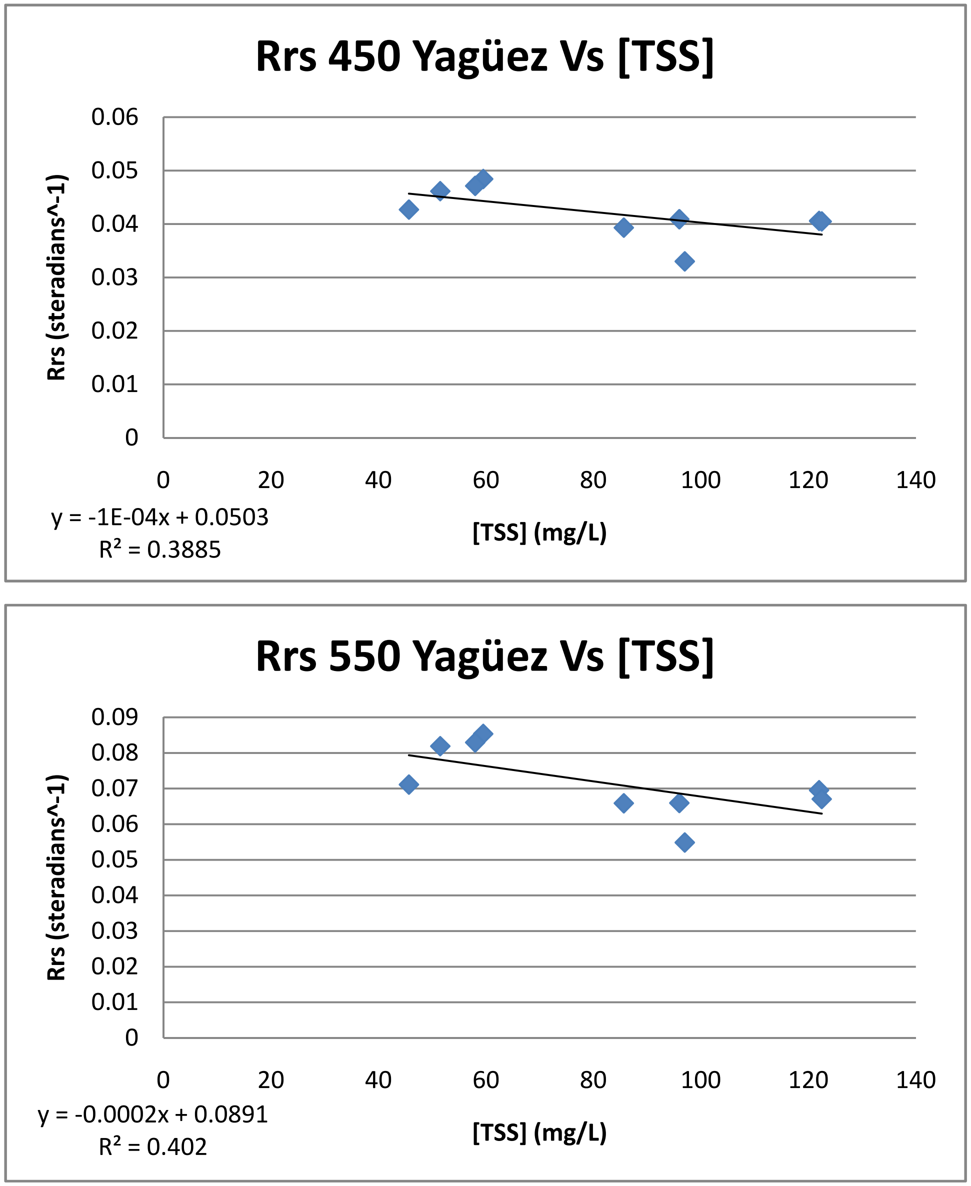


Figure 22. Rrs Añasco Vs [TSS]

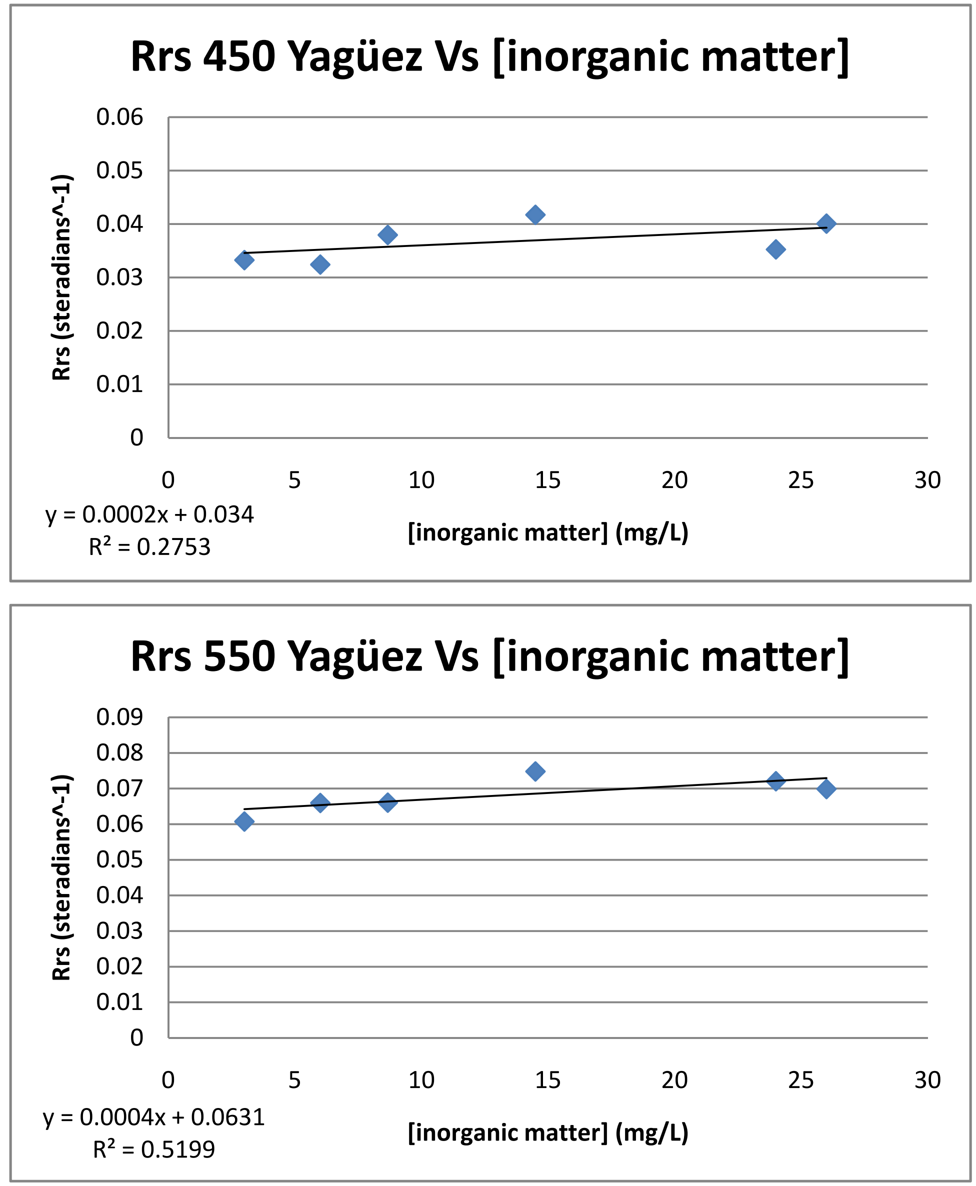
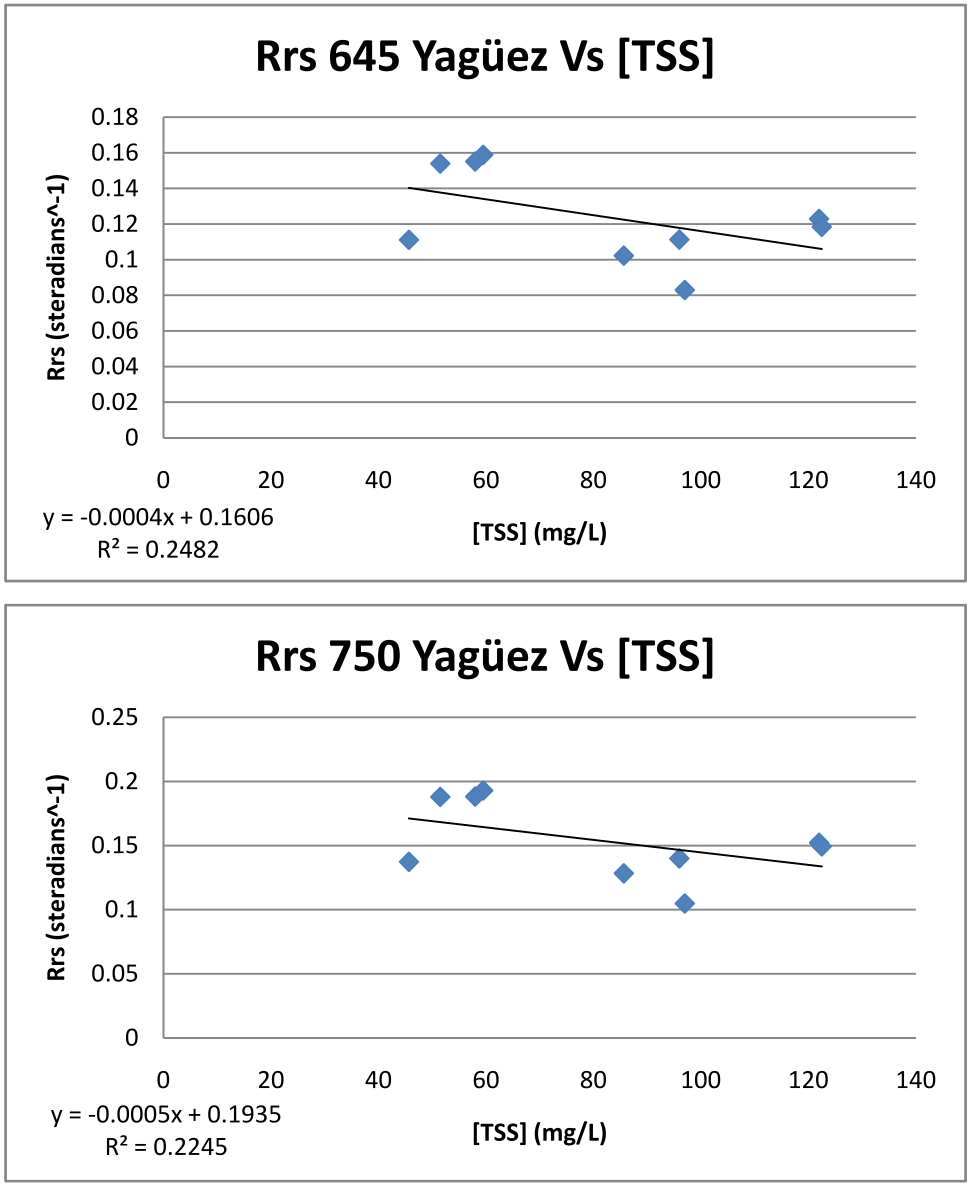


Figure 23. Rrs Añasco Vs [inorganic Matter]



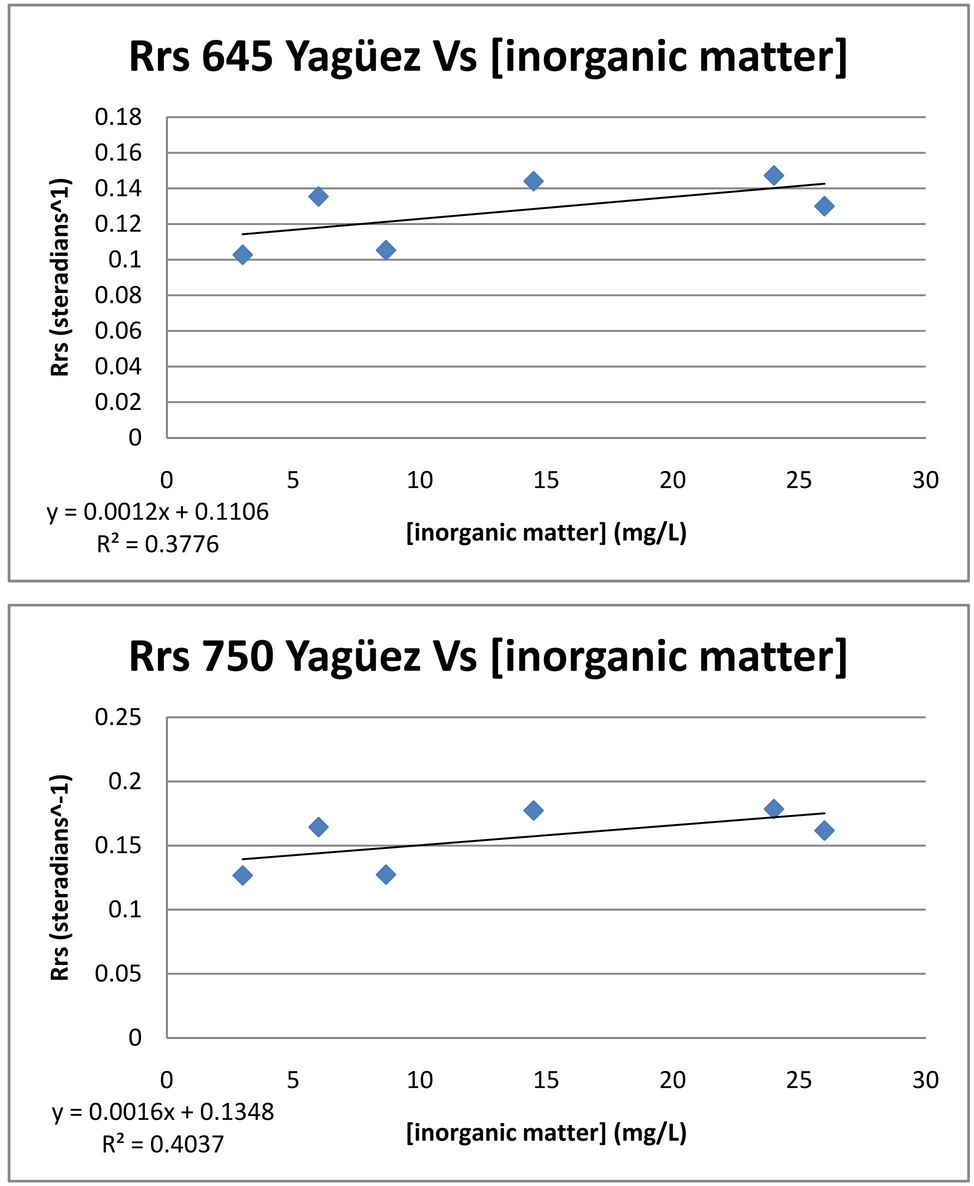


Figure 24. Rrs Añasco Vs [TSS]

Figure 25. Rrs Añasco Vs [inorganic Matter]

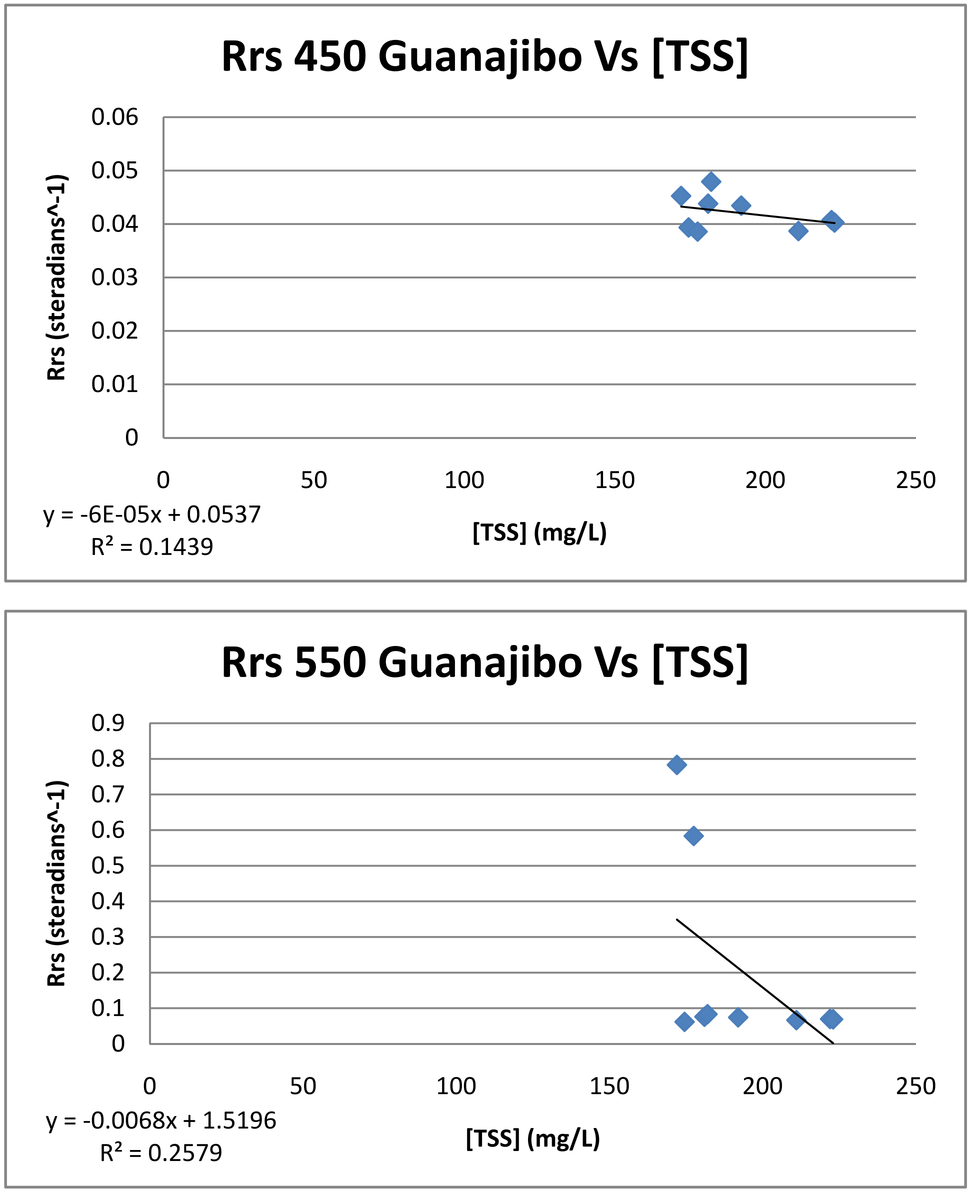


Figure 26. Rrs Añasco Vs [TSS]

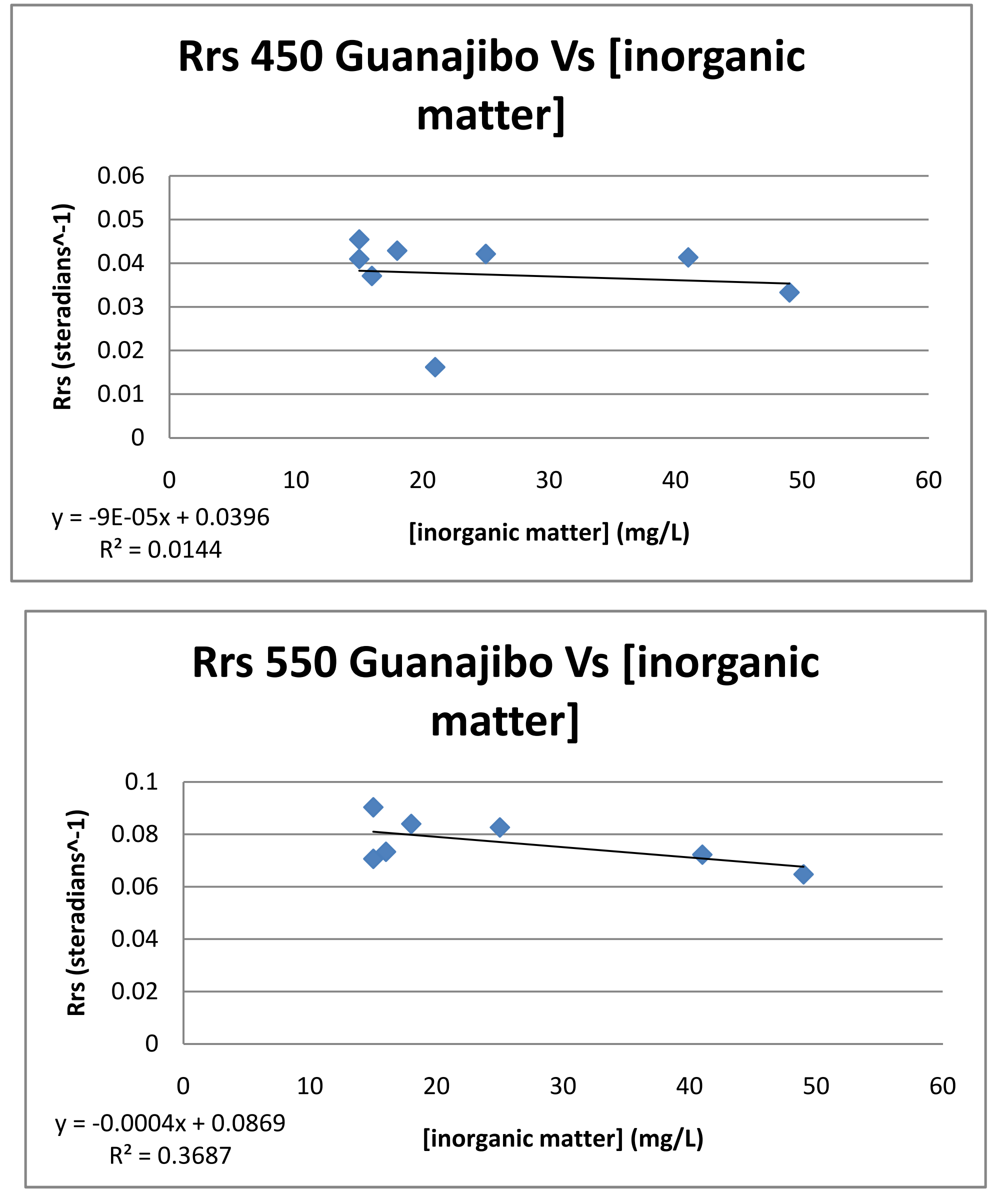


Figure 27. Rrs Añasco Vs [inorganic Matter]

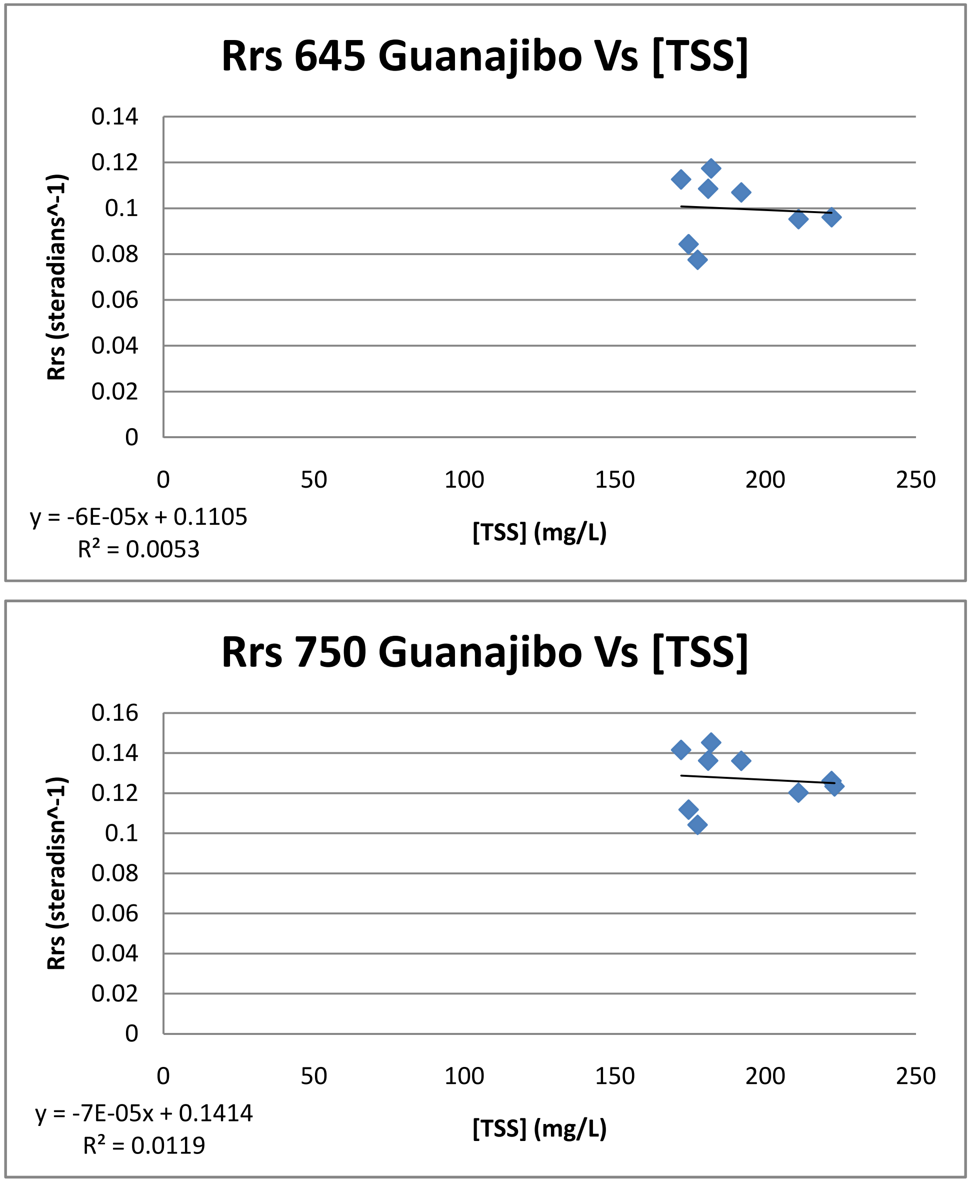


Figure 28. Rrs Añasco Vs [TSS]

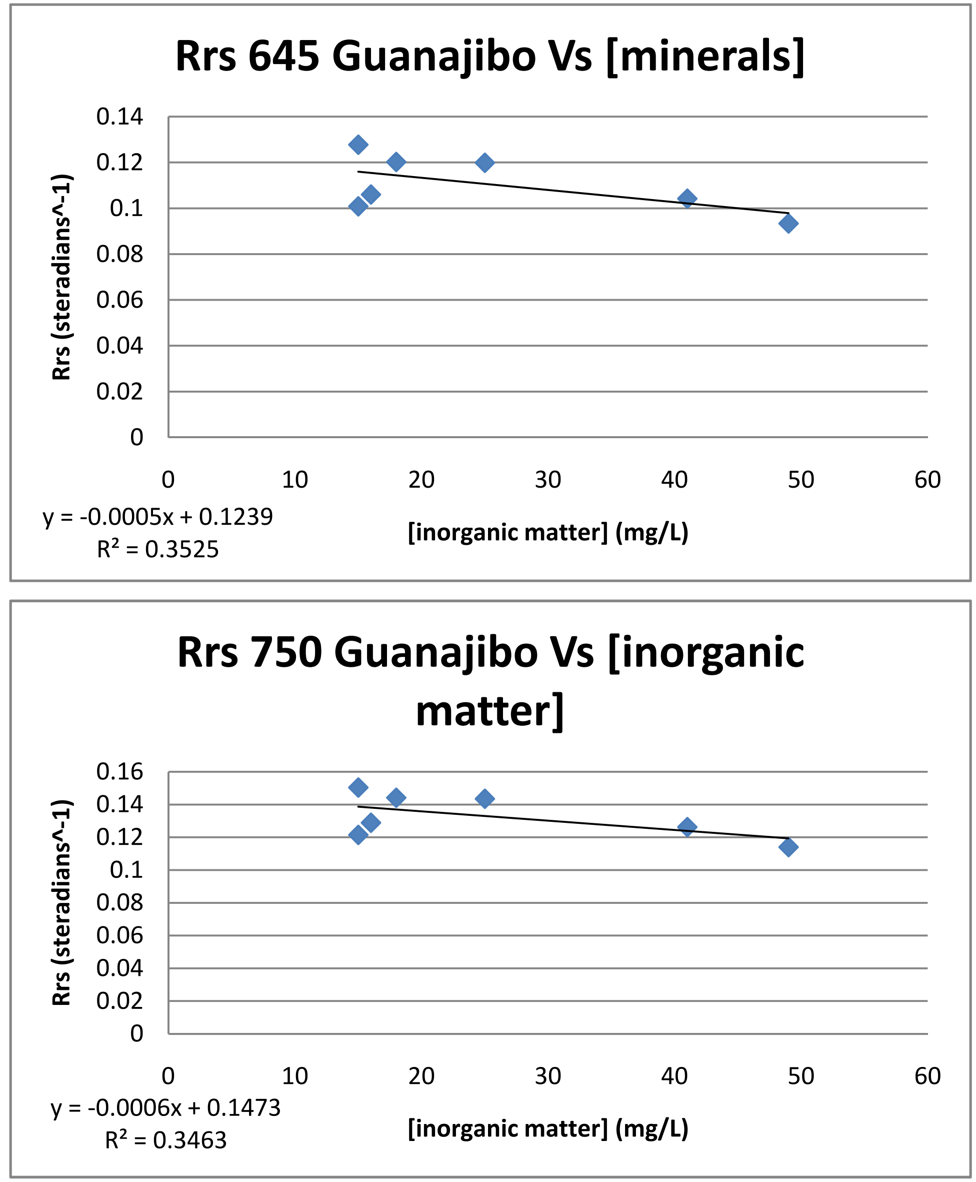


Figure 29. Rrs Añasco Vs [inorganic Matter]

VI. Discussion

Data collected in this study were affected by the high precipitation and discharge that occurred during September 21-24 in Puerto Rico. It was a unique event that produced extreme values of sediments concentration.

The first interpretation is that the values of Rrs are higher when the measure is taken directly from sediments than directly from water. This is because water absorbs more in infrared region of the spectrum, and the sediments reflect more in this region. Hernandez (2008) shows two graphs of % of reflectance Vs Wavelength sediments from Mayaguez Bay: one of wet sediments and other of dry sediments. In her work, dry sediments show a high % of reflectance than the wet sediments. A relation can establish that the Rrs in sediments for this project has a high value. In addition, in Figure 8 the Rrs is low in the infrared region (sediments in water), and the sediments of this research (which are dry) show a high value of Rrs.

When comparing Rrs data for each station before and after the removal of organic matter, the value of Rrs on Añasco with TSS was less than the Rrs with minerals only. A possible interpretation of this is that the organic matter reduces the spectral signal. In other words, it highly absorbs the radiation. Binding et al. (2007) establish that the organic matter may vary the absorption coefficient and affect the spectral signal. In this research, the organic matter may be the responsible for absorption of the radiation and affect the spectral signal that is received from the sediments. It looks like the minerals reflect more when are without organic matter. This was found in all the stations of Añasco and Guanajibo. In Rio Yagüez, only the station of Yagüez Dentro shows a higher value of Rrs with minerals than with TSS. The other two stations do not show it. This could be produced by the composition of minerals that are transported by Rio Yagüez, which may reflect less than those from the other rivers. Other possible reason is low concentration of organic matter in the sample, which produced very similar Rrs curves.

Most of the differences in the Rrs curves were detected in the red and infrared regions of the spectrum. In general, Rrs at those wavelengths decreased with an increase in TSS concentration. After bleaching and have only minerals, the graphs of regression show that with high [inorganic matter] (or [only minerals]), the value of Rrs increase. The expectation was true, because in Froidefon et al. (2001) said that a high concentration of minerals induces a high value of Rrs. However, in Guanajibo stations show a high value of Rrs without organic matter, but when is compared with [inorganic matter], the values of Rrs decrease. This could be by the type of minerals that Rio Guanajibo transported, or the organic matter was not totally removed.

VII. Conclusion

The total suspended sediments showed lower values of Rrs that the sediments without organic matter. A higher concentration of organic matter makes that the Rrs decrease. However, a higher concentration of minerals makes a higher value of Rrs. For future research, the methodology must be improved and errors of weighting, the use of bleach and methods of calculations need to be changed. The next step in this research is to identify the minerals that are in the suspended sediments of each one of the rivers. Reprocess and new analyses of the collected data will also be necessary.

VIII. References

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