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An Overview on Geographic Information System (GIS) Application in Environmental Management, Case Study: Algae Growth Assessment in Tampa Bay

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ABSTRACT ─ Today's world is the world of information and its optimal management. Since major parts of the decisions adopted by managers and urban planners at a regional macro level are somehow related to a specific situation with a location-source nature, the existence of precise, reliable and timely geographical information and its optimal management is necessary; Therefore there are no other options than using novel mechanized tools and technologies such as Geographic Information System (GIS) for their purpose. GIS enables environmental planners and decision makers for a time-efficient and cost-effective analyses. One of the most important parts of water and environmental management is quality studies of water resources such as rivers, estuaries, lakes, etc. In quality discussions of lakes and bays, the phenomenon of algal growth is of particular importance. Here, Tampa bay which is the part of the Gulf of Mexico and adjacent to the State of Florida is selected as the study area. By GIS tool, investigating different water quality parameters such as dissolved oxygen and nitrate revealed that the parts of this bay which are close to Bullfrog Creek-Wolf region have the highest susceptibility to algal growth. Also industrial pollution adds nitrate and phosphate in addition to other chemicals to water, which increases bays temperature.
KEYWORDS: *Geographic Information Systems (GIS), Environment, Tampa Bay, Algae*

Introduction

Effect of human on the environment is increasingly caused by the effects of urban life, which is itself due to human population growth and dominance of technology on human life. One of the widespread urban problems is environmental issues. A quick look at the situation of the environment in the last two decades shows that despite recent sensitivities on the environment, not only have human destructive effects not been reduced, but also acute and challenging issues such as severe atmospheric pollution, contamination of water resources and their multiple effects have been causing [1]. Many decisions in construction and environmental projects are somehow related to a specific geographical location and situation. Thus, the existence of an intelligent GIS can largely help managers to make optimal decisions. Geographic Information System (GIS) is used in many sciences and its application is increasingly expanding. Among the research on the use of GIS in environmental management issues is the study of Jensen and Christensen (1986), in which this tool was used for identifying potential locations of waste disposal. Also one of the first studies which was conducted using GIS was by Keyer et al. (1993), which aimed to zone areas suitable for waste disposal [2]. Since then, this tool has been extensively used in treatment installations (Gemitzi et al, 2007) [3] and water tanks (Al Adamet et al., 2010) [4].Quality studies of water resources such as rivers, lakes, estuaries, etc. are among the most important parts of water and environmental management. The phenomenon of algal growth has particular importance in the quality discussion of lakes and bays. Various factors influence occurrence of this phenomenon with different results occurring afterwards. Nutrients which enter the water resources from the upstream rivers are one of the major causes of this phenomenon. Tampa Bay is selected for conducting the present research because it has the best available data and also limited geographical scope of the study. Moreover, no extensive environmental studies relating to algal growth have been conducted there. Tampa Bay is an estuary as a part of the Gulf of Mexico, which is located on the west coast of Florida. In Florida, this area is known as an important water region, which is covered by agricultural and industrial areas. Accordingly, it is influenced by the phenomenon of algal growth that causes of dissolved oxygen loss of water. This issue would eventually lead to many problems including loss of animal life. Because of these difficulties, this gulf has been studied since a long time ago. Human intervention has led to entry of nutrients into water, such as phosphate and nitrate. Increasing growth in concentration of nutrients in the water along with the growth of other water quality parameters such as water temperature and pH has led to excessive algal growth in aquatic environments [5]. Morrison et al. (2011) conducted studies on environmental issues of Tampa Bay and concluded that, since 1970s, environmental conditions were improving in the bay owing to: 1- Modeling the existing data using experimental and mathematical models and data monitoring stations, 2- Improving cultural conditions of people around the bay as a result of controlling pollutants and fishing, 3- Mutual cooperation of various governmental and private companies in terms of performing projects such as flood treatment, fertilizer management on agricultural land, shipping, etc., 4- Developing rules related to different standards such as wastewater treatment [5]. Stidinger (2009) studied historical background of growth and blooming of algae in Gulf of Mexico along with their harmful effects and optimal management [6]. Sharmad and Al-e Sheikh (2007) used GIS to extract distribution maps of pH, temperature, dissolved oxygen and heavy metals (such as cobalt and cadmium) of Chabahar Bay and a part of the Sea of Oman. Measurement results of physical parameters of water, salinity and pH indicated that these factors were higher in the bay than the sea [7]. In 2000, Mu et al. studied oil region of Svalbard in Norway and used GIS to investigate the susceptibility of oil application and analyze its effectiveness and susceptibility. In this study, a simple mathematical model was developed to describe the extraction conditions. Based on various physical and biological factors, this model used Geographic Information System (GIS) for analyzing vulnerability and susceptibility of the habitats [8]. The purpose of this study was to identify vulnerable areas to algal growth using nutrient load data along with other factors such as water temperature and pH selected for an aquatic sample in GIS environment. Also, the relationship between concentration of nutrients and vegetation of the area was investigated.

2. Data collection

To find catchment of this bay, information system of catchment boundaries related to Florida was acquired from the website "Natural Resource Conservation" [9]. Then, it was used to determine the studied catchment. Also, National Hydrography Dataset existing in "NHDPLUS" website was applied for obtaining line of Florida surface flows [10]. The information related to nutrients, temperature and pH which was used in this research was obtained from "USGS[1]" website, the part related to comprehensive studies of Gulf of Mexico [11]. This investigation contained information about nutrients of different stations which was obtained throughout different years from different parts of the gulf. Unfortunately, this information has not been extracted from equal stations. Only 29 out of 429 available stations had updated information, which were used for this study [12, 13].

3. Data analysis

Formation of the bay catchment: The first step was to obtain the catchment boundary data of Florida from website of Natural Resource Conservation Center [9]. This catchment was inserted to "Arcmap" environment, in which the coordinate system of "GCS North American 1983" was used for the spatial adjustment. Using these data, catchment of this gulf was determined using "Attribute table" in graphical environment of GIS. Fig. 1 shows catchment of Tampa Bay along with its sub-catchment and their names that are clearly marked in green. These extra catchments were used in the figure since USGS had used them as catchment in the case study of this area.

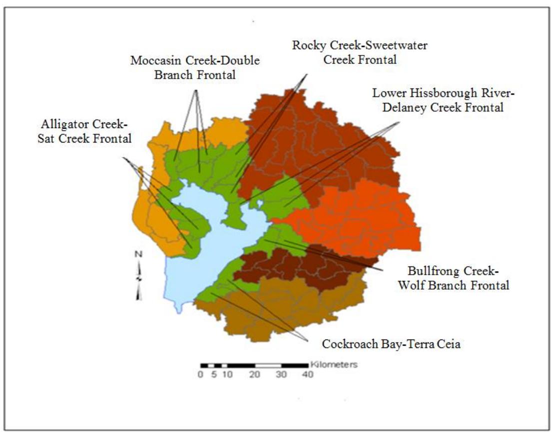

Figure 1. View of the sub-catchments

4. Organizing the data

Two important information systems were extracted from the case study "USGS Integrated Science Tampa Bay". The first one was location of observation stations and the second one was qualitative measurements in the same stations. Observation stations: Information of the stations obtained from USGS website was as "Shapefile" and in "Excel spreadsheet". Attempts were made to use Shapefile in GIS; but, because there were no data in geographic coordinate system, the Excel file was used. In this file, coordinate of the data was converted from geometric into geographic. Then, the data were transferred to Import software. In the next stage, the data were converted into "export<< Feature class" export for the evaluation. Location of all the observation stations

[1] *U.S. Geological Survey*

was determined in this catchment. To meet the purposes of this project, the stations in the bay itself were required; thus, the rest were removed. For this purpose, “Select by location << Arcmap” was used and the stations located in the bay sub-catchment were selected. These stations were exported as a new Feature and placed as a new layer Arcmap. Unfortunately, all the stations specified in the bay were not applicable because most of the data were related to years 1960, 70, 80 and 90. To determine the stations since 2003, each website was checked in the spreadsheet and the ones with more updated information were selected. Fig. 2 represents the finally selected stations.

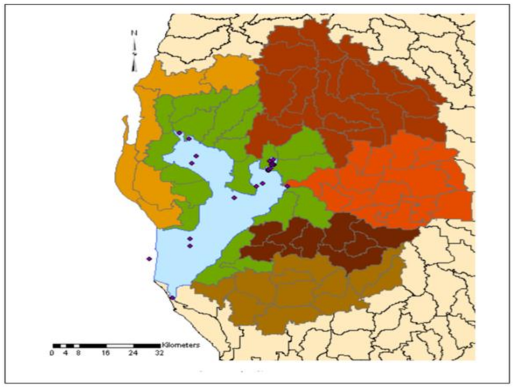

Figure 2. View of the stations used in the project

5. Water quality data

The quality parameters investigated in this research included: 1- temperature, 2- pH, 3- dissolved oxygen, 4- nitrate concentration and 5- phosphate concentration. The mentioned quality information was obtained from “USGS Tampa study” as spreadsheet [12]. To isolate the required data and to find out which stations had all the required information, a new spreadsheet was constructed. The only communication link in spreadsheet of quality data and that of observation stations was “Site number”. The number of the observation stations was taken from Fig. 2 and referred to in spreadsheet of quality data. Afterward, date of data measurement was received and investigated in terms of being updated. Their coordinates were then retrieved from the observation stations and added to the spreadsheet. Finally, the attributes were add to "monitoring sites point feature class" in “ArcCatalog” and “Editor Toolbar” was used to transfer all water quality parameters to “Attribute table <<feature class”. After modifying the input data, tools of Arcmap were used for making models of the bay data. “Spatial Analyst” is the first tool that is used in GIS environment: "Spatial "Analyst>> Interpolate >> to Raster”. The selected model differs according to users' views and depending on the circumstances. In this study, Spline interpolation was used for producing Raster for all the quality parameters, except for dissolved oxygen for which “Kriging” was used. Fig. 3 shows results of using this tool.

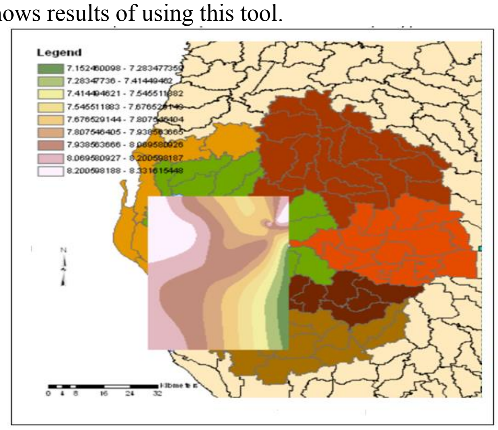

Figure 3. Spline interpolation for PH

As shown in Fig. 3, the pattern used by this interpolation could not be easily identified because it was a rectangle and exceeded the bay boundary. To solve the problem, Mask command could be used to cut that part of the interpolation, which was within the studied area. The result can be seen in Fig. 4.

5.1. PH: Fig. 4 shows final results of water pH. Unfortunately, this representation is not very promising because perfect environment for algal growth is between pH of 7.4 and 8.5; as can be seen in Fig. 7, changes of this parameter were approximately placed in the same range in the entire bay; thus, its entire surface was prone to algal growth. A similar process was also observed for other parameters of the bay.

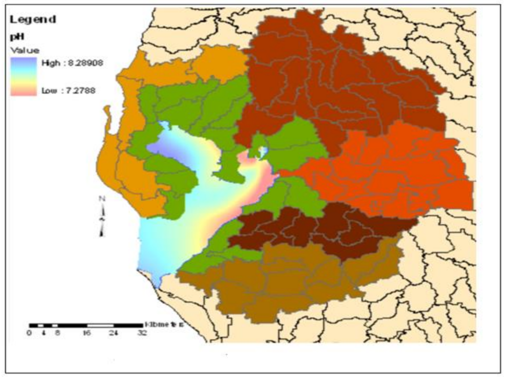

Figure 4. Mask tool on the Spline interpolation for pH

5.2. Water temperature: Algae have more tendencies to grow in waters with higher temperature, which shows the importance of this parameter. Fig. 5 demonstrates that water temperature ranged from 16 to 31°C in the lake. Also, three points of the bay had higher temperature than the rest of the bay. These areas were near the sub-catchments of: 1- Cockroach Bay-Terra Ceia Bay Frontal, 2- Bullfrog Creek-Wolf Branch Frontal, and 3- Rocky Creek-Sweetwater Creek Frontal.

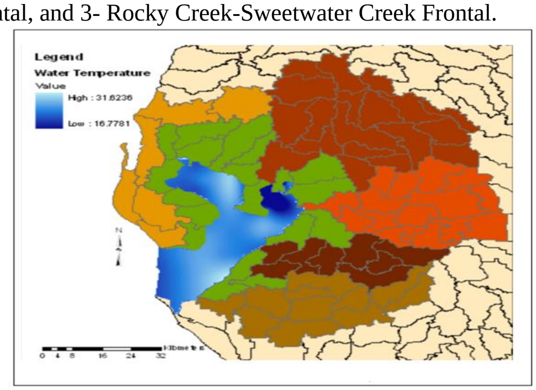

Figure 5. View of water temperature of the bay (°C)

5. 3. Nitrate: Fig. 6 clearly shows nitrate concentration pattern so that, in areas close to Bullfrog Creek-Wolf coast (this region is marked in green in Fig. 6), there was higher nitrate concentration. As algae have better growth in environments with higher nitrate concentration, the figure suggests that these areas were more vulnerable to this phenomenon. The flow lines are also shown in the figure in order to identify and evaluate the catchments with a more effective role while analyzing nitrate and phosphate.

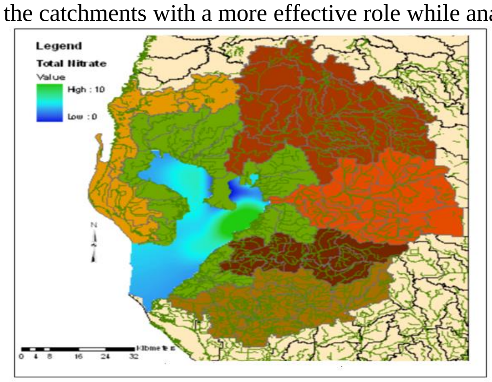

Figure 6. Nitrate concentration in the bay (mg/L)

5.4. Phosphate: It is clear in Fig. 7 that, similar to the phenomenon of nitrate in Fig. 6, some parts of the bay had higher concentration of phosphate, the most important of which was Bullfrog Creek-Wolf that was more vulnerable to algal growth. In this area, phosphate concentration increased up to 10 mg/L.

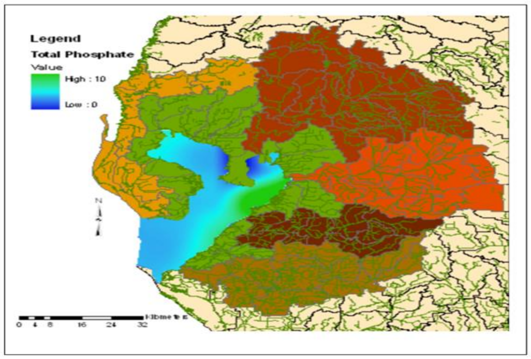

Figure 7. Phosphate concentration in the bay (mg/L)

5. 5. Dissolved oxygen: Dissolved oxygen is one of the most important parameters because growth of algae in water reduces the amount of dissolved oxygen and thus may lead to loss of its animal life. As can be seen in Fig. 8, low concentration of dissolved oxygen was repeated in the previous areas in Figs. 6 and 7. This model can represent growth of algae at this time according to the measurement resulting from high consumption of nitrate and phosphate in this area. Considering growth phenomenon of phosphate and nitrate and according to Fig. 8, minimum amount of dissolved oxygen was in Bullfrog Creek-Wolf area.

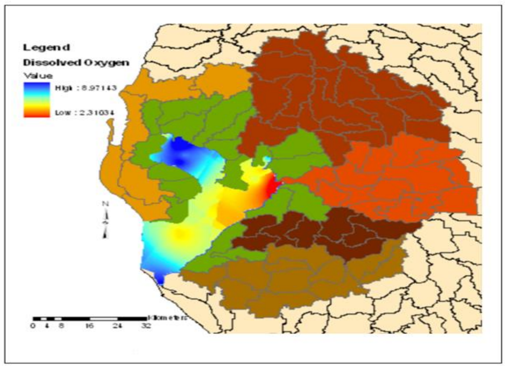

Figure 8. Concentration of dissolved oxygen (mg/L)

6. Land uses around bay

The land coverage data for whole area around bay is enormous and its analysis is so complicated. Also, it is difficult to distinguish between different uses if we use all the data.

Therefore it was decided that only part of the area which is the most critical areas to be investigated. It is BullfrogCreek-Wolf Branch Frontal.

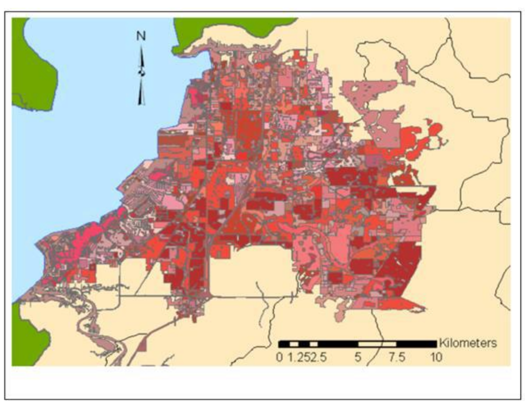

Figure 9 .Land use on the east part of the bay

Because of enormous information, we couldn’t understand correctly from Figure 9. Therefore, those land uses are selected that have most effect on producing nitrate in this area.

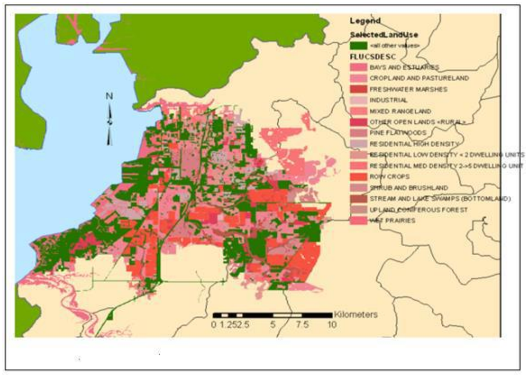

Fig-10 selected uses

Land use in Figure 10 states the factor that has greatest impact in concentrating nitrate. As shown above figure, most of this area includes below uses:

1. Pasture/farmland
2. Industry
3. Residence

Activities conducted in this region can import a lot nitrate in water. These activities include:

1. Fertilization of agricultural land
2. Detergents use
3. Industrial waste

Conclusion

Comparing different interpolations and the obtained results, it is clear that some parts of the bay that were close to Bullfrog Creek-Wolf had the highest vulnerability to algal growth. This result can be observed by comparing different quality parameters that affect growth of algae. Using the obtained results, cause of high density of algae in some areas can be understood and some preventive solutions can be applied. Low concentration of dissolved oxygen near Bullfrog Creek-Wolf states that algae probably exist when measuring the stations and thus time of measurement can be found because algae start to consume oxygen at night. Identifying polluting sources is also important for recognizing impact of pollution on the environment. In this case study, vegetation of the area at least helped to consider the possibility of contamination sources of the area. These polluting sources not only cause water pollution but also greatly raise water temperature. Industrial pollution adds nitrate and phosphate in addition to other chemicals to water, which increases its temperature.

Recommendations

According to the results, the following recommendations can be made:

1. Investigating unusual and direct relationship of dissolved oxygen with temperature in the bay considering that they are typically inversely related according to the majority of references.

2. Studying optimal management method of factories and industries around the bay in order to reduce waste entry into the bay, such as using advanced waste treatment systems (like nano-membranes, parallel multiple filters, etc.) in the wastewater outlet of industries to the bay.

3. Subsurface water measurement to investigate height of cliffs at the bottom of the bay and evaluate effect of their height on algal growth by GIS.

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