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Article

Analysis of the behavior of the seafloor of the mouth of the Grijalva river, Tabasco in the years 2012, 2017 and 2021

Análisis del comportamiento del fondo marino de la desembocadura del río Grijalva, Tabasco en los años 2012, 2017 y 2021

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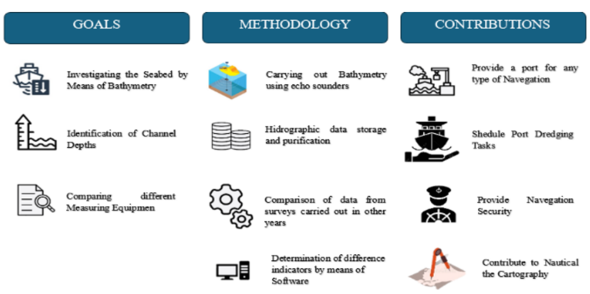
Abstract

Bathymetric surfaces created from bathymetric data obtained by Hydrographic Survey Brigades allow the representation of the relief of the seabed of a specific area and thus perform the analysis of its behavior. Therefore, the main objective is to characterize the seabed of the mouth of the Grijalva Tabasco River, by means of the difference surfaces and the TIN Model, and thus make a comparison between them, defining their variability as a result of sedimentation. The bathymetries of the hydrographic surveys that were considered for the study were those carried out in 2012 with the R2Sonic multi-beam echosounder, in 2021 with the Hydrotrac II ODOM single-beam echosounder and in 2021 with the Geoswathplus Compact multibeam echosounder, processing the data obtained with the hydrographic programs Caris Base Editor 5.5 and Hypack Software version 17.0 2021, obtaining the bathymetric surfaces of each year mentioned. The results obtained are that there are areas in the lateral parts of the mouth with a higher concentration of sediment, forming a coastal bar 2,500 m long by 612 m wide that reduces the depth to 1.8 m. In addition, it was determined that the period of greatest presence of rain and drag of material was the month of May to November. The above allows the implementation of actions to guarantee the safety of navigation of those larger vessels that sail towards the port of Frontera Tabasco.



Bathymetric surfaces, Depth, Sedimentation

Resumen

Las superficies batimétricas creadas a partir de datos batimétricos obtenidos por las Brigadas de levantamientos Hidrográficos permiten representar el relieve del fondo marino de un área específica y así realizar el análisis del comportamiento de este. Por ello el objetivo principal es caracterizar el fondo marino de la desembocadura del río Grijalva Tabasco, por medio de las superficies de diferencias y Modelo TIN, y así realizar una comparación entre ellas, definiendo su variabilidad por consecuencia de la sedimentación. Las batimetrías de los levantamientos hidrográficos que se consideraron para el estudio fueron las efectuadas en el año 2012 con el ecosonda multihaz R2Sonic, del 2021 con ecosonda monohaz Hydrotrac II ODOM y del año 2021 con la ecosonda Multihaz Geoswathplus Compact, procesándose los datos obtenidos con los programas hidrográficos Caris Base Editor 5.5 y Software Hypack versión 17.0 2021, obteniéndose las superficies batimétricas de cada año mencionado. Los resultados obtenidos es que existen áreas en las partes laterales de la desembocadura con una concentración mayor de sedimento, formando una barra litoral de 2500 m de largo por 612 m de ancho que reduce la profundidad hasta 1.8 m. Además, se determinó que el periodo de mayor presencia de lluvia y arrastre de material fue el mes de mayo a noviembre. Lo anterior permite la implementación de acciones para garantizar la seguridad de la navegación de aquellas embarcaciones de mayor porte que navegan hacia el puerto de Frontera Tabasco.

Superficies batimétricas, Profundidad, Sedimentación

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Introduction

Bathymetry is limited to the study of ocean depth. In the topographic-hydrographic field it relates to surveys of underwater surfaces. In the field, the surveyor focuses on obtaining heights; in the bathymetric survey, depths are acquired. The purpose of bathymetry is to obtain the XYZ coordinates of points on the seabed. Depth identification is called sounding and consists of calculating the vertical distance between the bottom surface and the specified water level (Ballestero and García, 2010).

A river is defined as a watercourse that is fed from various sources, such as rainfall, land runoff or snowmelt, and flows from its source to its mouth in the sea, lake or other body of water. It is worth mentioning that it is in its final part where the river sediments the materials dragged in the basin (Valdivielso, 2022).

Basile (2018) in his book 'Sediment transport and morphodynamics of alluvial rivers' defines this concept as the granular solid material found in the bed of a river, basin, lake or coast which has been transported and deposited by the action of marine currents or other transport methods throughout its morphological evolution.

Silt is a deposit of sediment, which is carried by water and accumulated in riverbeds, dams, underground reservoirs, wetlands, lagoons, estuaries, navigation channels, harbours, etc., is called silt. The cause of siltation is a decrease in the velocity of the current and a corresponding decrease in the amount and size of solid material that can be carried in suspension. Thus, siltation is the phenomenon in which sediment accumulates and results in the transformation of the environment (Carbajal, 2014).

Among the equipment used for the hydrographic surveys were: the R2Sonic Multibeam echo sounder, Hydrotrac II single-beam echo sounder and the Geoswathplus Compact 250 KHz interferometric Multibeam echo sounder.

The data acquired by means of this equipment provides a bathymetric surface with a resolution of even less than one metre, resulting in a high-resolution configuration of the seabed.

The single beam echo sounder, this type of electronic instrument has a transducer that generates a single acoustic pulse (all the acoustic energy transmitted is confined to a single beam that has a shape similar to a cone) that reaches the seafloor, so it is not possible to obtain 100% coverage of the bottom, being necessary to make lines at a certain distance without being able to know what is between them (sectors without information) (Ballestero, 2010).

The use of multibeam echo sounders for bathymetry has become the most developed and accurate technology available today. This system, which complies with the International Hydrographic Organisation (IHO) standards, provides accurate and complete knowledge of the depth and morphology of the seabed. This Multibeam system consists of a set of sounders that emit several narrow beams of sound in different directions, arranged in a fan-shaped pattern that sweep transversely in the direction in which the vessel is moving (Basile, 2018).

The data acquired by means of this equipment provides a bathymetric surface with a resolution of even less than one metre, resulting in a high-resolution configuration of the seabed. Speaking specifically of ports that are located on the banks of a river, one of their greatest obstacles is fluvial sedimentation, a process that originates from erosion and sediment movement, which produces the deposition of particles, their compaction and consolidation (Arreguín, Preciado, Val and Arganis, 2021).

One of the elements that enable the functionality of ports is the access or navigation channel, the path that safely guides vessels on their arrival, for which it must have sufficient depth and width to guarantee manoeuvres (Rosas, 2012).

Among its characteristics as a fiscal dock for the arrival and protection of vessels, it has a length of 300 m long, 15 m wide, 2.4 m high and an average depth of 6 m (Secretaría de Marina, 2022).

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Figure 1 shows the facilities of the port of Frontera in the state of Tabasco, one of the main ports on the banks of the Grijalva River, which has the potential to increase national maritime development and become the hub of support services for oil platforms on the coast of the state of Tabasco, as well as the promoter of coastal and riverine development. Its focus is the oil and fishing industry, managing diverse activities such as the embarkation of passengers and materials to the platforms in the Gulf of Mexico, berthing of vessels and sale of services (Gobierno del estado de Tabasco, 2022).

Box 1

Figure 1
Inner dock of the port of Frontera Tabasco

Source: https://www.apitab.com.mx

In accordance with the above, the case of the Grijalva river basin is mentioned, located in the Mexican Southeast (SE) with a large coverage in the states of Chiapas and Tabasco, one of its main ports being the city of Frontera, located on its banks, approximately 10 kilometres (km) from its mouth. As a relevant fact, the depth at the mouth and the navigation channel of the Grijalva River is maintained by dredging, due to the silt generated by the combination of sediment input from the river and coastal dragging, leading to the formation of a bar (plug) with average depths that vary from 2.5 m to 3 m (Comisión de Planeación para el Desarrollo del Estado de Tabasco, 2019).

The Grijalva basin (Figure 2) has a surface area of about 58,025 ^{km2}; it comprises in Guatemala a little less than a tenth of its surface area and the rest continues in Mexico (Plascencia *et al*, 2014).

Its extreme geographical coordinates are between 89.6° to 94.5° W, and 15.3° to 18.7° N. It mainly encompasses the Mexican states of Chiapas and Tabasco (World Meteorological Organization, 2006).

This basin can be described in its simplest form as a high mountainous area (Guatemala and Chiapas) where water runoff begins and concentrates in a well-defined channel, which crosses the Northern Chiapas Mountains, receiving water from other tributaries and flows out towards the lower parts of the Tabasco plain, frequently flooding it, and finally flows into the Gulf of Mexico (Plascencia et al, 2014).

Box 2

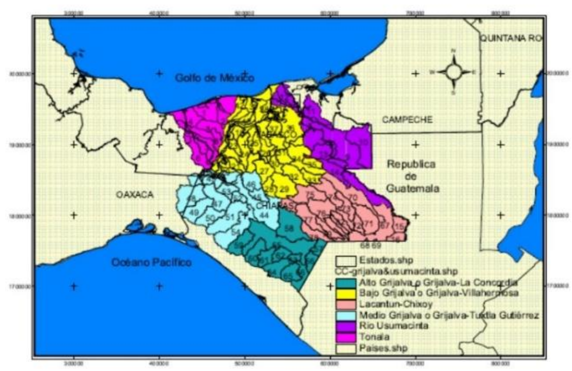

Figure 2
Division of the Grijalva basin

Source: Official Journal of the Federation (2010)

Methodology

This research was carried out by means of bathymetric data, acquired in accordance with the established bottom coverage standards (IHO, 2020) at the mouth of the Grijalva River, Tabasco in the years 2012, 2017 and 2021, with the R2Sonic, Hydrotrac II ODOM) and GeoSwath Plus Compact multibeam echo sounder where their technical specifications are detailed in Table 1.

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Box 3

Table 1

Specification System for the Konigsberg R2Sonic, Hydrotrac II ODOM and GeoSwath Plus Compact echo sounders

Features	**Echo sounders**		
	Hydrotrac II ODOM	**R2Sonic**	**GeoSwath Plus Compact**
Type	Monohaz	Multihaz	Multihaz
Frequency	Operator selectable via menu 24, 28, 33, 40, 100, 120, 200, 210 and 340 kHz	170 kHz-450 kHz & 700 kHz (optional)	250 kHz
Maximum depth below transducer		400m+**	100 m
Maximum sweep width	600 m o 1800ft.	100 m	390 m
Maximum coverage	-	-	Up to 12 times the depth
Resolution	ft/.01 m	-	3 mm
Width of the two beams (Horizontal)	-	10° to 160°	0.75 °
Pulse length	Positioning accuracy: 0.63 metres, CEP 50%. - 1.31 metres, 95%. - Typical dynamic accuracy 3 to 5 metres	15 μs-1115 μs	64 us a 448 uS
Maximum refresh rate	-	-	30 times per second (range dependent)
Transducer dimensions	368 mm x 419 mm x 203 mm	280 x 170 x 60 mm	360 x 352 x 150nn
Transducer weight	10.2 kg	2.4 kg	20 kg
Dimensions of the cover unit	-	480 x 109 x 190 mm	135 x 400 x 342 mm

Source: Konigsberg R2Sonic , Hydrotrac II ODOM and GeoSwath Plus Compact operating manuals

Initially, the Hypack 2021 programme in its version 1.21 was used to generate bathymetric surfaces for each epoch, consecutively and through one of the software tools called "TIN model" (Triangle Irregular Network), data processing was carried out to determine the volume of sediments.

The "TIN model" generates a type of vector-based digital geographic data that is constructed by triangulating a set of vertices (points). The vertices are connected with a series of edges to form a network of triangles. In other words, they connect three soundings to make a triangular "face" (Figure 3). The faces can then be used to represent a bathymetric surface detailing volumes created from these triangles.

Box 4

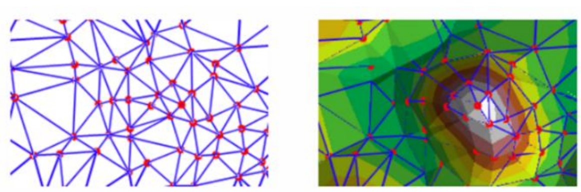

Figure 3
Creation of TIN models

Source: Hypack (2021)

The result after the creation of the TIN model (Figure 4), is the comparison between two bathymetric surfaces that overlap exactly, generating a report which, from the triangle network, determines the volume of sedimentation added and removed, in this case at the mouth of the Grijalva river at the manoeuvring dock of the port of Frontera, Tabasco.

Box 5

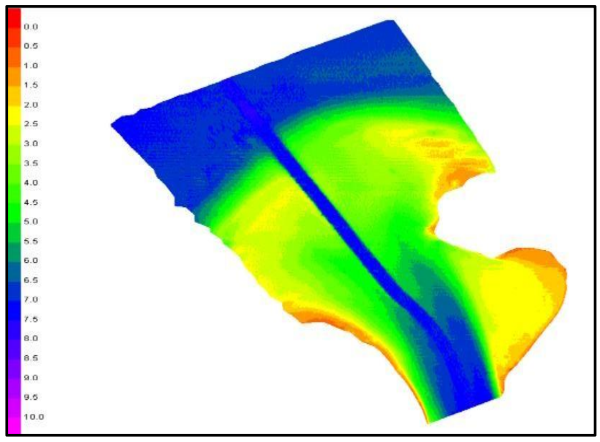

Figure 4
TIN model of the bathymetric data for the year 2021

Source: Hypack (2021)

On the other hand, with the CARIS Base Editor program, the bathymetric surfaces were generated from the same sounding data with which the TIN models were made in Hypack, with the intention of maintaining the same information used and to serve as a point of comparison. The bathymetric surfaces were generated through 'XYZ' files (Figure 5), which contain the information on coordinates and depths, using the WGS84 reference datum.

Box 6

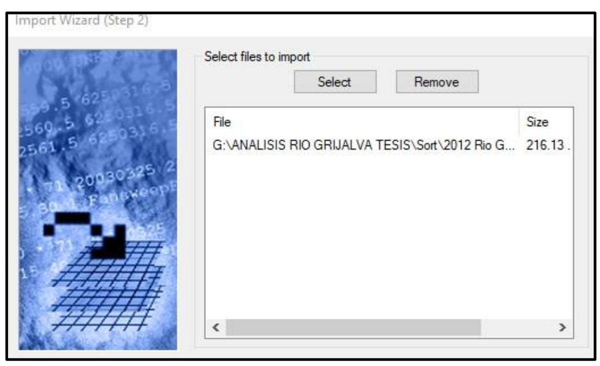

Figure 5
Data in XYZ format, loaded in the ImportWizard

Source: Own elaboration with Caris software Base Editor 5.5 module (2022)

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The subsequent result was a three-dimensional bathymetric surface (Figure 6) for each year (2010, 2018 and 2021), where details of the seabed can be seen, distributed uniformly and by colour, in order to obtain a clear idea of the configuration of the area in question.

Box 7

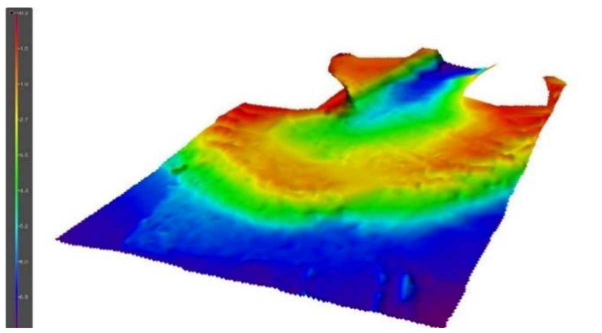

Figure 6
Grid-type base surface of the Grijalva river mouth in 2012

Source: Own elaboration with Caris software Base Editor 5.5 module (2022)

Once the bathymetric surfaces have been generated for each year, the CARIS Base Editor program has a tool called "coverage difference" which, by interpolating two surfaces, generates a third one, which is the result of the difference between the two surfaces.

Results

Caris module Base Editor 5.5

Difference surfaces

With the base surfaces described above, the Caris Base Editor 5.5 software module allows the creation of a difference surface, which is a tool for recognising variations in the seabed related to the depth of a given space. A 200 m x 200 m grid was superimposed for the establishment of reference points for the analysis of the difference surfaces, allowing a better comparison between the two established periods. In addition, the "Rainbow Map" colour palette was maintained, with negative values (red) indicating sediment accumulation and positive values (blue) highlighting areas of erosion. Finally, the study area was divided into three sections: the offshore part of the mouth, the central part and the upstream end.

In the case of the difference surface of the year 2012-2017 (Figure 7), 30 reference points were taken as a sample, selecting 15 points representative of the aforementioned sections, indicating the depth and the difference between them.

Box 8

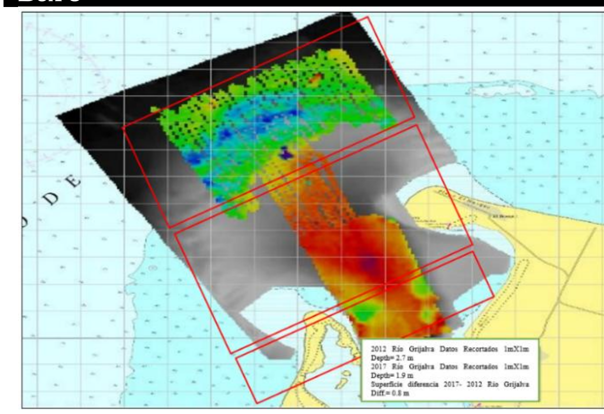

Figure 7
Area difference between the years 2012-2017

Source: Own elaboration with Caris software Base Editor 5.5 module (2022)

Analysing Figure 7, from the offshore part, we can see in blue and green a maximum increase in depth varying from 3.4 to 6.6 m (3.2 m difference) and a minimum increase from 2.4 to 3.8 m (1.4 m difference), i.e. the phenomenon of seabed erosion occurred in that area. As one moves towards the central part, a decrease in depth is observed, going from 4.2 to 3.8 m (0.4 m difference) as a minimum and from 5.8 to 4.8 m (1 m difference) as a maximum, this being due to the siltation present in the area. This phenomenon becomes constant towards the upstream part of the mouth, especially in the navigation channel, with a greater range in the decrease in depth from 2.7 to 1.9 m (0.8 m difference) as a minimum and from 4.3 to 3.3 m (1 m difference).

For the analysis of the difference surface of the year 2017-2021 (figure 8), 15 representative points were selected from 29 reference points, together with the depth data in the years 2017, 2021 and the difference between them.

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Box 9

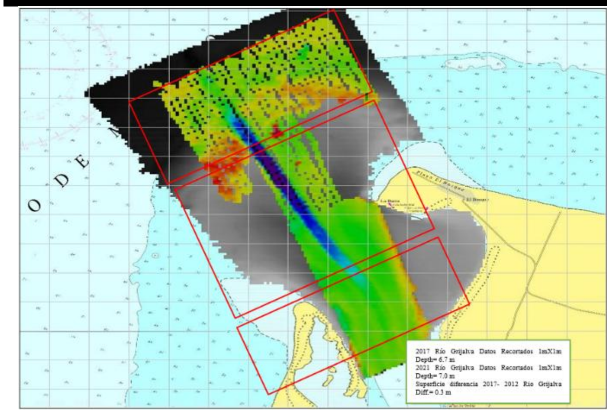

Figure 8
Difference area between the years 2017-2021

Source: Own elaboration with Caris software Base Editor 5.5 module (2022)

Analysing the previous figure and comparing it with Figure 9, a greater uniformity in the colour scale is observed, highlighting the green colour, indicating that the depth of the seabed remained constant; however, some orange areas stand out, revealing accumulation of sediment. Speaking of depths in the outer part, they varied from 6.4 to 7.4 m (1 m difference) as a maximum and from 5.9 to 6 m (0.1 difference) as a minimum; in other words, the seabed showed erosion in that part. However, if we move towards the central part of the mouth, we can clearly see the coastal bar that is beginning to form as a result of sedimentation, changing from 4.0 to 2.3 m (1.7 m difference) as a maximum and from 3.2 to 3.0 m (0.2 m difference) as a minimum. It should be noted that the bathymetry of the year 2021 is after the dredging of the Dutch company Van Oord in this area, therefore, it is not surprising that the part of the mouth upstream presents an increase in depth, going from 4.9 to 6.0 m (1.1 m difference) as a maximum and from 7.2 to 7.3 m (0.1 m difference) as a minimum. This difference surface shows the benefits of applying proper maintenance based dredging works.

Finally, a difference surface (Figure 9) was created between the years 2012 and 2021, showing a predominance of yellow and orange, i.e. the phenomenon of sedimentation prevailed in the study area, forming a kind of barrier with a tendency towards the eastern side of the mouth. In terms of depths, there was a decrease in average depth of 0.3 m in the area of the river, which was caused by the phenomenon of sedimentation.

Box 10

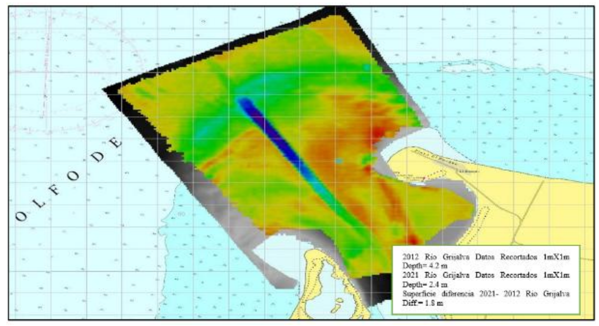

Figure 9
Area difference between the years 2012-2021

Source: Own elaboration with Caris software Base Editor 5.5 module (2022)

Hypack Version 2021

TIN models

Below are the TIN Models for the years 2012, 2017 and 2021, elaborated with the aforementioned programme, based on the information obtained by the Hydrographic Survey Brigades, using the bathymetric and positioning equipment described in the previous chapter. As a preamble, it should be mentioned that the input files were in XYZ format, as required by the system.

Figure 10 shows the TIN Model that was created using the 2012 bathymetric data in XYZ format as base files. For this model a colour scale was attached to reference the depths in a range of 0.0 to 10.0 m with a spacing of 0.5 m; the option to observe the isobaths was also selected.

Box 11

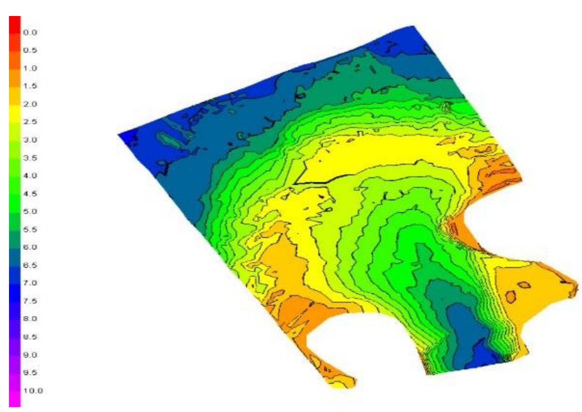

Figure 10
TIN model of bathymetric data for the year 2012
Source: Own elaboration in the Hypack Version 2021 (2022)

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Similarly, Figure 11 shows the TIN Model that was created using the bathymetric data of the year 2017 in XYZ format as base files. For this model, the same colour scale of the previous model in a range of 0.0 to 10.0 m was attached, in order to have the same reference in terms of depths.

Box 12

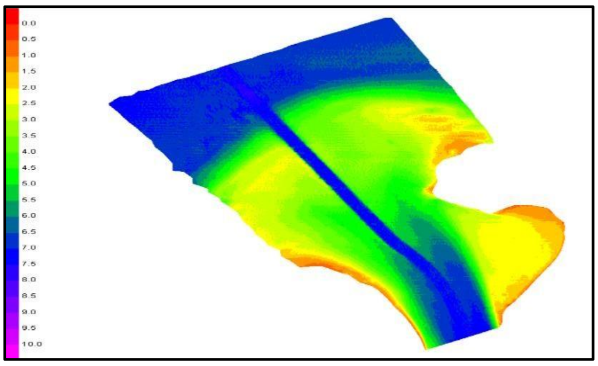

Figure 11
TIN model of bathymetric data for the year 2017

Source: Own elaboration in the Hypack Version 2021 (2022)

Finally, Figure 12 shows the TIN Model considering the bathymetry of the year 2021. The same characteristics annexed to the previous models were taken into account. It is worth mentioning that this model is defined by being elaborated with multibeam data, i.e. it has a large amount of bathymetric information that allows visualising how the seabed of the study area is constituted.

Box 13

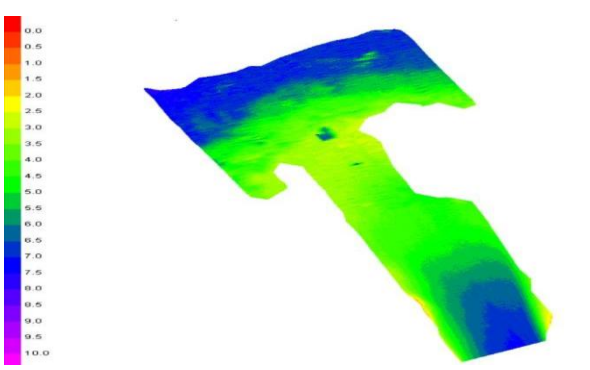

Figure 12
TIN model of bathymetric data for the year 2021

Source: Own elaboration in the Hypack Version 2021 (2022)

Calculation of TIN-to-Level volumes

According to the Hypack Version 2021 manual, for the volume calculation it is indicated that the Main File to be entered is the oldest or pre-dredging file and the Additional File should be the most recent or Post-dredging file.

Figure 13 shows the results obtained after the calculation of the TIN- a- LEVEL volume of the XYZ difference file for the years 2012 and 2017. Analysing the above Figure, we can state that the maximum difference detected was 5.13 m and the minimum was 1.61 m, with an average difference of 0.82 m. The number of triangles created for the TIN Model was 7,100,188. A sedimented area of 2,521,400.7 m2 and a gained volume of 3,320,165.6 m^3 was determined; the eroded area was 1,051,637.3 m^2 and a lost volume of 388,276.2 m^3; the calculation of the net sedimented volume yielded a result of 2,931,889.4 m^3. Considering that the sea surface area surveyed is 10,433,028.3 m^2, this indicates an average of 0.28 m^3 of sediment per m^2.

Furthermore, if we take into account the seasonality of the bathymetric data, we can deduce that in the study area an amount of 586,337.88 m^3 of sediment was deposited per year.

Box 14


```
TIN64 Versión Archivo 21.0.0.0
Archivo TIN : C:\HYPACK 2021\Projects\ANALISIS RIO GRIJALVA TESIS\Sort\2012-2017 DIFERENCIA RIO GRIJALVA.XYZ
Modo: Prof.
Alinear a LNW: No
Remover Triangulo Angosto: No

Tramo Max: 150.00
X Max: 532866.00
X Min: 530488.00
Y Max: 2060349.00
Y  Min: 2056498.00
Z Max: 1.61
Z Min: -5.13
Z Promedio: -0.82
Número Puntos: 3550095
Numero de Triangulos: 7100188

Totales Volumen TIN vs Nivel
Unidad Volumen: Metro Cubico
Archivo TIN: C:\HYPACK 2021\Projects\ANALISIS RIO GRIJALVA TESIS\Sort\2012-2017 DIFERENCIA RIO GRIJALVA.XYZ

Nivel   Volumen Sobre   Area Sobre     Volumen Debajo  Area Debajo
-----------------------------------------------------------------------
   0.00       3320165.6       2521400.7       388276.2       1051637.3
```

Figure 13
Results of the TIN-to-Level volume calculation between 2012 and 2017

Source: Own elaboration in Hypack Version 2021 (2022)

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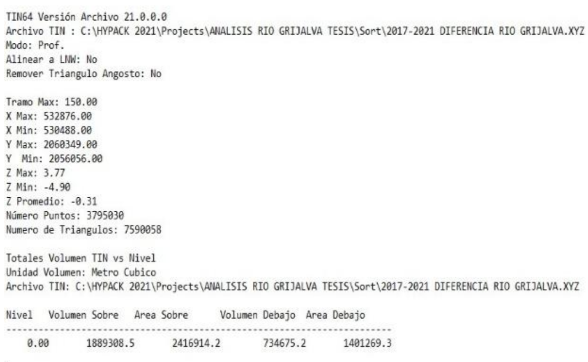
Figure 14 shows the results obtained after the calculation of the TIN-at-LEVEL volume from the XYZ difference file for the years 2017 and 2021. With the information shown, it is concluded that the maximum difference detected was 3.77 m and the minimum was 4.90, with a mean of 0.31 m.

The number of triangles created for the TIN Model was 7,590,058. A sedimented area of 2,416,914.2 m^2 and a gained volume of 1,889,308.5 m^3 was determined; the eroded area was 1,401,269.3 m^2 and a lost volume of 734,675.2 m^3; the calculation of the net sedimented volume yielded a result of 1,154,633.3 m^3.

With a study area of 10,433,028.3 m^2, an average of 0.11 m3 of sediment per m2 is obtained, which is much lower compared to the previous period; this can be related to the mm of accumulated rainfall and runoff in the basin, as well as other external factors such as marine currents, tides and wind, etc. Considering the temporality between the bathymetric data, it is deduced that in the study area an amount of 288,658.325 m^3 of sediment was accumulated per year.

Box 15



```
TIN64 Versión Archivo 21.0.0.0
Archivo TIN : C:\HYPACK 2021\Projects\ANALISIS RIO GRIJALVA TESIS\Sort\2017-2021 DIFERENCIA RIO GRIJALVA.XYZ
Modo: Prof.
Alinear a LNW: No
Remover Triangulo Angosto: No

Tramo Max: 150.00
X Max: 532876.00
X Min: 530488.00
Y Max: 2060349.00
Y  Min: 2056056.00
Z Max: 3.77
Z Min: -4.90
Z Promedio: -0.31
Número Puntos: 3795030
Numero de Triangulos: 7590058

Totales Volumen TIN vs Nivel
Unidad Volumen: Metro Cubico
Archivo TIN: C:\HYPACK 2021\Projects\ANALISIS RIO GRIJALVA TESIS\Sort\2017-2021 DIFERENCIA RIO GRIJALVA.XYZ

Nivel   Volumen Sobre   Area Sobre      Volumen Debajo  Area Debajo
--------------------------------------------------------------------
   0.00      1889308.5       2416914.2        734675.2       1401269.3
```

Figure 14
Results of the TIN-to-Level volume calculation between 2017 and 2021

Source: Own elaboration in Hypack Version 2021 (2022)

Conclusions

Through the analysis and processing of the bathymetric information obtained in the hydrographic surveys of 2012, 2017 and 2021, it can be concluded that there is a variation in depth as a result of sedimentation and precipitation in the basin.

However, it is important to mention that there are other external factors that intervene in the decrease in depth and that should be taken into account in future research, such as marine currents and periodic tidal movements. This was established by processing the bathymetric information in the hydrographic software Caris and Hypack, and the following was determined.

Firstly, using the hydrographic programme Caris Base Editor 5.5 module and the corresponding bathymetries, difference surfaces were created that allowed an adequate comparison of depths. For a more detailed analysis, control points were set up in both programmes to ensure a controlled and organised measurement. It was found that between 2012 and 2021 the study area showed constant sedimentation in the central part and upstream of the mouth, with the formation of a littoral barrier 2,500 m long by 600 m wide and a drastic decrease of the operational draught in certain areas of the access channel of up to one and a half metres. This dynamic of the seabed does not guarantee the safety of larger vessels that would allow for port development in Frontera.

Secondly, it was determined that the longest period in which there was the greatest volume of sediment was between 2012 and 2017, when it was calculated at 2,931,889.4 m3; this is related to the variable rainfall that was greater in the same period due to the large presence of meteorological phenomena.

Among the benefits of the Hypack programme is the creation of the TIN models of the XYZ difference files, which, based on a reference, made it possible to visually analyse the areas of the navigation channel where sedimentation forms sandbanks that represent a danger to ships. It was noted that, due to the geomorphology of the river delta and the marine currents, the material tends to be deposited on the left bank of the study area.

One of the problems encountered was the type of bathymetric data being compared. When using bathymetric data from 2012 and 2017, the data is considered to have gaps or blanks between the surveyed lines, therefore, maximum confidence in the results obtained was not guaranteed.

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Recommendations

In view of the above conclusions, a series of recommendations are described with which one of the specific objectives of the present investigation is fulfilled in view of the problem of siltation and change of depth at the mouth of the Grijalva river.

To ensure the use of Multibeam echo sounders in the subsequent hydrographic survey in the study area, which would guarantee more bathymetric information and a better analysis of the dynamics of the seabed. In addition, consideration should be given to the implementation of an Annual Hydrographic Survey Plan and Programme for the river delta in question, as this would allow to determine how the loss of depth is carried out and thus communicate the operational draft of the access channel to vessels.

Implementation of structures known as breakwaters on the sides of the mouth, which would prevent the participation of sea currents in the phenomenon of siltation, which is one of the variables that should be included when analysing the behaviour of the seabed in subsequent studies. This reinforcement at the entrance of the river would reduce the constant application of maintenance works and a saving for the port administrations at the moment of guaranteeing the operational draught of the area.

It is recommended to implement an adequate long-term dredging plan and programme prior to the construction of the breakwaters, which together with the Multibeam bathymetry, will guarantee that the depth in the access channel is adequate for navigation of larger vessels and therefore a notable increase in the activities registered by the port of Frontera, Tabasco.

That the three levels of government, private companies and academic institutions coordinate to carry out similar studies not only of the mouth, but of the entire Grijalva-Usumacinta river basin, since the process of the present investigation was halted on several occasions due to lack of information. This would allow for better quality in future research and, consequently, a more solid basis for finding the most viable and adequate solutions to the problem of siltation.

Conflict of interest

The authors declare that they have no conflicts of interest. There are no known competing economic interests or personal relationships that could have influenced the article reported in this paper.

Authors' contribution

The contribution of each researcher in each of the points developed in this research was defined based on:

Aguilar Ramírez, Ana María: Contributed to the project idea, method and research technique. She carried out the data analysis and wrote the article.

Domínguez González, Agustín: Systematised the background to the article. He supported the data cleaning and processing. He also contributed to the drafting of the article.

Utrera Zarate, Alberto: Contributed to the research design, the type of research and the approach.

Molina Navarro, Antonio: Worked on the determination of statistical data differences and systematisation of results. He also collaborated on the writing of the paper.

Availability of data and materials

The bathymetric survey data for the years 2012, 2017 and 2021 were provided by the Dirección General Adjunta de Oceanografía, Hidrografía y Meteorología (DIGAOHM) through the Dirección de Hidrografía belonging to the Secretaria de Marina, which together with the Instituto Oceanográfico del Golfo y Mar Caribe allowed the processing of this information.

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References

Basics

Gobierno del Estado de Tabasco. (2022). Administración Portuaria Integral de Tabasco. Obtenido de https://www.tabasco.gob.mx

Comité de Planeación para el Desarrollo del estado de Tabasco. (2019). Programa Institucional de la Administración Portuaria Integral Tabasco.

M. González Espinosa, & M. C. Brunel Manse, Montañas, pueblos y agua. Dimensiones y realidades de la cuenca Grijalva (págs. 29-79). Ciudad de México, México: Juan Pablos Editor.

Valdivielso, A. (2022). IAGUA.

Apitab (2024) obtenido de https://www.apitab.com.mx/

Soporte

Hypack. 2021. Hypack. Obtenido de https://www.Manual de software Hypack y Hysweep (Acceso el 17 de junio de OHI. 2020. "Normas de la OHI para los Levantamientos Hidrográficos publicación S-44". Mónaco Bureau Hidrográfico Internacional.

Secretaría de Marina. (2022). Frontera, Tabasco. DIGAOHM, Hidrografía.

Ballestero Mora, L., & García Sala, D. (2010). Estudio batimétrico con ecosonda multihaz y clasificación de fondos. Universidad Politécnica de Catalunya. Escola Politécnica Superior d' Edificación de Barcelona, Barcelona, España.

Differences

Organización Meteorológica Mundial. (2006). Gestión Integrada de Crecientes-Caso de estudio- México: Rio Grijalva. Programa Asociado de Gestión de Crecientes.

Rosas Carrillo, E. G. (2012). Dragado en puertos mexicanos. Dragado en puertos mexicanos.

Discussions

Basile, P. A. (2018). Transporte de sedimentos y morfodinámica de ríos aluviales. Rosario: UNR Editora. Editorial de la Universidad Nacional de Rosario

Plascencia Vargas, H., González Espinosa, M., Ramírez Marcial, N., Álvarez Solís, D., & Musálem Castillejos, K. (2014). Características físico-bióticas de la cuenca del Río Grijalva.

Carbajal Evaristo. 2014. "Evaluación del impacto del azolvamiento en La Laguna Cerritos a partir de la canalización del Río Cintalapa Vol. 1 P. 8-116.

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