Anthropogenic Impacts on the Rio Grande Delta: Sediment, Flow, and Precipitation in the Delta

1. Abstract

The Rio Grande has been an emblematic feature and a source of life for the region. Since Pre-Historic times it has provided the resources that allowed waves of humans to migrate inland from the coast, and communities to thrive in a land where water is scarce. Large scale anthropogenic activities including, river diversions and dam construction have negatively impacted the river. Twenty-three major dams and many small ones have been built on the main channel, and in many of its tributaries, in the last century. The high number of these structures have drastically reduced water discharge and eliminated sediment delivery to the delta. This is cause of major concern since it is accelerating shoreline erosion due to a lack of sediment replenishment. To better understand the real impact that humas are having in the Rio Grande, I looked at precipitation data to help understand how much of the changes in flow can be attributed to direct human impact and how much to other factors. This study aimed at creating an assessment of the current conditions of water flow and suspended sediment concentrations in the Rio Grande delta. Using the processing power of python, several statistical operations were done using flow data from the International Boundary and Water Commission and sediment data from the USGS National Water Information System. All data sets were later divided by decade groups to perform the same statistical operations. It was clear at the end of this study that humans have in fact played a huge role in reducing water and sediment reaching the shoreline.

2. Introduction

The Rio Grande formed a sizable delta of around 7,770 km2 that spans from Southeast Texas to Northeast Tamaulipas with a shoreline length of approximately 300 km, and begins near the city of Harlingen, 88 km from shore, (Ewing and Gonzalez, 2016) (Figure 1). Mostly rural region with a sub-tropical climate with an average precipitation of 1.6 mm in 2020, according National Oceanic and Atmospheric Administration. The major urban hubs within the confines of this area are Brownsville, Texas (population 182,781) and Matamoros, Tamaulipas (population 520,367). Like all modern deltas, the Rio Grande delta is thought to have formed due to the slowdown in the rate of sea-level rise between 8500- and 6500-years BP that allowed the accumulation of sediment in coastal areas (Stanley and Warne, 1994).

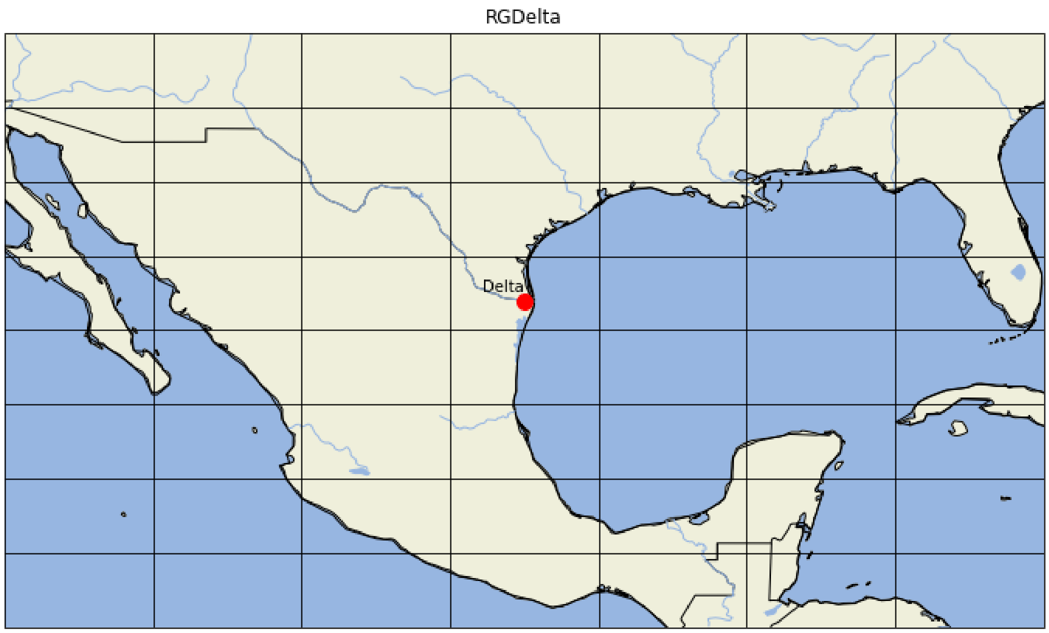

Figure 1.- Location of the Rio Grande Delta. Delta is indicated with red dot.

1.3.- Human activity on the Rio Grande

There is evidence from Franciscan missionaries that tells of Pueblo-Indians already diverting water for irrigation and other uses as far back as the late 1500s. Moreover, when Mormon settlers arrived at the Rio Grande, they also built structures to divert water from the river for irrigation. As communities kept expanding along the Rio Grande, the US Congress realized the need to improve their water management practices. For this reason, they decided to approve the construction of the first major dam on the Rio Grande in 1906; ten years later, Elephant Butte Dam was inaugurated. Since then, over twenty major dams and diversions, and many more minor structures, have been built in the Rio Grande channel and its tributaries. Two of these major dams are located within the Lower Rio Grande reach; these dams are Amistad dam and Falcon dam, which are located at 546 km and 212 km from the mouth of the river, respectively.

As a result of intense human activity, humans are now considered the major force shaping delta landform, and other ecosystems (Rogers and Overeem., 2017; Higgins et al., 2018). Paying attention to the effects of human activity on the Rio Grande is of paramount importance. Coastal erosion, the increase of relative sea level rise rates, sediment depletion, land subsidence, and human pressure on delta land are expected to negatively affect the efficiency of conventional approaches currently use to protect delta environments (Schmitt et al., 2017). It is important for local communities such as the Rio Grande Valley to understand the changes that are happening in the Rio Grande system.

1.4.- Flow Discharge and Sediment Concentration

To understand how much humans affected the Rio Grande delta, it is necessary to see how much flow discharge and sediment budget have changed. Drastic changes in discharge and sediment load have the potential to get the any river out of equilibrium. A river reaches an equilibrium state when there is net balance between deposition and erosion, and when sediment budgets change, rivers get out of balance (Nanson and Huang, 2018). For this reason, it is necessary to understand the current conditions of water flow and sediment concentration reaching the Rio Grande delta

1.5.- Precipitation

Precipitation data has been in declined in several regions around the world, and the Rio Grande Valley is not the exception. This change has only worsened the situation here since we already live in a semi-arid region, where evaporation rate is double that of precipitation. Looking at precipitation data is necessary to understand how much blame can be put on dams and other man-made structures for the drastic decline in water discharge reaching the Gulf of Mexico. Since we have two major dames so close to the mouth of the river (Amistad Dam and Falcon Dam), precipitation downriver from Falcon Dam is essential to help the river recuperate from the massive disruptions happening upriver.

1.6.- Hypothesis

After years of constant human development on the Rio Grande, by building dams and diversion structures, it can be assumed that water discharge and sediment budgets have decreased as a result.

3. Methods

To create an assessment of the conditions, present in the Rio Grande delta, I looked at flow discharge data and suspended sediment concentration reaching the delta. I used water flow data provided by the International Water Information System and sediment data from USGS Water Information System. Additionally, I looked at changes in precipitation data to understand if the changes in flow could be attributed to changes in flow. Also, comparison with precipitation data also helped understand the real impact human structures are having in the decline of flow reaching the Gulf of Mexico.

I used functions and coding in python that allowed me to analyze the records of discharge and sediment data. I used functions such as: .mean(), std(), var(), describe(), and pct_change() to perform a basic and more in depth statistical analysis on my datasets. Additionally, I introduced a loop function to help me create a plotted graph depicting the results from the statistical analysis to help visualize the result from the inquiry.

The data was latte divided in groups by decade starting with 1970s, 1980s, 1990s, 2000s. In the case of the sediment and precipitation data, a group was also made to cover the 2010s; flow data stopped in the year 2011. Thus, not having enough data to create its own group for the 2010s decade. The same statistical functions (.mean(), .std(), and var(), describe(), and pct_change())on the decades groups. This was to identify where the major changes have occurred and try to understand why they happened, if present.

3.1.- Approach

I used basic functions in python to perform statistical analysis and create a visual interpretation of sediment concentration and water discharge (flow) reaching the Gulf of Mexico. Precipitation data was also analyzed and compared with flow discharge looking for a connection between the two. This was done to create a baseline of human impacts on the river.

4. Results

Both datasets, flow discharge and suspended sediment concentration (SSC), show decrease starting in the decade of 1970s. Although both datasets experienced a rebound in their decade averages, the overall trend is downward. Suspended sediment had a rebound in the 1980s. Two important facts about this event are that it happened in the following decade after measurements started to be taken, so it cannot be considered an actual rebound, and it can be attributed to an isolated event that happen in the late 1970s that had in inflation effect on the final results. Flow discharge data had an actual rebound in the 2000s decade after a downward trend in the previous decades. Figures 2 shows the decline in SSC and Flow throughout the decades.

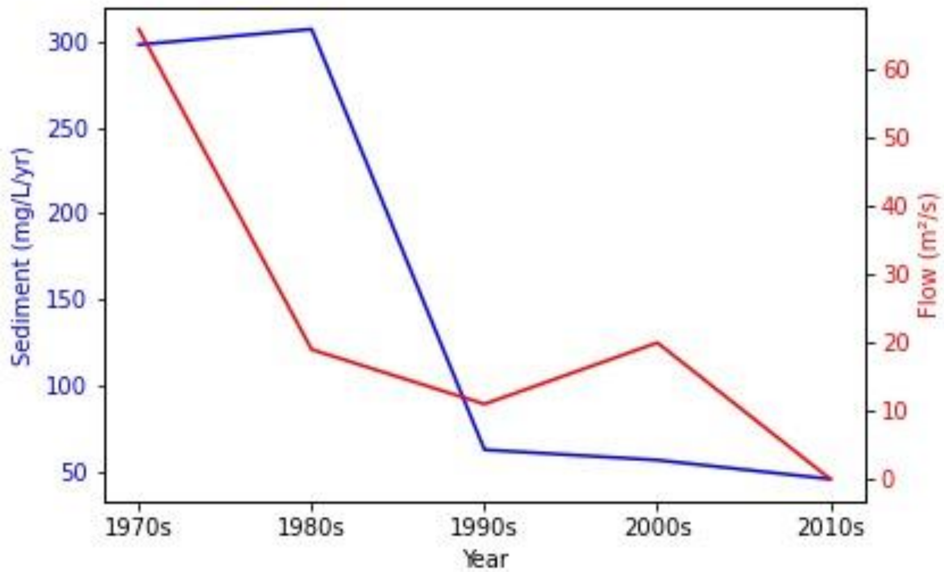

Figure 2.- Plotted graph showing patterns of suspended sediment concentration and flow organized by decades.

Precipitation data also yielded a decline from the 1970s to the 2010s. It reported a decline of .02 from a decade average of 2.0 in the 1970s to a decade average of 1.8 in the 2010s. Although this seems as a minor reduction, it can have severe consequences on not only the Rio Grande hydrologic system, but in ecosystems and human populations in the area. In the case of precipitation, there was no rebound detected. Although it yielded not changes between 1980s and 1990s and 2000s and 2010s, the data had a declining trend overall. This negative trend does not follow the trend from flow data. Figure 3 shows the precipitation trend from 1970s to the 2010s.

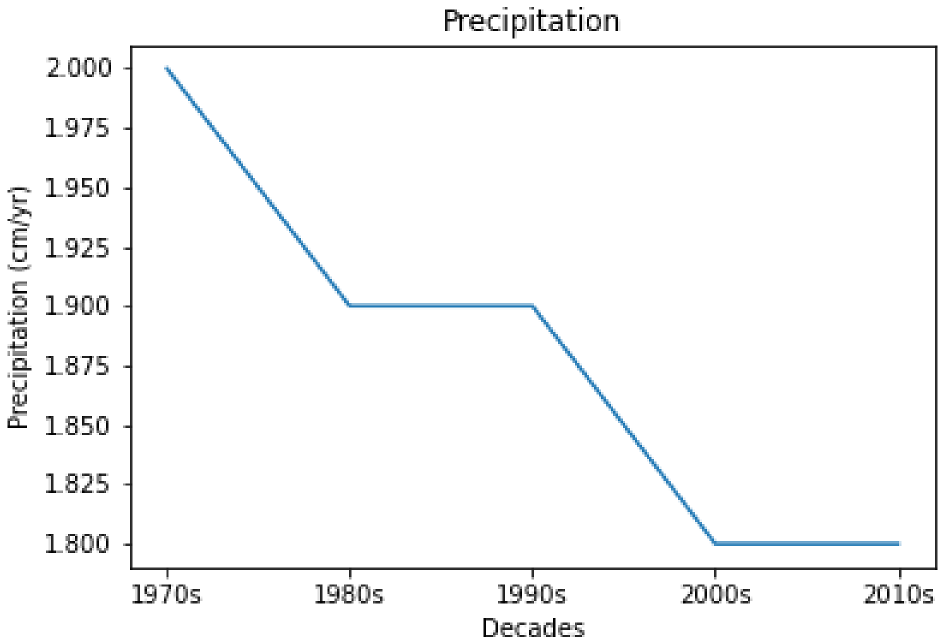

Figure 3.- Plotted graph showing the trend in precipitation through the decades.

5. Discussion

Statistical analysis yielded an overall downward trend for both the flow and sediment data. This same patter was visible when the datasets were organized and analyzed by decades. Although they increased their average at some point during their history, the main trend was a reduction on their levels. Precipitation data also yielded a downward trend from the 1970s to the 2010s. But, while sediment and flow data experiences isolated events of upward trend, precipitation did not exhibit a similar pattern; it kept the same downward trend overall. It is important to mentioned that between 1980s-1990s and 2000s and 2010s precipitation seems to remain stable at the same decade average.

When precipitation data was compared to flow data, not apparent relation exists. At least, not important relation. As mentioned above, flow had a re-bound episode from the 1990s to 2000s, and precipitation never experienced a similar event. Additionally, the changes in precipitation from 1997s to 2010s were of only ~10%, from a 1970s average of 2.0 to an average in the 2010s of 1.8. It would be hard to attribute the reduction in flow to this decrease in precipitation, but further research on other areas, such as changes in land use is necessary. Table 1 summarizes the changes occurred in all three categories in each decade.

After careful analysis of the results obtained in this brief study, it can be concluded with a strong confidence that humans are playing a major role in changing the conditions in the Rio Grande Delta. Both directly though the construction of dams and other structures and indirectly through climate change and reduction in precipitation levels.

Table 1. Summary of statistical analysis of sediment, flow, and precipitation data.

River Data

	DecadesSSC	DecadesFlow	DecadesRain
1970s	298	66.0	2.0
1980s	307	19.0	1.9
1990s	63	11.0	1.9
2000s	57	20.0	1.8
2010s	46	0.0	1.8

% River Data:

	DecadesSSC	DecadesFlow	DecadesRain
1970s	-0.029316	2.473684	0.052632
1980s	3.873016	0.727273	0.000000
1990s	0.105263	-0.450000	0.055556
2000s	0.239130	inf	0.000000
2010s	NaN	NaN	NaN

6. Conclusion

The result obtained in this research serve to support the notion that human activity has had an important impact on crucial conditions in the Rio Grande delta such as water discharge and sediment budgets. The initial hypothesis is correct; human activity has in fact change the conditions in the region. Comparisons between flow and precipitation data helped create a better understanding of the real impact humans are having on the river. Although precipitation decreased from the 1970s to the 2010s, the change was nor significant enough and did not follow the same trend in flow data to be considered the major force affecting water discharge levels in the Rio Grande delta. But it still needs to be taken seriously. The Rio Grande Valley is located in a semi-arid region and any changes in precipitation can have severe consequences on the river itself, natural habitats, and our communities.

This research serves as proof that humans are the major factor in the reduction of flow and sediment reaching the mouth of the river. Also, they can be considered the major force in changing precipitation patterns, which as a secondary outcome can also add to the already alarming situation in the Rio Grande delta. These results should help increase awareness of the damage that dams and diversion are causing to the Rio Grande delta. Unfortunately, this same situation is happening on deltas all over the world. Dams have become a major force changing the natural water cycles of rivers and their deltas.

Code Appendix

Pakages:

- import pandas as pd
- import numpy as np
- import matplotlib.pyplot as plt
- import csv
- import statistics
- from statistics import mean
- from scipy import stats
- import matplotlib.animation as ani
- from pylab import rcParams
- import cartopy.crs as ccrs
- import cartopy.feature as cfeature
- from cartopy import config
- from cartopy.io import shapereader

Statistical Functions:

- .mean()
- .std()
- .var()

- RiverDataFrame = pd.DataFrame(data=river_decadesdf)

```
print("Dataset Values:")
print(RiverDataFrame)

statistics = RiverDataFrame.describe();

print("Descriptive statistics for River Data:")
print(statistics)
```

- print(river_decadesdf);

```
print("% River Data:")
decades = river_decadesdf.pct_change(periods=-1);

print(decades);
plt.plot(decades)
```

- Rain_trend = stats.linregress(RainData.index, RainData["Precipitation"])

```
Rain_trend
```

- Flow_trend = stats.linregress(NewRiverData.index, NewRiverData["Flow"])

```
Flow_trend
```

- SSC_trend = stats.linregress(NewRiverData.index, NewRiverData["SSC"])

```
SSC_trend
```

Organizational Functions:

- river_decadesdf=pd.DataFrame(decades)

```
river_decadesdf
river_decadesdf=river_decadesdf.fillna(0)
river_decadesdf
```

*Loop functions 1 and 2 helped me divide my data by decades

```
1.-def SSC_decades(mydata, istart):
     a=dec_avg=mydata.iloc[istart:istart+9,0]
     b=dec_avg=mydata.iloc[istart:istart+10,0]
```

```
    if istart == 2:
        return round(np.std(a),1)

    else:
        return round(mean(b),1)

2.-def flow_decades(mydata, istart):
    a=dec_avg=mydata.iloc[istart:istart+9,1]
    b=dec_avg=mydata.iloc[istart:istart+10,1]

    if istart == 2:
        return round(mean(a),1)

    else:
        return round(mean(b),1)
```

*I used this code to create a table with all my results

```
decades={'DecadesSSC':{'1970s':298,'1980s':307,'1990s':63,'2000s':57,'2010s':46},
         'DecadesFlow':{'1970s':66,'1980s':19,'1990s':11,'2000s':20}}

river_decadesdf=pd.DataFrame(decades)
river_decadesdf
river_decadesdf=river_decadesdf.fillna(0)
river_decadesdf
```

Map Creation:

```
plt.figure(figsize=(12, 9))

ax = plt.axes(projection=ccrs.PlateCarree())
plt.title('RGDelta')
ax.set_extent([-80,-115,35,15], ccrs.PlateCarree())
ax.coastlines(resolution='110m')
ax.gridlines(color='black')

ax.add_feature(cfeature.OCEAN)
ax.add_feature(cfeature.LAND)
ax.add_feature(cfeature.LAKES)
ax.add_feature(cfeature.BORDERS)
ax.add_feature(cfeature.COASTLINE)
ax.add_feature(cfeature.RIVERS)


plt.plot(-97.5110, 25.9815, markersize=10, marker='o', color='red')
```

```
plt.text(-97.5110, 26.2815, 'Delta', horizontalalignment='right',
transform=ccrs.PlateCarree())
plt.savefig('delta.png')
plt.show()
```

References

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