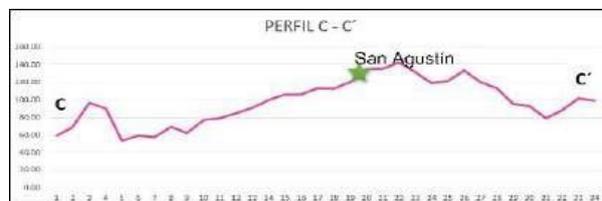
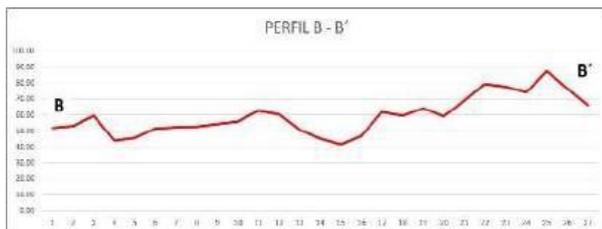
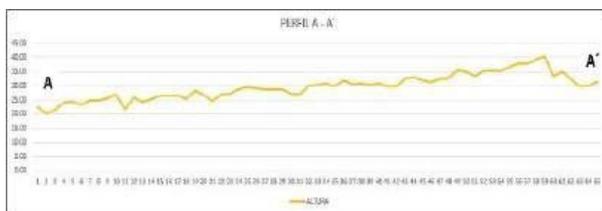
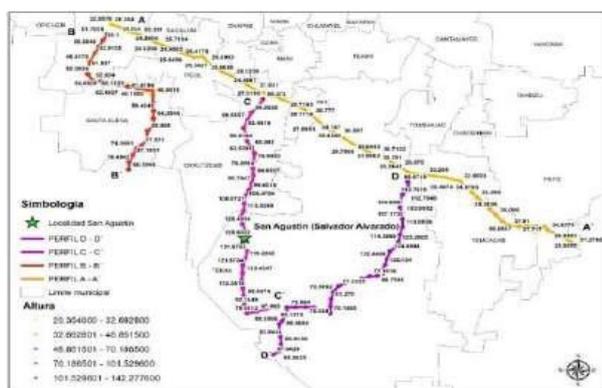




The terrain elevation ranges from 50 to 180 meters higher than in the northern peninsula, with some very steep slopes. Figure 2 shows the national geodetic data network marked in meters above sea level (INEGI, 2022), along the most important communication routes in the Biocultural Puuc Region. Below it is the topographic cross-sections in the NW-SE direction (A to A') and three general NE-SW cross-sections. These clearly illustrate the higher elevation of the terrain and its subsequent drop to the SW, forming a watershed dividing two micro-basins: Salvador Alvarado (Ejido de San Agustín) to the NE, and Chan Dzinup – San Isidro Yaxché to the SW (C to C').

Fine-grained Paleocene–Eocene limestones with gypsum deposits, silicates, and few fossils are found (Bautista et al., 2012a). Structural and karst plains are reported in the region, as well as coastal plains, a swamp area with "petenes," the semicircle of cenotes, and tectokarstic hill ranges (aligned hills locally known as "Sierrita de Ticul") and karstic hills (isolated cone-shaped hills known as cerros and valleys), which are the main geomorphological features (Lugo & García, 1999; Bautista et al., 2003ab). A prominent karstic structure acts as a sink draining the plains, locally known as "Xuuch." Each geomorphological landscape has a particular soil association. The Leptosol group is omnipresent, with greater soil development observed in karstic and tectokarstic hills.

**Figure 2.** Topographic profiles of the Biocultural Puuc Region. Each point represents the location of a physical plate containing data and records from INEGI (2022). Altitude values are referred to as mean sea level.



Source: Prepared by the authors using data from INEGI, 2022. National Geodetic Control System of Mexico.

## 2. Flood Dynamics in the Biocultural Puuc Region

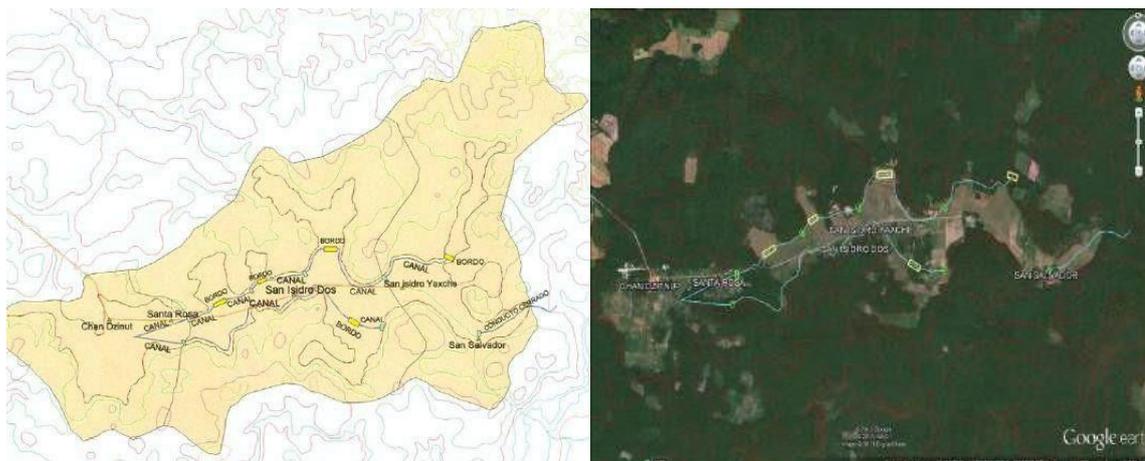
Flooding in the hills-and-valleys area of the Biocultural Puuc Region is highly variable. In general, the region comprises small endorheic–arrec micro-basins, meaning they have no outlet to the sea and/or water quickly infiltrates into the ground. Floods occur at varying frequencies and durations. Some areas flood every one or two years, while others require heavier rainfall events with recurrence periods of over ten years.

Additionally, some floods recede within a few hours, while others last several weeks. Over time, human settlements—along with their agricultural and grazing lands—have progressively expanded into areas periodically affected by flooding.

In the Chan Dzinup–San Isidro Yaxché micro-basin, for example, an extraordinary rainfall of 300 mm in 24 hours from Hurricane Isidore allowed an estimation of 252 mm runoff in the lowest flat area (within the 140 m contour line) and 129 mm runoff in the hilly areas outside that flat zone (Espinosa Graham, 2004). This caused flooding with water depths exceeding 1.5 meters.

Espinosa's study recommended surface infrastructure to control flooding, such as containment dikes and diversion canals or drains, shown in Figure 3. These drains correspond to the lowest part of the micro-basin. This framework also helps describe the functional middle and upper parts of the hydrological micro-basin.

**Figure 3.** Location of surface works in the Chan Dzinup basin.



Source: Espinosa Graham, 2004 and own elaboration.

Only in the municipalities of Tekax, Tzucacab, and Peto are there 187 localities in extreme poverty, 56 of which are in flood-prone areas. Of these, 26 are in ordinary flood zones and 30 in permanent flood areas, impacting over 600 families. Flood-risk communities in extreme poverty include:

San Salvador and Piste Akal; Tigre Grande; Blanca Flor; La Esperanza; Huntura Dos; San Manuel; Benito Juárez; La Herradura; Telil; Nueva Santa Cruz; Mesatunich; Mac-Yan; Huntochac; San Diego B; San Felipe Segundo; San Juan T; San Martín Hili; San Pedro Azula; Sudzal Chico; San Jorge; Lázaro Cárdenas; Ayim Dos; Cruz Aka; San Gregorio; San Nicolas; Santa Rita; Xcunya; X-kanlol; El Huiro Dos and Chun Wits, including Salvador Alvarado in the San Agustín Ejido micro-basin (Reyes & Santillanes, 2006).

### 3. Biocultural Context and Micro-Basin Management Using LiDAR and GPR

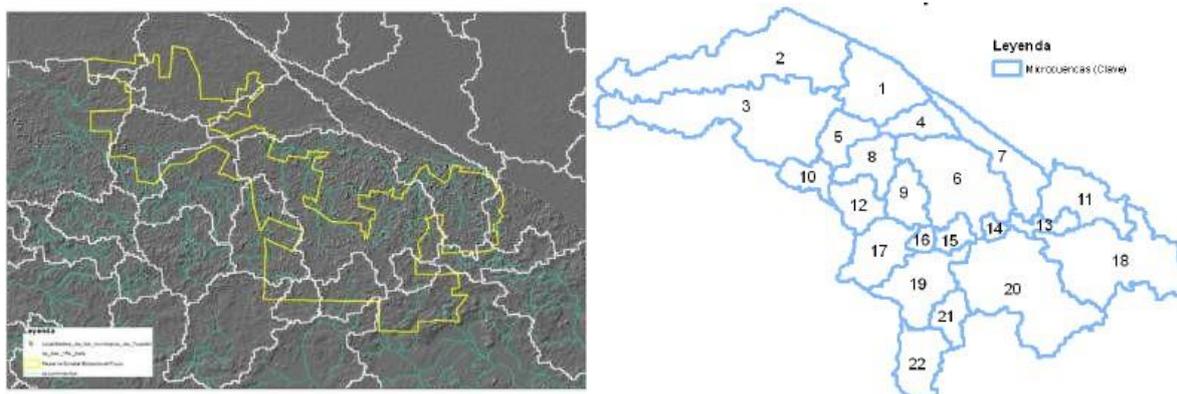
Within the framework of biocultural interaction studies, the evolution of resource management must be analyzed not only on a regional scale but also at the local site level. Natural and anthropogenic sedimentary deposits, along with the micro-relief of the landscape, are the main indicators of both current and past land use and resource management. In the Biocultural Puuc Region, the dry tropical forest significantly limits systematic

and detailed studies of this land use, especially for extensive micro-topographic work (Castanet, Cyril et al., 2019).

The nature, use, spatial distribution, temporal changes, challenges, and management of these resources have led Maya populations to implement both structural and non-structural strategies, such as hydraulic and agricultural modifications. These include works related to risk management associated with both water scarcity and excess, serving both domestic and agricultural purposes. They may also relate to erosion and soil hydro morphology management.

The work by Hernández et al. (2011) presents an interferometric radar image of the Yucatán Peninsula relief, used to generate a digital elevation model (DEM) via the USGS Hydrosheds online tool (<http://hydrosheds.cr.usgs.gov/>). This model allows the identification of local depressions that can be considered micro-basins associated with the small surface runoffs in the Biocultural State Reserve of the Puuc and surrounding areas (Figure 4). Using this information, 22 micro-basins were delineated. These first-order geographic units were used to develop the Management Program for the Biocultural State Reserve of the Puuc, published in the Official Gazette of the State of Yucatán, Number 485, in 2022. The town of Salvador Alvarado in the San Agustín Ejido lies in the southern part of micro-basin 6.

**Figure 4.** Micro-basins derived from the digital elevation model and presence of surface runoff in the Biocultural Puuc Region.

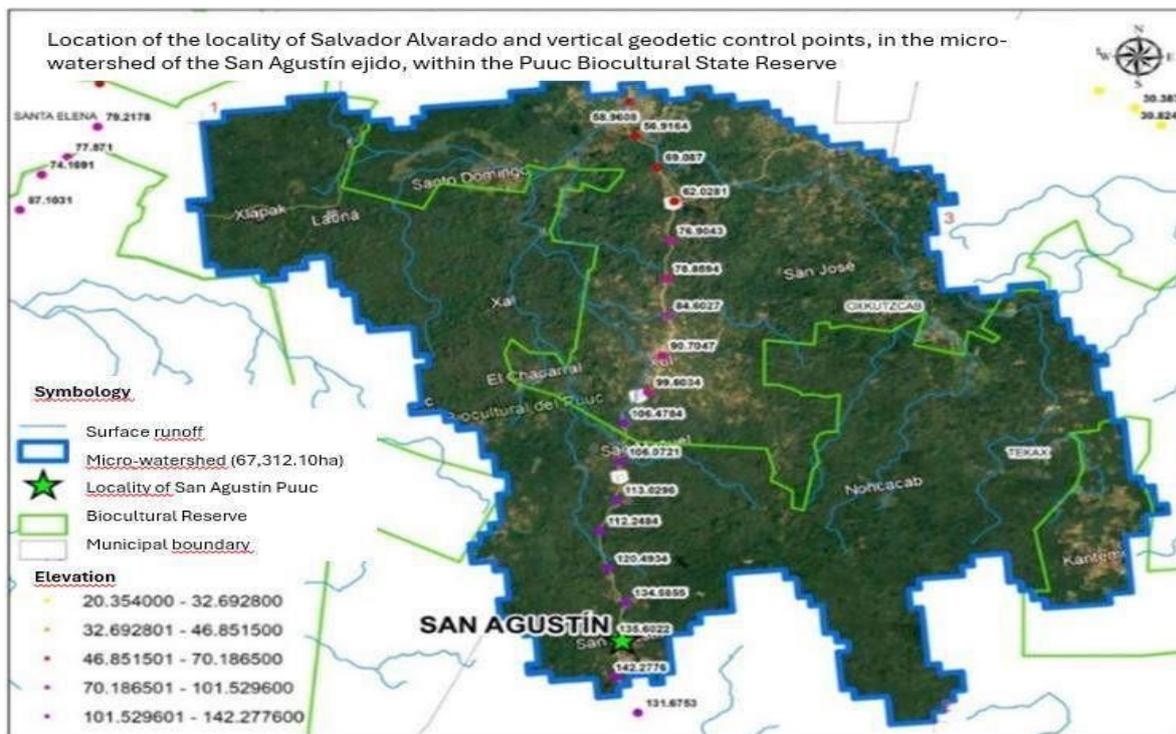


Source: Hernández et al. (2011), own elaboration

These landscape units are described in Figure 5, showing the boundaries of micro-basin 6 of San Agustín and the location of Salvador Alvarado to the south, with a total surface area of

67,312.10 hectares, near the Chan Dzinup–San Isidro Yaxché micro-basin to the south.

**Figure 5.** The town of Salvador Alvarado in the San Agustín Ejido is located at the highest part of micro-basin 6.

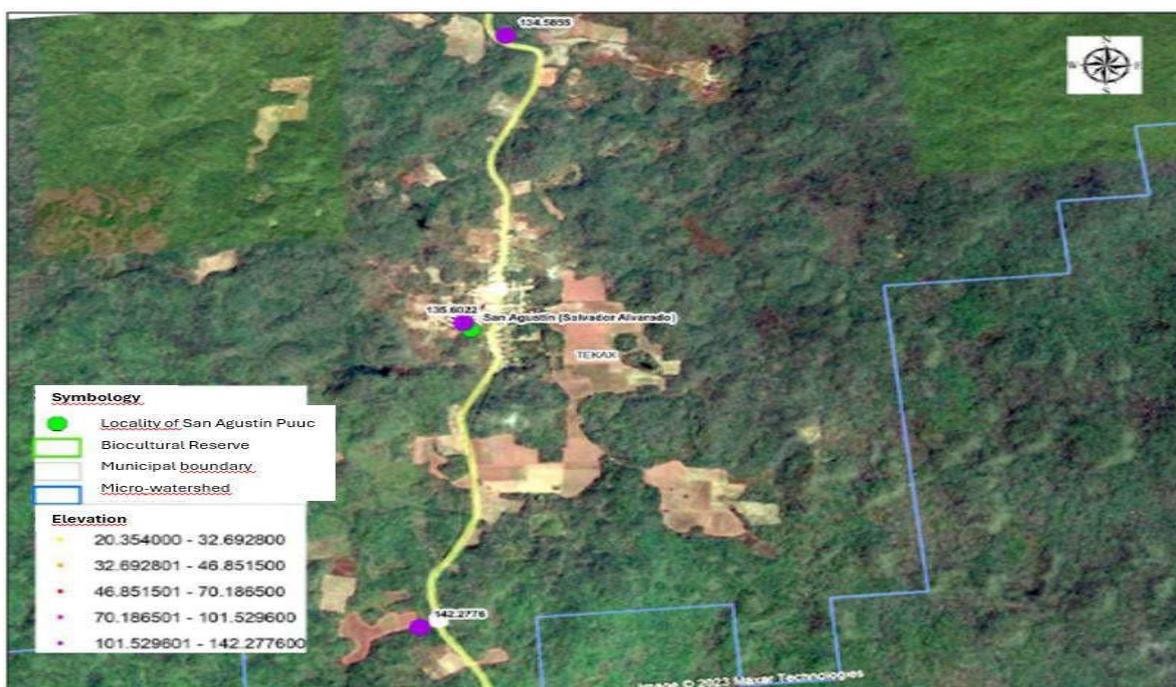


Source: Own elaboration

Even at the micro-basin level, there is significant physiographic variability. It is possible to identify smaller basin units, which within this framework can be considered facies basins. In this case, the facies basin of Salvador Alvarado in the San Agustín

Ejido is shown in Figure 6, where the micro-basin (yellow box) of the central transect (point C to point C' from Figure 1) is located.

**Figure 6.** The image shows the boundaries of Micro-basin 6 (blue line) and purple topographic points from INEGI (2022) along transect C to C' on its southwest edge. The central purple point in the yellow box corresponds to an INEGI plate located at the multipurpose sports court in the urbanized zone of Salvador Alvarado.



Source: Own elaboration

The approach to studying the hydrological conditions of the Biocultural Puuc Region aims to use LIDAR technology to assess local-level micro-basin conditions and their karstic development— particularly the xuuch formations—and to understand the urban, hydraulic, and agricultural adaptations present in these micro-basins and their agro-systems. This contributes to understanding resource management—both water and soil—by Preclassic and Classic Maya populations and how such practices sustained a population that radically and permanently transformed its local environment and landscapes.

#### 4. Methodology.

LiDAR (Light Detection and Ranging) is a remote sensing method that uses laser pulses to measure the distance between a sensor and objects on the Earth's surface. This technology allows for the generation of accurate and detailed three-dimensional

information about the environment. Models developed by LiDAR allow for the observation and interpretation of microreliefs resulting from previous surveys. They can broadly reveal nature, density, and spatial distribution of detected structures, from a local to a microregional scale.

As a first step, a reconnaissance of the area is conducted. The flight plan and ground control points are prepared. Field data acquisition is performed (optimal acquisition parameters). Data backup and organization are performed. The raw point cloud is reconstructed. Quality standards are compared, and the point cloud is processed through cataloging, visualization, and classification. From this, the digital elevation model, intensity map, and orthophoto are developed.

The LIDAR acquisition and orthophoto mosaic were divided into two sectors, which are shown in Figure 7.

**Figure 7.** Sectorization of the facies basin for study purposes. Sector 1 and Sector 2 (4,250,000 m<sup>2</sup>). The urban area of Salvador Alvarado is outlined on the right.

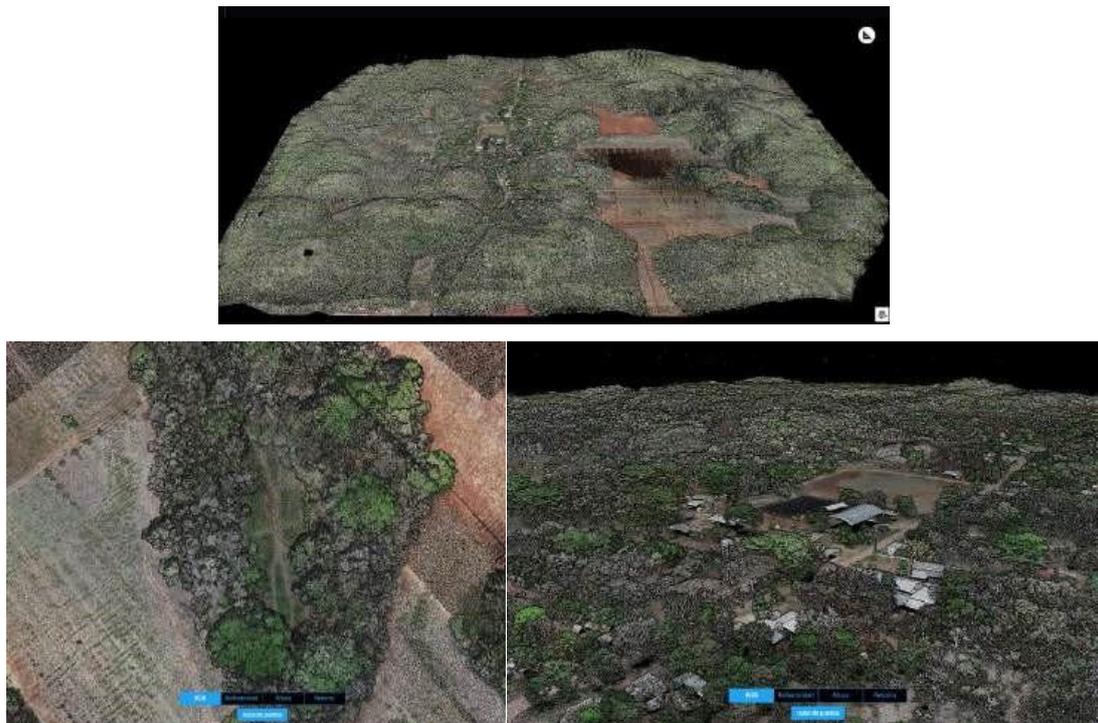


Source: Own elaboration

The point cloud reconstruction is presented below, colored with RGB (Figure 8). Centimeter resolution allows for more precise analysis of structures. The orthophoto and intensity maps are

developed (Figure 9). From this, the digital elevation model is developed (Figure 10).

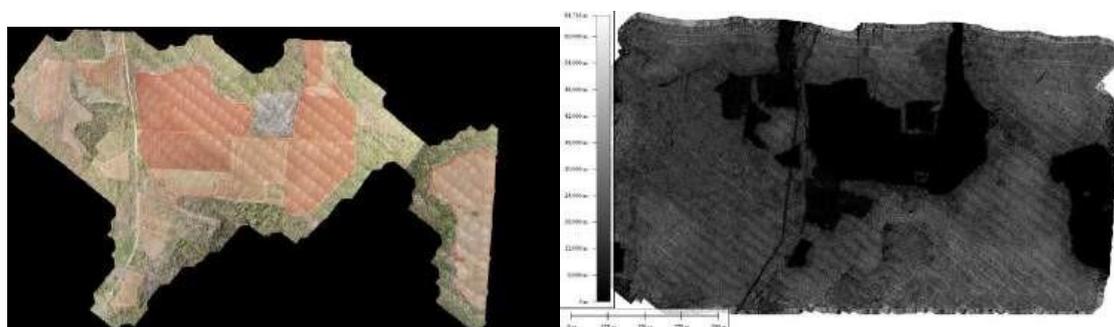
**Figure 8.** San Agustín Sector 1, point cloud view, colored with RGB.



Source: Own elaboration

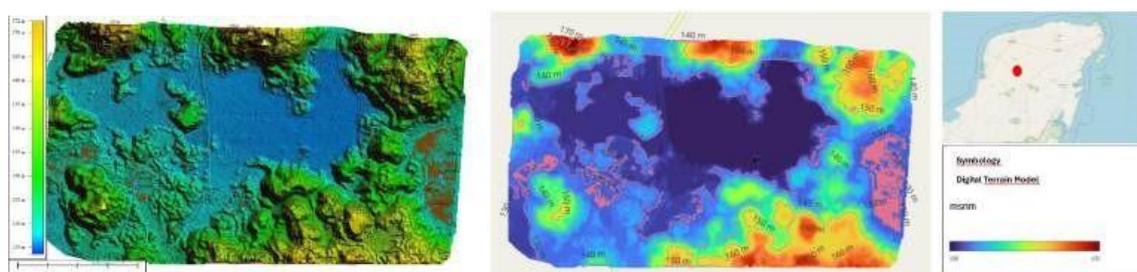
The intensity map represents feedback information from laser light reflected by objects on the surface. It can be useful for vegetation analysis, terrain modeling, object identification, planning, and more.

**Figure 9.** San Agustín Sector 2, Development of orthophoto and intensity map.



Source: Own elaboration

**Figure 10.** Digital terrain model (DTM) of the San Agustín Sector 2 segment with contour lines. Two representation methods.

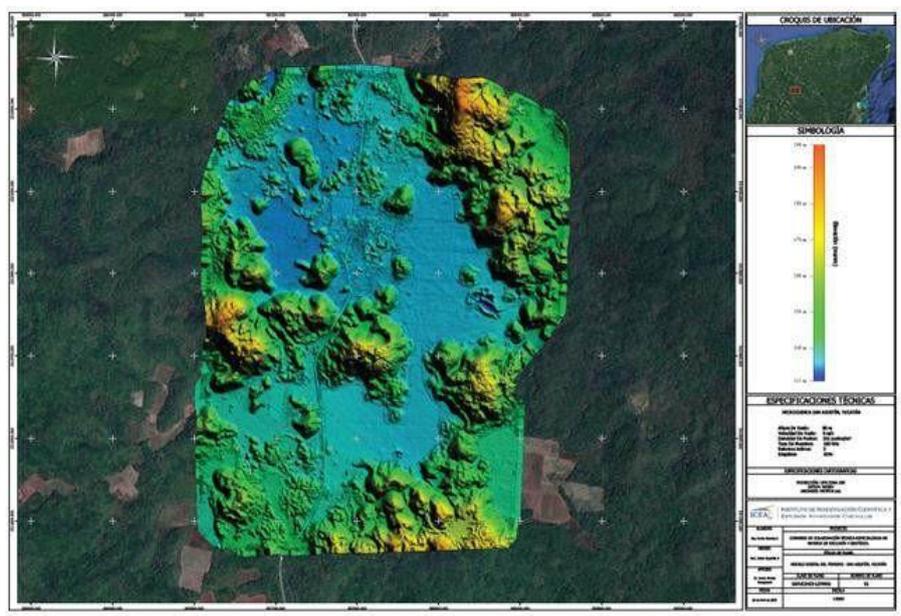


Source: Own elaboration

The result is a lidar image of the town of Salvador Alvarado in the San Agustín Ejido (Sectors 1 and 2), representing the facies basin at the minimum elevation of 132 meters above sea level

and the maximum elevation for overflow and runoff at 137 meters above sea level (Figure 11).

**Figure 11.** Lidar image of the facies basin of the town of Salvador Alvarado, San Agustín Ejido (Total image area: 3,962,354.72 m<sup>2</sup>).



Source: Own elaboration

In this last image, in the central-eastern area, a structure known locally as "Aguada" (yellow contour box) can be seen. It is composed of at least 3 depressions or regulating vessels with banks almost 2 meters high above the plain terrain, at more than 5 meters of total depth, and which allow the containment of temporary surface runoff water from the slopes that surround it to the east and are drained through channels that can be seen to the east of the aguada, as clearly seen in the following Figure 12. The origin of this structure is unknown; it is unique in this facies basin.

There are two other small watering holes, but these were built as livestock watering troughs. They are much smaller in size and feature a small dam constructed of stones of various sizes covered with soil derived from the excavation inside the trough to capture runoff water from the eastern slope.

Small depressions known as "sartenejas" (watering pans) also appear as containers in the limestone rock. These are flooded during the rainy season, and the water remains in them for several months, or until the next rainy season (Figure 12).

**Figure 12.** Various water control structures, the first known as an aguada (watering hole), the second a square livestock watering trough, and the third a sartenejas (watering pan).



watering trough



Natural troughs



Source: Own elaboration

These structures have some common characteristics, such as their hydrological function, their layout, and the general type and thickness of the soils covering their surface.

Various xuuche-type karst structures are also found in the eastern and northern portions of the facies basin (Figure 13). These often feature vertical drops of more than 30 meters, where surface water flows, carrying large quantities of stones and logs.

**Figure 13.** A hollow-type karst structure or cavern-type karst structure, locally known as "Xuuch."



Source: Own elaboration

In the central and southern portion of the facies basin is a Puuc archaeological site, named Rancho Pérez by the INAH. It still requires much study. However, it is very interesting to learn how rainwater was collected and stored as a source of water for

human consumption and religious practices by excavating a type of waterproofed cistern called "Chultún" in the rock, which is still used by ancient families (Figure 14).

**Figure 14.** Ancient and current forms of water management for family and household consumption, Archaeological Sites and Ancient Chultún.



Modern Chultun in Salvador Alvarado's home

Source: Own elaboration

Figure 18 presents the results of the vertical (longitudinal) and horizontal (transverse) elevational variations of the basin facies. As can be seen, all of them show significant elevations at the extremes, leaving an extensive plain with minor elevational variations in the center. It is evident that the most evident depression is the "Aguada" basin, with an elevation of 132 meters above sea level.

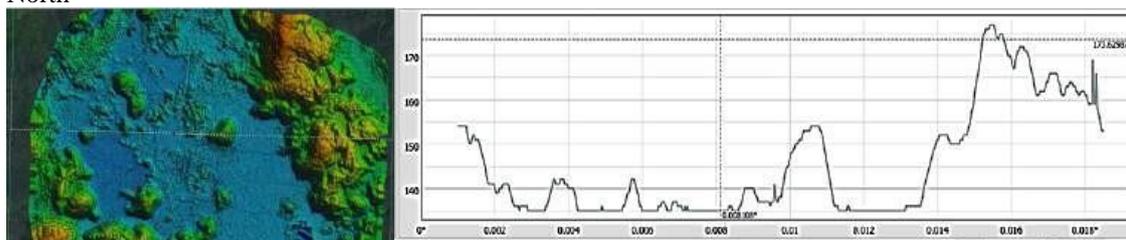
The middle basin develops from 137 to 140 meters above sea level, and the upper reaches reach over 160 meters above sea level, with the eastern zone presenting the highest elevations of almost

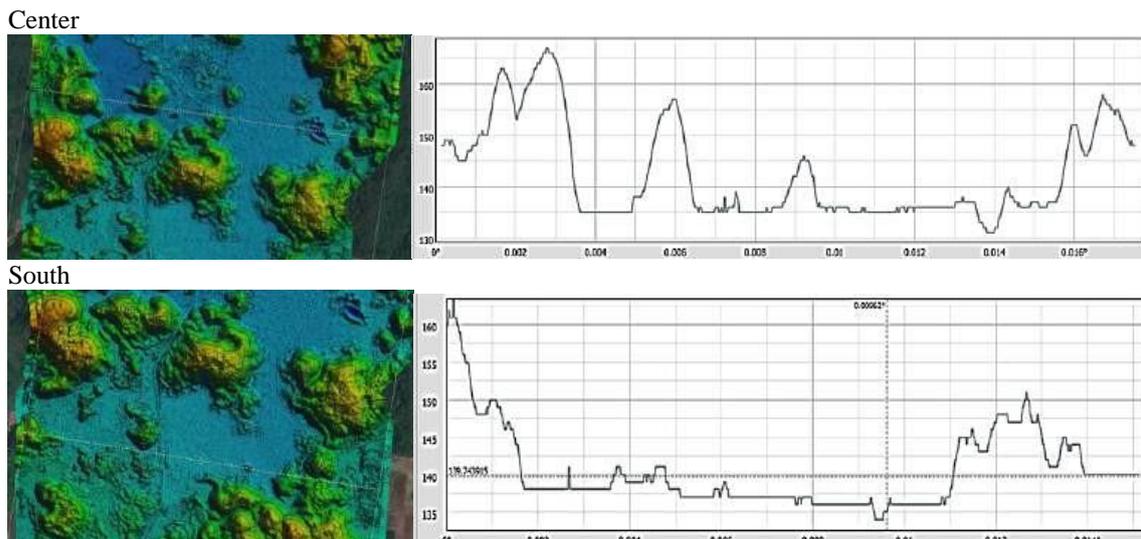
180 meters above sea level. Also notable is the presence of a slope of the plains that run from the south at 140 meters above sea level to the north at 132 meters above sea level, a drop of almost 8 meters.

**Figure 15.** LIDAR image results and elevational variation within the basin facies.

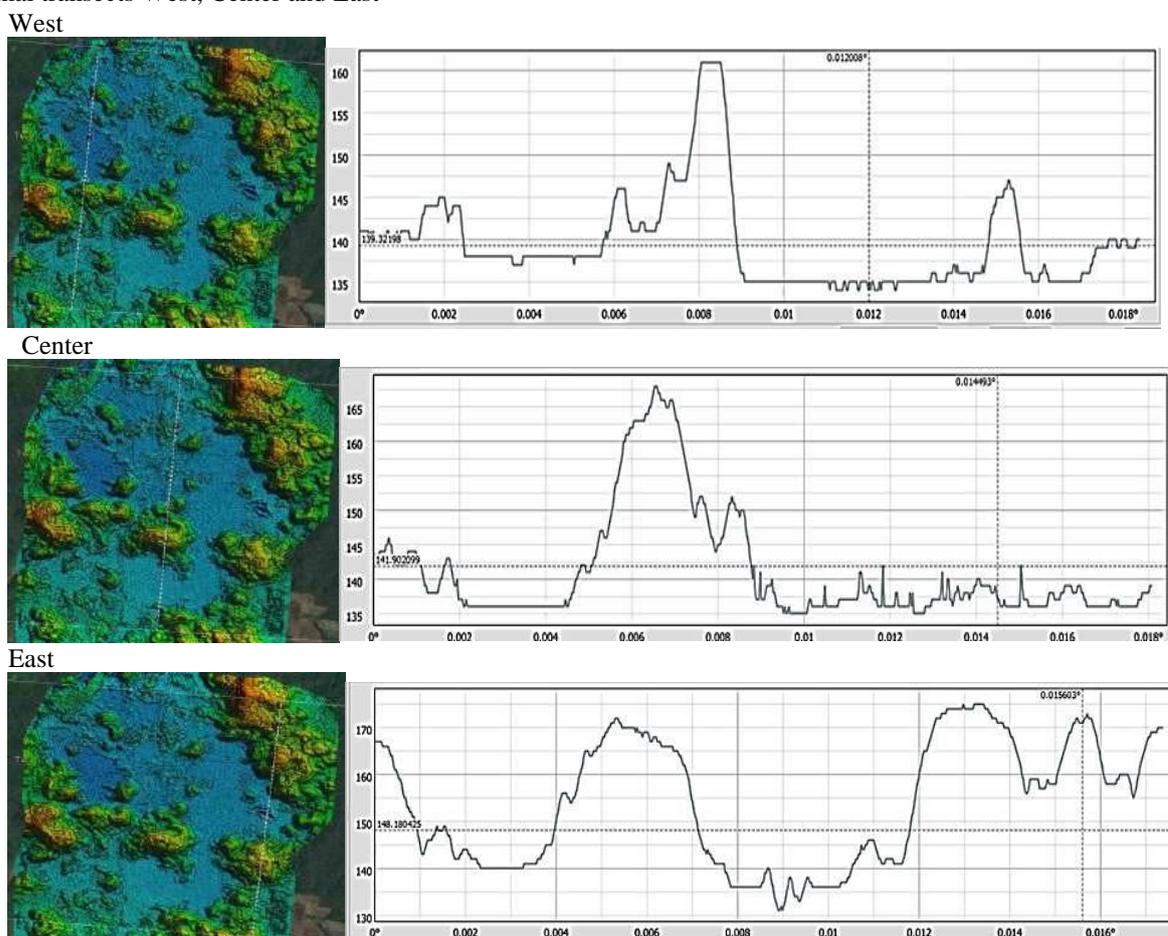
a). North, Central, and South transects.

North





b). Longitudinal transects West, Center and East

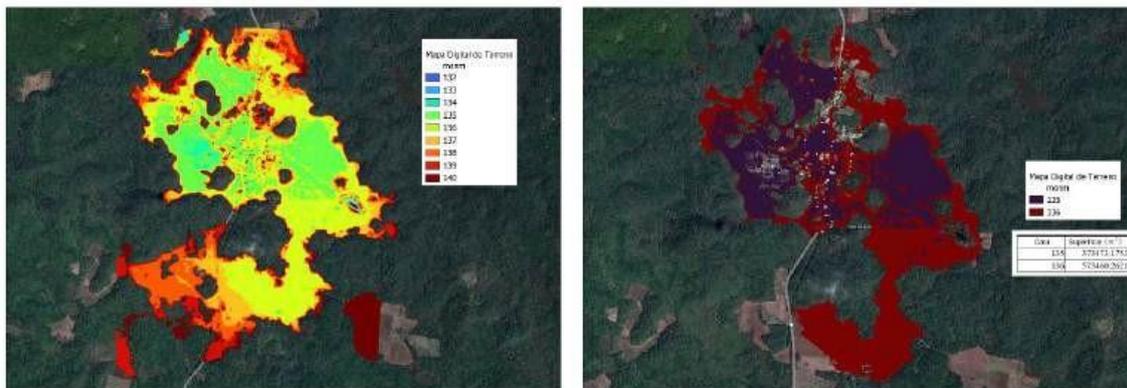


Source: Own elaboration

The area of the sub-basin between 135 and 136 meters above sea level can be considered the main extension representing the functional zone of the lower basin (elevation of 132 meters above sea level in the watershed to the level of 136 meters above sea level) and extends over 96.89 hectares (representing 24.45% of the total lidar image). The probable start elevation of flooding is 137 meters above sea level, as seen to the north of Figure 16,

and which extends over a cumulative area of 121.14 hectares (Table 1). According to Figure 16, with flooding greater than this topographic elevation, water would begin to overflow in the north of the facies basin toward the runoff from the upper part of Micro-basin 6, described above. This gives an idea of the surface water storage capacity that this facies basin could contain.

**Figure 16.** Surface extension of the various topographic heights of the 132 masl facies basin and the 140 masl elevation, and the accumulated surface extension for the 135 and 136 masl elevation, called the lower basin, is detailed.



Source: Own elaboration

**Table 3.** Value of the elevation in meters above sea level, the pixels that comprise it and their respective surface area in m<sup>2</sup>, as well as the accumulated and total surface area of the facies basin.

Value masl	No. Pixel	Area (m <sup>2</sup> )	Cumulative surface area (m <sup>2</sup> )
131	2480	486.62	
132	4503	883.57	
133	4857	953.03	
134	100290	19,678.69	
135	1903359	373,473.17	395,475.08
136	2922568	573,460.26	968,935.34
137	1235724	242,471.21	1,211,406.55
138	1250764	245,422.33	
139	942917	185,017.23	
140	1099486	215,738.87	1,857,584.98
141	795795	156,149.25	
142	770514	151,188.66	
143	754648	148,075.47	2,312,998.36
>143	8405737	1,649,356.36	<b>3,962,354.72</b>

Source: Own elaboration

It is evident that both the urban and agricultural areas are located primarily at an elevation of 136 meters above sea level, making them highly exposed to flooding. Furthermore, in this basin, the surface drainage channels that generate temporary runoff have been lost due to the intensive use of tractors to flatten and align the soil for monoculture production, primarily soybean and corn.

The soil distribution in this region is very peculiar, with a wide variety of soils found within a few meters (Figure 17). In a longitudinal or lateral profile, it is possible to observe that the higher elevations are covered with Leptosol-type soils, particularly lithosols, very thin soils. As one reaches the middle of the slope, the soil changes to rendzina-type soils, with thicknesses greater than 20 cm and a high presence of organic

matter. Finally, we reach the lowest area of the plain, where Luvisols, soils deeper than 2 meters, are found. This is where the structure of the "Aguadas," the Xuuches, the agricultural fields, and the urbanized area are located. This coincides with the high elevation difference of up to 50 meters between the plains and the countless isolated domed hills distributed above them, creating a strongly undulating landscape. This generates a series of temporary surface runoffs that reach the flat terrain of the steep hillsides. Currently, this area is dedicated to corn farming, as well as some extensive cattle ranching, which takes advantage of the secondary associations of wild vegetation resulting from leaving cornfields that have been cultivated for two or three consecutive years fallow. These lands have potential for agricultural and forestry.

**Figure 17.-** Hills devoid of vegetation to the north of the facies basin, in the town of Salvador Alvarado (Ejido de San Agustín), where the Leptosol – Luvisol soil catenary can be observed, according to the altitude of the slope.



*Source: Own elaboration*

Leptosol-type soils are characterized by very thin layers, called lithosols and rendzinas, overlying the calcareous shell, to which, thanks to its advanced state of cracking and fracturing, they owe their abundant stoniness. Both soil types are closely associated with the undulating relief of the area. These shallow soils (no more than 0.30 m) pose severe restrictions for agricultural development. The scarce soil has a low water storage capacity in its mineral matrix. These lands are suitable for forestry, growing tropical hardwoods and nectar pollinifera, as well as for wildlife (Duch, 1988). The GPR studies were conducted entirely on luvisol (L)-type soils. According to Duch (1988), these soils have an argillic B horizon (clay accumulation by illuviation) with a base saturation of 50% or greater, at least in its lowest part at a depth greater than 100 cm; they have a mollic A horizon with moderate organic matter content. Chromic luvisol has a

dark brown to red B horizon and is highly susceptible to erosion. Lithosol (I)-type soils are up to 10 cm thick, bounded by hard, continuous, or brittle, coherent rock. Their susceptibility to erosion depends on the area where they are located and can range from moderate to high.

A soil profile was created within the pond where the four GPR profiles meet. (May 2023), as shown in Figure 9. It was carried out during the dry season. Figure 18 shows the 2-meter-deep soil profile, as well as details of the profile showing the clayey nature of the material, with a slightly dark layer as Horizon A, with some organic matter derived from periods of flooding and drought. This is accompanied by a Horizon B present in the first 2 meters of depth, reaching the bottom with significant fracturing of the clay, with the formation of calcium salts.

**Figure 18.** Beacon number 1 natural waterhole. Geographical position: 19° 58'32.1" N and 89° 28'54.5" W. Depth: 2 m. Excavation sequences and profile characteristics.



Fracturing of dry soil and formation of calcium salts at the bottom



Source: Own elaboration

At the Municipal Commissioner's House in the town of Salvador Alvarado (Ejido de San Agustín), there is a soil and geological profile section measuring just over 4 m. Its location is shown in Figure 9. **Figure 19** shows the soil profile in the first 2 meters, which represent Horizon B, a primarily clayey soil with a highly

eroded and scarce layer of organic matter in the top few centimeters, leaving Horizon A very small.

Below a depth of 2 meters, what is identified as Horizon C is the calcareous rock that underlies the mineral soil, as shown in Figure 19.

**Figure 19.** Four-view sections of the site with soil and rock profile. Municipal Commissioner's House. Geographical Position: 19° 58'36.0" N and 89° 29'17.4" W.





Approach to the variability in the different rock strata.



Source: Own elaboration

The soil found in the hills and valleys of Salvador Alvarado have the following important characteristics in the water cycle (Table 4):

**Table 4.** Important soil characteristics in the water cycle in Salvador Alvarado.

Soil Type	Location	Thickness (cm)	Texture	M.O %	Hydro morphism	Field capacity %	Usable water capacity %	Infiltration cm/hr.
Lithosol	Plains and highlands	≤10	Sandy crumbs to clayey crumb	10	Null to Strong	14 - 21	10 - 12	≥ 2.5
Rendzina	Plains, hills, mounds, and hills	≤40	Clay crumb	40	Absent	21.5	11.3	
	Black Color			15 - 20				≥ 2.5
	Brown color			6 - 15				1.75 – 2.5
	Red color			≤ 6				0.25–1.75
Luvisol	Floodplains and lowlands	>100	Clayey to loamy – clayey and sandy	1-15	Absent strong too	22.6	7.9	0.25- 1.75

Source: Own elaboration

In this case, the luvisol soil (Table 2) has a field capacity of 22.6%, a usable water capacity of 7.9%, reflecting its clayey nature, and its wilting point of 14.7%, the highest recorded, retaining a large amount of water unavailable to vegetation. This is coupled with its very slow infiltration rate (0.25– 1.75 cm/hour), which favors flooding in the soil after rainfall. Considering that the luvisol-type soil observed in the plains has an average thickness of 2 m (or 2,000 mm), and its usable water capacity is 7.9%, this means that the soil thickness can only contain a usable water column of 158 mm (or 158 liters per square meter). The topographic elevation of 132 to 136 meters above sea level has a surface area of 968,935.34 m<sup>2</sup>. The amount of water stored when usable water saturation is reached is 153,091.73 m<sup>3</sup>. This is the amount of usable water that can be

retained in the soil at that elevation in the lower part of the basin, prior to an overflow. Table 6 presents information from daily records obtained by a resident of the town of Salvador Alvarado, who recorded rainfall events by collecting the rainfall in a container and measuring the amount of rain with a millimeter ruler. So far, records are available for six months, from May to October (2023), the rainiest season of the year in Tekax.

The community rainfall record shows that August 2023 was the wettest month in the town of Salvador Alvarado with 62.6 mm (2.4 in). This was followed by September with 56.9 mm (2.3 in). The month with the least rainfall was June, with a total of 10.7 mm (0.4 in). All other months had values less than 20 mm (0.8 in). These months, from May to October, account for 78 to 82% of the total annual rainfall.

**Table 6.** Values in millimeters of daily precipitation recorded (year 2023) in the town of Salvador Alvarado (Ejido de San Agustín).

Day/month	May	June	July	August	September	October	Total
1	1.4	0	0	2.5	0	0	
2	0	0.5	0	1.5	0	2.1	
3	0	0	0	6.0	0	0	
4	0	0	1.5	8.0	0	0	
5	0	0	0	3.6	0	7.0	
6	0	0	0	0	0	0	
7	0	0	0	4.0	2.0	3.7	
8	0	0	0	6.0	0	5.5	
9	0	0	0	0	11.0	0	
10	1.6	4.0	0	0	4.0	0	
11	2.2	0	0	0	7.2	1.2	
12	0	6.2	0	0	2.4	0	
13	0	0	0	0	0	0	
14	2.5	0	0	0	3.6	0	
15	0	0	0	7.0	0	0	
16	0	0	0	0	4.4	0	
17	0	0	0	0	0	0	
18	0	0	1.9	0	0	0	
19	1.6	0	0	0	0	0	
20	0	0	0	1.0	0	0	
21	0	0	9.0	0	2.5	0	
22	0	0	0	6.0	0	0	
23	0	0	0	0	0	0	
24	0	0	0	0	0	0	
25	0	0	0	15.5	0	0	
26	0	0	0	0	0	0	
27	1.2	0	0	0	0	0	
28	1.5	0	0	0	15.6	0	
29	1.3	0	1.0	1.5	2.4	0	
30	0	0	0	0	1.8	0	
31	0		2.5	0		0	
<b>Total</b>	<b>13.3</b>	<b>10.7</b>	<b>15.9</b>	<b>62.6</b>	<b>56.9</b>	<b>19.5</b>	<b>178.9</b>

Source: Doña Rita, resident of the town of Salvador Alvarado, Ejido de San Agustín, Municipality of Tekax.

If we compare these data with the Semarnat (2006) data series for the Ecological Planning Program of the State of Yucatán, we see that they are below the average values recorded for the Municipality of Tekax. Therefore, the year 2023 can be considered dry, well below the average monthly rainfall, almost reaching the minimum recorded by Semarnat (2006).

However, this total rainfall from May to October of 178.9 mm, without considering the effect of free surface evaporation that occurs in the Tekax area, could saturate the soil up to an elevation of 136 meters above sea level. There would still be a surplus of 20.9 mm, a remainder of 20,250.74 m<sup>3</sup> (exposed mainly within the pond, which in a field sampling in September showed a water depth of 240 mm at its deepest part), as surface

water. All this water, added to the infiltrated water, will be subject to evaporation during the time that gravitational water begins to percolate into the water table.

The water quality of the well and a Chultún (located in a residence south of the town of Salvador Alvarado) was determined by the Coastal Environmental Sciences Laboratory of the Faculty of Chemistry in Sisal, UNAM, and the Environmental Geochemistry and Water Pollution working group. The results of the measurement of the physicochemical

and nutrient parameters of the water samples received on June 2, 2023, are shown in Table 12.

The results were compared with current national legislation: NOM-127-SSA1-2021, for water for human use and consumption. It was observed that they were generally within permissible ranges. Only hardness was close to the maximum value for well water. However, ammonium slightly exceeded it in the case of the Chultún water (Table 12).

**Table 12.** List of parameters in well and Chultún, and comparison with NOM-127-SSA1-2021.

* Parámetro			Valor normado
	POZO	CHULTUN	NOM-127-SSA1-2021
Temperatura °C	6.4	7	---
Oxígeno %	86.7	32.2	----
Oxígeno disuelto mg/L	10.99	3.82	----
Conductividad Eléctrica µS/cm	835	276.5	----
Sólidos totales disueltos mg/L	838.5	273	1000
pH	7.29	7.4	6.5-8.5
ORP mV	159.6	160.1	----
Na (mg/L)	55.2	16.99	200
K (mg/L)	6.2	2.34	----
Ca (mg/L)	221.2	139.2	----
Mg (mg/L)	20.57	1.16	----
<sup>b</sup> Alcalinidad Total	262.7	160.2	----
Cloruros (mg/L)	152.86	70.9	----
<sup>c</sup> Dureza (mg/L)	408.94	188.02	500
N-NO <sub>3</sub> (mg/L)	7.64	ND	11
N-NH <sub>4</sub> (mg/L)	ND	1.13	0.5
N-NO <sub>2</sub> (mg/L)	ND	ND	0.9
Silicatos	1360.92	778.03	----
Ortofosfato (mg/L)	ND	ND	----
Sulfatos (mg/L)	21.05	130.9	400
Cu (mg/L)	<LD	<LD	2.00
Zn (mg/L)	0.23	0.12	5.00
Sr (mg/L)	2.85	1.14	----

ND = Not determined due to being outside the detection limit = 0.002 mg.

Source: Coastal Environmental Sciences Laboratory of the Faculty of Chemistry in Sisal, UNAM

Some important differences are observed between the well water supplying the community and the water collected from the rainwater inside the Chultún. Typically, the concentrations of oxygen, conductivity, total solids, sodium, potassium, calcium, magnesium, alkalinity, chlorides, hardness, nitrates, and silicates in the Chultún are lower than in the well water. However, sulfate is higher within the Chultún; this material was possibly used to line and waterproof the Chultún.

## 5. Conclusions

The lidar image allowed us to characterize the Salvador Alvarado basin facies of the Ejido de San Agustín, which covers a total area of 396.23 hectares. The presence of a flat slope in the basin facies is noticeable, ranging from the south at 140 meters above sea level to the north at 132 meters above sea level, a drop of almost eight meters. This facies basin extends into the southern part of Micro basin 6, described in the Management Program of the Puuc State Biocultural Reserve, with an area of influence of 67,312.10 hectares.

The area of the facies basin up to 136 meters above sea level can be considered the main area representing the functional zone of the lower basin (elevation of 132 meters above sea level in the watershed to 136 meters above sea level in the main plains) and

extends over 96.89 hectares (representing 24.45% of the total LIDAR image). This is where urban and agricultural infrastructure is developed, leaving it highly exposed to flooding of more than one meter, since the probable start of flooding is at 137 meters above sea level, and which extends over 121.14 hectares. This overflow would begin in the north of the facies basin toward the runoff from the upper part of Micro basin 6. The amount of water stored in the soils when usable water saturation is reached is 153,091.73 m<sup>3</sup>. This is the amount of water that can be retained in the soil at that elevation in the lower part of the facilitation (below the elevation of 136 meters above sea level), prior to overflow and percolation.

The community rainfall record shows that 2023 was a dry year, well below the average monthly precipitation, approaching the minimum value recorded by Semarnat (2006). Therefore, it appears that the vegetation system may have suffered a negative water balance, with deciduous vegetation predominating. The soil profile of a luvisol-type soil is observed, 2 meters deep, with a slightly dark layer, Horizon A, containing some organic matter derived from periods of flooding and drought, as well as crop residues. This is accompanied by Horizon B, present in the first 2 meters of depth, reaching the bottom with significant clay fracturing, with the formation of calcium salts. Horizon C

appears after 2 to 4 meters of depth, with very marked reflectors characterized by the inclination of the strata. It can be associated with calcareous rock with the presence of dissolution or fragmented zones.

It is necessary to consider the possibility of relocating certain urban infrastructures (schools, water collection wells for the population), as well as the relocation of certain homes. Likewise, the entire mechanized agricultural area is at risk of flooding. So far, flood control experiences have been implemented as technical infrastructure solutions, such as containment dams, channeling, and drainage in wells or xuuchs. Therefore, it is necessary to consider solutions based on the biocultural ecosystem, through agroecological practices with vaso-regulating systems (such as aguadas), drainage canal restoration, Xuuche rehabilitation, and rainwater recovery and management for family and solar consumption, both in ancient and modern chultuns. As has been seen, well water is compromised by its hardness and high concentrations of silicon and ammonium in the case of the Chultun, which is also distinguished by having fewer salts than groundwater, except for the higher presence of sulfate.

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