

## Morphological, sediment and soil chemical characteristics of dry tropical shallow reservoirs in the Southern Mexican Highlands

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### ABSTRACT

*The morphometry, sediment and soil chemical characteristics of eleven dry tropical shallow reservoirs situated in Southern Mexican Highlands were studied. The reservoirs are located at 1104 to 1183 meters above sea level in a sedimentary area. Seventeen morphometric and eight sediment and soil chemical parameters were measured. The results of the morphometric parameters showed that these reservoirs presented a soft and roughness bottom, with an ellipsoid form and a concave depression that permit the mix up of water and sediments, causing turbidity and broken thermal gradients; their slight slopes allowed the colonization of submerged macrophyte and halophyte plants and improved the incidence of sunlight on water surface increasing evaporation and primary productivity. Dry tropical shallow reservoirs have fluctuations in area, and volume according to the amount of rainfall, the effect of evaporation, temperature, lost volume for irrigation, and other causes. The sand-clay was the most important sediment texture and their values fluctuated with the flooded periods. The concentration-dilution cycle showed a direct relationship in the percentage of organic matter in the soil as well as with pH, soil nitrogen and phosphorus. El Tilzate, El Candelerero and El Movil were related by the shore development and high concentrations of organic matter and nitrogen in the soil. Finally, we emphasize the importance of this study, in relation to possible future changes in morphometrical parameters as a consequence of human impact.*

*Key words: Morphometry, bathymetry, soil chemical characteristics, tropical shallow reservoirs, Southern Mexican Highlands*

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### 1. INTRODUCTION

A limnological description of dry tropical shallow reservoirs is a necessary step in the research of the aquatic ecosystem (Håkanson 1981). The morphology of shallow reservoir basin exerts a major control over a wide range of processes and features in a lacustrine ecosystem and reflects a series of actions closely related to its origin, operation and use.

One of the oldest limnological principles is that basin morphometry influences lake metabolism (Thienemann 1925; Neumann 1932), as a consequence, many studies have demonstrated how tropical shallow reservoirs morphometry affects the rate of certain limnological processes and the distribution of physical, chemical and biological parameters (Ponce-Palafox *et al.* 1998), phytoplankton and submerged macrophyte abundance, structure and production (Schindler 1971; Duarte & Kalff 1988; Pinel-Alloul *et al.* 1990), loading, dilution and recycling of nutrients (Pick & Lean 1987), ratio

of nitrogen to phosphorus (Smith 1982), light in surface layer (Sterner 1990), sediment focusing (Blais & Kalff 1995), thermal structure (Robertson & Ragotzkie 1990), and phytoplankton structure (Eloranta 1986). In this sense Guiral & Pérez (1980) pointed out the importance of the cartography and morphometry of lake ecosystems as a first step in any kind of limnological research.

The majority of the morphometric analyses carry out on tropical shallow reservoirs have been based on measures of surface dimensions in different basins (Ponce-Palafox *et al.* 1998), but this type of study is insufficient to establish a good relationship between physico-chemical and biological parameters, and for elaboration of a good integrated management plan. It would be necessary to include a more detailed analysis of morphometrical parameters of both, surface and subsurface dimensions. In dry tropical shallow reservoirs of Latin America there are few studies on morphometric parameters. This research aim contributes to this type of knowledge

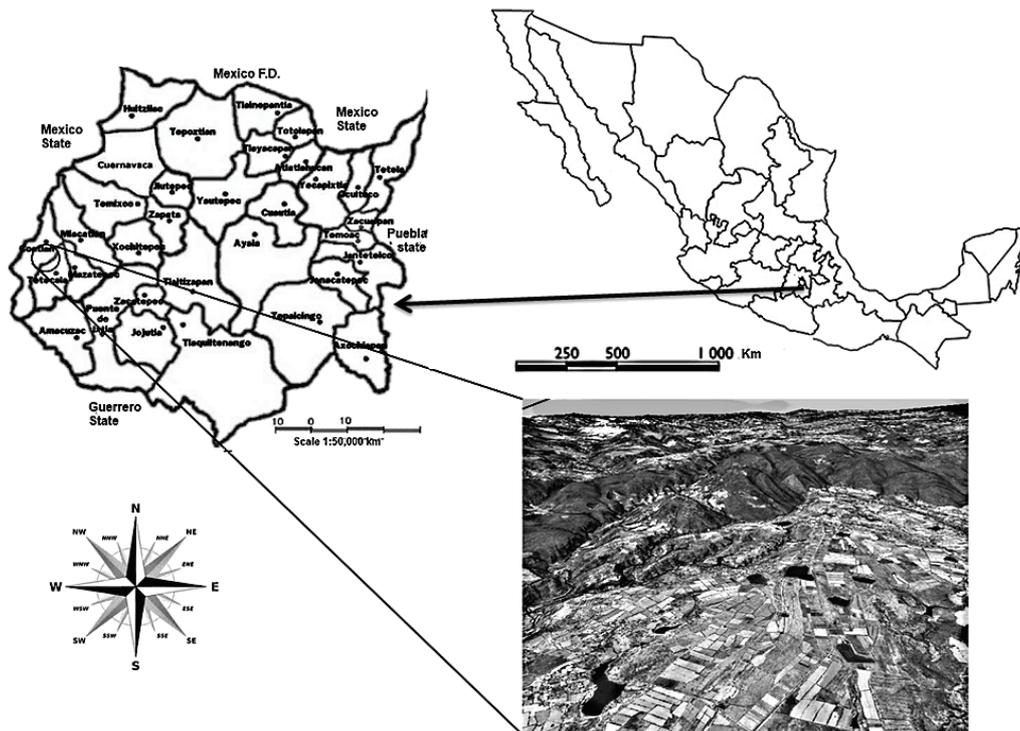


Fig. 1. Geographic location of the dry tropical shallow reservoirs in the southern Mexican highlands.

by means of morphometric, sediment and soil chemical studies in tropical shallow reservoirs in the Southern Mexican Highlands. This study complements previous works realized by Ponce-Palafox and Arredondo-Figueroa (1986) and Ponce-Palafox *et al.* (1998), and can be used as a basis for future limnological studies.

### 1.1. Study area

The dry tropical shallow reservoirs are located in the geographic coordinates  $18^{\circ}39'44''\text{N} : 99^{\circ}26'38''\text{W}$ ;  $18^{\circ}42'09''\text{N} : 99^{\circ}28'19''\text{W}$  in the extreme southwest of the State of Morelos, Mexico (Fig. 1). They border north and west with the State of Mexico, south with the municipalities of Amacuzac and Tetecala, east with Tetecala and Miacatlán, and west with the State of Guerrero. Eleven reservoirs named El Tilcate, Contlalco, El Tilzate, Laguna de En medio, Laguna Seca, El Movil, El Candelerero, Las Alzadas, Las Guayabitas, La Nopalera and Michapa were studied, with a surface ranging from two to ten hectare. Eight reservoirs are semi-permanent and three of them temporary, with an altitude from 1104 to 1183 meters above sea level in a sedimentary soil area. The climate is warm, sub-humid with summer rains and a dry season in winter. The hottest months are April and May, while the coldest months are December and January. The average precipitation is 1000 millimeters per year. Maximum temperature is  $34.0^{\circ}\text{C}$ , average  $24.0^{\circ}\text{C}$  and minimum  $14.0^{\circ}\text{C}$ . From a hydrological point of view, dry tropical shallow reservoirs receive direct supply from rainfall, ground-water flow, and surface runoff from sporadic streams.

## 2. METHODS

### 2.1. Morphometric parameters

The construction of a bathymetric or contour map was performed during three different periods of the flood cycle, flooding during periods of minimum, medium and maximum. The depth was determined at the deepest point near the gate of the reservoir, using a manual probe graduated in centimeters. The technique of separate segments was used in order to prepare the contour map, measuring the perimeter of coastline with a fiberglass 30 meter ADIR coated PVC tape measure graduated in centimeters and inches and resistant to extreme temperatures. To integrate the superimposed line segments to the coast, we used a Directional compass Engineer orienting the segments according to the degrees of the four main directions (azimuth). Once in the laboratory, was performed the outline with the stroke of oriented segments in cumulative sequence completing the circuit, using the scale 1:400. Contour intervals were 0.5 m. The morphometric analysis followed Håkanson (1981).

### 2.2. Sedimentological and soil chemical characterization

Six sediment samples were collected in the dry season and six in the rainy season, when the reservoirs began desiccation process and the maximum depth was less than 0.5 m. Samples were taken at three different points distributed randomly within the reservoir basin,

**Tab. 1.** Morphometric parameters of the dry tropical shallow reservoirs in the south-west of the State of Morelos. Shallow reservoirs: 1 =Tilcuate; 2 = Laguna Seca; 3 = Tilizate; 4 = Candelero; 5 = Michapa; 6 = En medio; 7 = Guayabitos; 8 = Alzadas; 9 = El Móvil; 10 = Contlalco; 11= Nopalera.

Parameters	Shallow reservoirs										
	1	2	3	4	5	6	7	8	9	10	11
Area (m <sup>2</sup> )	128,000	67,196	48,952	45,588	45,496	43,416	42,868	41,872	38,112	34,316	32,644
Volume (m <sup>3</sup> )	694,095	50,001	122,971	101,926	40,532	28,821	72,826	136,859	86,783	37,110	67,793
Mean depth (m)	5.42	0.74	2.51	2.24	0.89	0.66	1.70	3.27	2.28	1.08	2.08
Maximum depth (m)	9.70	1.50	5.80	4.75	1.50	5.80	3.35	6.90	5.10	2.00	4.40
Relative depth (m)	2.40	0.51	2.32	1.97	0.62	2.47	1.43	2.99	2.32	0.96	2.16
Shoreline length (m)	2820	1014	930	900	886	810	780	820	840	692	728
Shore development	2.22	1.10	1.19	1.19	1.17	1.10	1.06	1.13	1.21	1.05	1.14
Maximum length (m)	720	380	330	302	290	240	272	320	252	240	240
Maximum width (m)	350	280	220	222	230	240	190	144	142	190	170
Mean width (m)	177.8	176.8	142.9	151	156.9	148.4	157.6	130.9	151.2	180.9	135.1
Maximum depth (m)	9.70	1.50	5.80	4.75	1.50	5.80	3.35	6.90	5.10	2.00	4.40
Depth ratio ( $Z_{\text{mean}} Z_{\text{max}}^{-1}$ )	0.56	0.49	0.43	0.47	0.59	0.11	0.51	0.47	0.45	0.54	0.47
Volume development	1.68	1.49	1.62	1.41	1.8	1.3	1.52	1.42	1.34	1.15	1.46
Vd 3 <sup>-1</sup> (%)	56.0	49.7	54.0	47.0	60.0	43.3	50.7	47.3	44.7	38.3	48.7
1-Vd 3 <sup>-1</sup> (%)	44.0	50.3	46.0	53.0	40.0	56.7	49.3	52.7	55.3	61.7	51.3
Dynamic ratio	0.66	0.35	0.17	0.09	0.24	0.09	0.12	0.06	0.09	0.31	0.09
Direction of major axis	Southwest	East	South	East	Southeast	East	East	East	East	Southwest	East

to 5 cm deep. A granulometric study was carried out by sieving the sediment sample and analyzed in a Robinson pipette with the following fractions: clay (<2 µm), silt (2-50 µm) and sand (50-2000 µm) (Soil Conservation Service 1972). Gravel fractions (>2 mm) were not detected. Other analyses were carried out on the fine fractions of the sediment (<2 mm), the organic carbon content was calculated by the dichromate oxidation method and pH in a 1:1 fine fraction: water suspension (w w<sup>-1</sup>) according to Wolt (1994). Organic matter content was estimated by multiplying organic carbon percentage by a correction factor of 1.724 (Soil Survey Staff 1999). Analysis of soil nitrogen and phosphorus was performed according to Castellanos *et al.* (2000).

### 2.3. Cluster analysis

To examine the morphology, sediment and soil chemical characteristics of dry tropical shallow reservoirs, agglomerative weighted pair-group average and Euclidean distances were used according to Ponce-Palafox *et al.* (1998).

## 3. RESULTS AND DISCUSSION

### 3.1. Morphometric parameters

The shallow reservoirs are supplied with rain water and runoff from the mountains located at north; the upper basin is occupied by a zone induced grassland that is considered a Municipal Ecological Reserve. The land has a gentle slope with north - south direction so that when it rains the water current drags sediments, which are deposited, in the shallow reservoirs. The watershed that drains into the reservoirs has an elongated shape with northwest - southeast orientation, with one single basin. These water bodies have fluctuations in area and volume, according to the amount of rainfall, the effect of evaporation, lost volume by irrigation, and

other causes. Leakage is caused by loss of sediment to provoke the so-called lateral loans (Naselli-Flores 2003).

Their maximum capacity fluctuated from 32,644 to 128,000 m<sup>2</sup> with an average of 51,678 m<sup>2</sup>, they are shallow with a maximum depth from 2.0 to 6.9 meters, and only one reaches 9.7 meters. The morphometrical parameters of the dry tropical shallow reservoirs are shown in table 1. Among these parameters, the mean depth ( $Z_{\text{mean}}$ ) is probably the most important morphometric feature because it could be related with the productivity and trophic status (Håkanson 1981). The shallow reservoirs presented an average  $Z_{\text{mean}}$  of  $2.1 \pm 1.4$ , indicating that their bottom is soft, easily removed and mixed with the water column causing turbidity. They serve as a surrogate for most morphometric attributes and a host of biological processes, but no correlation could provide with unambiguous information on underlying causes (Kalff 2002). However, a low value of  $Z_{\text{mean}}$  normally tends to show high levels of nutrients in water and consequently is a productivity indicator (Sakamoto 1966). Moreover, mean depth may be used to determine the lake bottom roughness, which is a useful parameter in sedimentological studies and in the optimization models for lake hydrographical surveys (Håkanson 1981).

Neumann (1959) concluded that the depth ratio ( $Z_{\text{mean}} Z_{\text{max}}^{-1}$ ) provides a useful approximation to lake form. The shallow reservoirs showed an average value of 0.56, similar to an ellipsoid form that it is characteristic of shallow lakes with flat bottoms (Carpenter 1983). Also showed a relative depth ( $D_r$ ) ranging between 0.51 to 2.40 m. These values are related with the stability of the column of water and the stratification process that is typical of small and shallow basins. Shore development was near of one and it represents a measure of the irregularity of the shoreline (Håkanson 1981), which is one of the morphological parameters that reflects processes related to the lakes' origin. Dyna-

**Tab. 2.** Texture and soil chemical characteristics parameters of the dry tropical shallow reservoirs in the south-west of the State of Morelos. C= Concentration; D= Dilution. Shallow reservoirs: 1 =Tilcuate; 2 = Laguna Seca; 3 = Tilzate; 4 = Candelero; 5 = Michapa; 6 = En medio; 7 = Guayabitos; 8 = Alzadas; 9 = El Móvil; 10 = Contlalco; 11= Nopalera.

Parameters	Shallow reservoirs										
	1	2	3	4	5	6	7	8	9	10	11
Sand (%)	C=68.60	C=24.60	C=58.60	C=34.60	C=36.60	C=60.60	C=40.62	C=66.6	C=18.60	C=32.6	C=60.60
	D=92.92	D=47.28	D=86.92	D=67.82	D=58.92	D=90.92	D=68.92	D=88.92	D=91.28	D=69.28	D=58.92
Silt (%)	C=18.72	C=28.72	C=22.72	C=24.72	C=24.72	C=24.72	C=26.72	C=18.72	C=28.72	C=30.72	C=16.72
	D=3.84	D=20.92	D=9.84	D=18.92	D=17.84	D=5.84	D=9.84	D=7.84	D=2.92	D=24.92	D=15.84
Clay (%)	C=12.68	C=46.68	C=18.68	C=40.68	C=38.58	C=14.68	C=32.68	C=14.68	C=52.68	C=36.28	C=22.68
	D=3.24	D=31.8	D=3.24	D=13.8	D=23.24	C=3.24	D=21.24	D=3.24	D=5.8	D=5.8	D=25.24
Texture	C=crumbly-sandy D=sandy	C=clay D=clay - crumbly - sandy	C=crumbly - sandy D=sandy	C=clay D=crumbly - sandy	C=crumbly - clay D=crumbly - clay - sandy	C=crumbly - sandy D=sandy	C=crumbly - sandy D=crumbly - clay - sandy	C=crumbly - sandy D=sandy	C=clay D=sandy	C=crumbly - clay D=crumbly - sandy	C=crumbly - clay - sandy D=crumbly - clay - sandy
Organic matter (%)	C=2.23	C=3.77	C=0.84	C=5.30	C=4.33	C=3.63	C=4.46	C=9.7	C=5.30	C=4.05	C=2.65
	D=2.8	D=2.3	D=6.9	D=1.4	D=1.4	D=2.3	D=1.4	D=4.46	D=2.1	D=1.6	D=3.2
Nitrogen (kg ha <sup>-1</sup> )	C=80.0	C=135	C=30	C=190	C=156	C=130	C=160	C=377.2	C=190	C=150	C=95
	D=107.8	D=89.8	D=269.4	D=53.9	D=53.9	D=89.8	D=53.9	D=160	D=80.8	D=62.9	D=125.7
Phosphorus (mg L <sup>-1</sup> )	C=206	C=230	C=78.0	C=176	C=220	C=117	C=206	C=240	C=226	C=246	C=246
	D=17.8	D=15.6	D=38.5	D=3.0	D=39.6	D=107	D=19.9	D=15.6	D=67.8	D=114.6	D=132
pH	C=5.83	C=5.77	C=5.6	C=5.77	C=5.87	C=5.59	C=6.55	C=5.7	C=5.77	C=6.25	C=5.66
	D=6.19	D=5.91	D=6.71	D=6.03	D=6.8	D=6.16	D=5.78	D=6.15	D=6.08	D=6.04	D=6.31

mic ratio (DR) is designed to represent bottom dynamic conditions (Lindström *et al.* 1999). The influence of this parameter over the diminishing of volume and other processes related to the water-sediment interface denoted its importance. The average dynamic ratio value of 0.21 indicates that there are lower bottom areas exposed to wind/wave energy. The developments of volume values were greater than one, which indicates a concave depression. The distribution coefficient ( $V_d 3^{-1}$ ) is a useful tool to know the amount of sediment available for re-suspension on the erosion and transport areas (ET-areas), the fraction that goes to deep waters, and the fraction ( $1-V_d 3^{-1}$ ) that goes to surface waters (Håkanson *et al.* 2000). The values obtained mean that 49.0% of the matter available is transported to deep waters and 51.0% to surface waters.

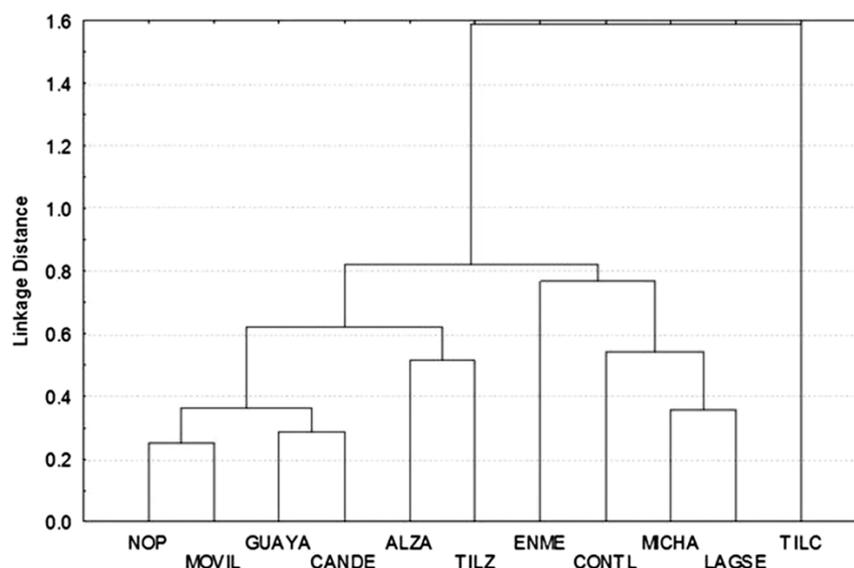
The relative depth for all shallow reservoirs was above 2%, which indicates the structure of daytime thermal discontinuities, however, in this case the water column is mixed by the effect of wind velocity over the maximum fetch in these reservoirs that fluctuated from 240 to 720 m, resulting in a complete mixing, as a consequence the thermal gradient is eliminated. Shallow reservoirs have slight shore slopes, although there is some dissimilarity between the two shorelines. The slight slope allows for colonization of the sediment by submerged macrophytes and halophytes (Ortega & Guerrero 2003).

The less shallow-slope reservoirs were El Tilcuate, Laguna Seca and Laguna de En Medio, this last one being saucer-shaped and having a higher ratio of surface area and maximum depth and bathymetric bit steep decline, reflected in an outstanding average of 4 to 5%. This also improves the incidence of sunlight on the water surface, which increases the process of evaporation, therefore, heat loss, and gain in the water column increases primary productivity. The maximum length

increases wind action creating movements that impact the entire mass of water throughout the day. This causes a greater exchange of material from the sediment (Barbanti 1985). A perfectly circular basin has a shore development of one; irregular basins have values greater than one. It is important to know shore development as a starting input of nutrients to the reservoir as a function of the perimeter. Theoretically similar lakes in all morphometric traits, with the highest shore development will be more productive (Castro *et al.* 2003). The El Tilcuate has the highest shore development with 2.2. El Tilzate, El Candelero, Michapa and El Movil follow it with 1.17 to 1.21.

### 3.2. Sedimentological and chemical soil characterization

Results obtained from the sediment study showed that sand-clay is the most common texture in surface samples. The trend of soil texture in all the shallow reservoirs was to increase the proportion of sand, and clay decrease as the basin was flooded. This was due to washing of sediments from the watershed by carrying heavy material. The percentage of organic matter in the soil of the shallow reservoirs in general decreased (average 3.7 to 3.2%) from minimum to maximum flood (Tab. 2). This was directly related to the concentration-dilution cycle. In the El Tilzate, Las Alzadas and La Nopalera the concentration increased with the period of flooding. In the Las Alzadas, concentration of organic matter was highest (9.7 mg L<sup>-1</sup>) at the stage of concentration and the lowest was 1.4 to 1.6 mg L<sup>-1</sup> at El Candelero, Michapa, Las Guayabitas and Contlalco at the stage of dilution. Soil nutrients from reservoirs generally decreased (nitrogen: 153.9 to 104.3 kg ha<sup>-1</sup>; phosphorus: 199.2 to 52.8 mg L<sup>-1</sup>) and the pH increased from 5.9 to 6.2, from minimum to maximum flood.



**Fig. 2.** Dendrogram of morphological and soil chemical characteristics on dry tropical shallow reservoirs. (TIL = Tilcuate; ENME= Laguna de en Medio; CONTL= Contlalco; MICHA= Michapa; LAGSE = Laguna Seca; ALZA= Alzadas; TILZ = Tilzate; CANDE = Candelero; MOVIL= el Móvil; NOP = Nopalera; GUAYA = Guayabitos).

This was directly related to the concentration-dilution cycle and mineralization of the system.

### 3.3. Cluster analysis

The morphological, sediments and soil chemical characteristics of the reservoirs analyzed by cluster analysis showed two groups. The first was represented by El Tilcuate and the second by the rest of reservoirs which formed two subgroups a and b (Fig. 2). In the first subgroup (a) La Nopalera, el Movil, Las Guayabitos, El Candelero, Las Alzadas and El Tilzate reservoirs conform a cluster, and in the second subgroup (b) laguna de En Medio, Contlalco, Michapa and Laguna Seca reservoirs matched other. It was found that subgroup (a) in general has higher shore development and organic matter. Subgroup (b) has the highest dynamic proportions.

The Factor Loadings Extraction from the Principal Component Analysis (Tab. 3), indicated that the first component was related mainly to morphometric parameters (area, volume, shoreline length, shore development and maximum length), and the second component explained the relationship between some morphometric parameters and the percentage of organic matter, and soil nitrogen.

In general, it was found that El Tilzate, El Candelero and El Movil, are related with shore development and high concentrations of organic matter, and soil nitrogen. The hierarchical agglomerative cluster analysis (HACA) have been used as a efficient method to recognize groups of samples that have similar chemical and physical characteristics (Güler *et al.* 2002; Farnham *et al.* 2000) and in this research the method permitted distinguish relationships between the morphometric, sediment and soil chemistry parameter. Consequently, we

want to emphasize the importance of this study in terms of possible future changes in morphological, sediment and soil chemical characteristics of dry tropical shallow as a result of the use and management of these reservoirs.

**Tab. 3.** Factor Loadings Extraction: Principal components (Marked loadings are  $>0.700000$ ) of parameters morphological and chemical characteristics of soil on dry tropical reservoirs.

Parameters	Component 1	Component 2
Area (m <sup>2</sup> )	0.880841**	-0.305477
Volume (m <sup>3</sup> )	0.893427**	0.206866
Mean depth (m)	0.736072**	0.431480
Maximum depth (m)	0.596731	0.740565**
Relative depth (m)	0.323230	0.899870**
Shoreline length (m)	0.939272**	-0.198855
Shore development	0.922058**	-0.095292
Maximum length (m)	0.926515**	-0.203611
Maximum width (m)	0.614552	-0.560551
Mean width (m)	0.173374	-0.790629**
Depth ratio	0.228598	-0.465036
Volume development	0.638918	-0.294727
Vd 3 <sup>-1</sup> (%)	-0.630846	0.326809
1-Vd 3 <sup>-1</sup> (%)	0.636355	-0.304551
Dynamic ratio	0.652847	-0.599337
Sand (%)	-0.586775	-0.690058
Silt (%)	0.601981	0.637321
Clay (%)	0.468970	0.660445
Organic matter (%)	0.048471	-0.721121**
Nitrogen (kg ha <sup>-1</sup> )	-0.083397	0.746596**
Phosphorus (mg L <sup>-1</sup> )	-0.434369	-0.180237
pH	0.040104	-0.368525

## 4. CONCLUSIONS

Dry tropical shallow reservoirs have fluctuations in area, and volume according to the amount of rainfall, the effect of evaporation, temperature, lost volume for irrigation, and other causes. Leakage is caused by loss

of sediment so-called lateral loans. Shallow reservoirs showed a mean depth ratio ( $Z_{\text{mean}} Z_{\text{max}}^{-1}$ ) of 0.56 similar to an ellipsoid form that is characteristic of shallow lakes with flat bottoms. The relative depth for all shallow reservoirs was above 2%, which indicates the structure of daytime thermal discontinuities. The sediment shows that sand-clay is the most common texture in surface samples. The trend of soil texture in all the shallow reservoirs was to increase the proportion of sand, and clay decrease as the basin was flooded. The percentage of organic matter in the soil of the shallow reservoirs in general decreased (mean 3.7 to 3.2%) from minimum to maximum flood. La Nopalera, el Movil, Las Guayabitas, El Candelero, Las Alzadas and El Tiltate reservoirs had the highest shore development and organic matter. In general, it was found that El Tiltate, El Candelero and El Movil are related by the shore development and high concentrations of organic matter and nitrogen in the soil.

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