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INDEX

Articles

Academics Papers

EDITOR'S LETTER

We welcome you to the most recent issue of the Digital Journal of the Universidad Autónoma de Chiapas, *Espacio i+D Innovación más Desarrollo,* with which we inaugurate Volume XIV, Number 39. We are grateful for these past 12 years because we have witnessed the growth of our publication and the consolidation of our mission: to disseminate the science and knowledge of our highest house of studies. So we celebrate the beginning of a fruitful 2025, wishing that our university community, readers, and collaborators have fullness in all aspects of their personal, academic, and professional lives. This year marks a significant event in our university history, as well as in our state and Mexico, as we begin a new management that will bring renewed perspectives accompanied by the same commitment to quality that characterizes our institution.

This new issue is also an inter-institutional celebration because it offers us articles that address interdisciplinary matters within the framework of the Twentieth Anniversary of the Environmental Engineering program of our sister institution, the Universidad de Ciencias y Artes de Chiapas (UNICACH), among them are: "Study of Generation of Municipal Solid Waste in the Municipality of Chiapilla, Chiapas, and Waste Management Improvement Strategies"; "Application of an electrochemical process to treat liquid waste from GRAM staining tests"; "Waste Destination: A view of its impacts"; "Spectral Characterization and True Color Analysis of Different Natural Dyes such as *Bixa Orellana* and Brassica oleracea var.

Capitata comparados con *Indigofera suffruticosa* y azul de metileno"; "Panorama ambiental del Caribe mexicano como sector hotelero en crecimiento y generador de aguas residuales; retos y alternativas"; "Peligro sísmico en la zona metropolitana de Tuxtla Gutiérrez: dos casos de estudio"; y "Organizarse por el agua en contexto rural e indígena: El caso de la Asociación de Patronatos de Agua del Municipio de Sitalá".

In addition, with the arrival of this new year, we work to continuously improve our processes and continue to provide a quality space for the academic community, in which every voice and every contribution is heard and valued.

We invite you to read the articles in this issue, which reflect the hard work of the research and academic community in the region.

We deeply appreciate your continued support and encourage you to continue to accompany us on this path toward innovation, development, and knowledge!

Sincerely :
The editors
Espacio I+D, Innovación más Desarrollo journal.

"*Por la conciencia de la necesidad de servir*"
Universidad Autonoma de Chiapas

ARTICLES

Reception: **May 15, 2023** | Acceptance: **November 10, 2024**| Publication: **February 1, 2025**

Study of Generation of Municipal Solid Waste in the Municipality of Chiapilla, Chiapas, and Waste Management Improvement Strategies

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— Abstract—

Municipal solid waste management is one of the main challenges faced by society today. Knowing the quantities of waste produced allows us to quantify the equipment needed to acquire it, such as garbage trucks and containers. In addition, they serve as a basis for designing engineering works, such as landfills and waste separation plants.

In this work, a study of the generation of municipal solid waste in the municipal seat of Chiapilla, Chiapas, was developed to generate information that allows making decisions regarding the management of such wastes. The work carried out allowed us to determine the per capita generation rates for the municipal generation source (0.733 kg/inhabitant-day), households (0.615 kg/inhabitant-day), and non-domestic generation (0.118 kg/inhabitant-day). On the other hand, through the study of the composition of solid waste, it was determined that the organic component continues to maintain high percentages in the study area (65.71 %), followed by other subproducts such as plastics (7.38 %), as well as paper and cardboard (4.31 %). Based on the results obtained, some waste management strategies were proposed for the City Council, which include the modification of its local regulations, the formulation of environmental education campaigns, and others. All these actions can serve to improve current conditions in the municipality in terms of waste management.

Keywords:

Solid waste; subproducts; waste generation.

Globally, there has been a drastic change in the generation rates and characteristics of Municipal Solid Waste (MSW), influenced by factors such as population growth, changes in consumption habits, purchasing power, migration, or new customs (Buenrostro & Bocco, 2003; GTZ, 2003; Ojeda & Beraud, 2003). In Mexico, this phenomenon is also present, causing the entities responsible for providing urban cleaning services to face new challenges in the search to provide greater efficiency in those activities.

According to Bernache (2015), among the main challenges faced by the municipalities of Mexico are: i) the lack of economic resources to meet the payment of personnel involved in urban cleaning; ii) the poor vehicle fleet to carry out waste collection; iii) the inadequate location of final disposal sites and their poor operation; iv) the lack of strategies for sustainable waste management; v) the low social participation in management processes, particularly about minimizing the production and separation of waste. Other challenges that include political aspects are established in (Environmental Protection Agency [EPA], 2020), such as the political rotation between trienniums of municipal government and government coordination between different state and municipal agencies.

Before solving problems and challenges associated with MSW through good decision-making, it is essential to know the amounts of waste generated, so studies are used to generate and quantify sub-products of MSW. Bernache et al. (2001) and Ojeda et al. (2008), point out the importance of systematizing methodologies for generation studies, which provide information that serves for the planning of urban toilet services. They are also indispensable because they technically make it possible to quantify the equipment necessary to purchase collection trucks and containers. In addition, they serve as a basis for the design of engineering works, such as landfills and separation plants (Ministry of Environment and Natural Resources [SEMARNAT], 2020). Unfortunately, few municipalities have the infrastructure or knowledge to be able to carry them out

The lack of data on waste production in municipalities can be detrimental to proper waste management. Currently, there are few works carried out in small municipalities or rural communities. The work of Alvarado et al. stands out (2009) and Araiza et al. (2015), since not only waste management figures are generated, but also proposals according to the size of the settlement. This work shows the results of a study of generation and quantification of sub-products of MSW, carried out in the municipality of Chiapilla, Chiapas. This municipality, like many others in the country, has undergone different socio-cultural changes in recent years, which have had an impact on MSW generation rates. For example, according to data from the National Institute of Statistics, Geography, and Informatics (INEGI, 2010, 2020), between 2010 and 2020, the population had an increase of 13.65% that is, the population went from 3,809 to 4,329 inhabitants. In this same sense, the number of homes went from 1,139 to 1,447, that is, there was an increase of 27.04%. In terms of services and commercial establishments, in the same period, there was a small increase in these establishments, from 198 to 205. It is important to mention that the most notable change can be seen in the central area of the municipality or the first picture.

This work is expected to generate useful information for municipal authorities that can use the data to design works, plans, and programs in waste management, for example, redesign the current final disposal site, as well as acquire more collection units. Additionally, some strategies focused on regulatory aspects and environmental education are proposed.

MATERIALS AND METHODS

Waste Management Study Area and Context

This work was carried out in the municipality of Chiapilla, Chiapas, located in southeastern Mexico. Its location coordinates are 16°34' 12.67'' north latitude and 92° 43' 12.76” west longitude (**Figure 1**). The municipality has a total territorial area of 53.04 km^2, has seven localities, of which only the capital is urban, and has a population of 4,329 inhabitants (CEIEG 2023). Currently, the municipality has some deficiencies in waste management, particularly in the stages of collection and final disposal, which are operated with poor infrastructure, so their attention is urgent. Regarding the final disposal site, new cells are required, while, in the case of collection, a greater number of collection vehicles. These deficiencies can be solved through the information provided by the study of sub-product generation and quantification.

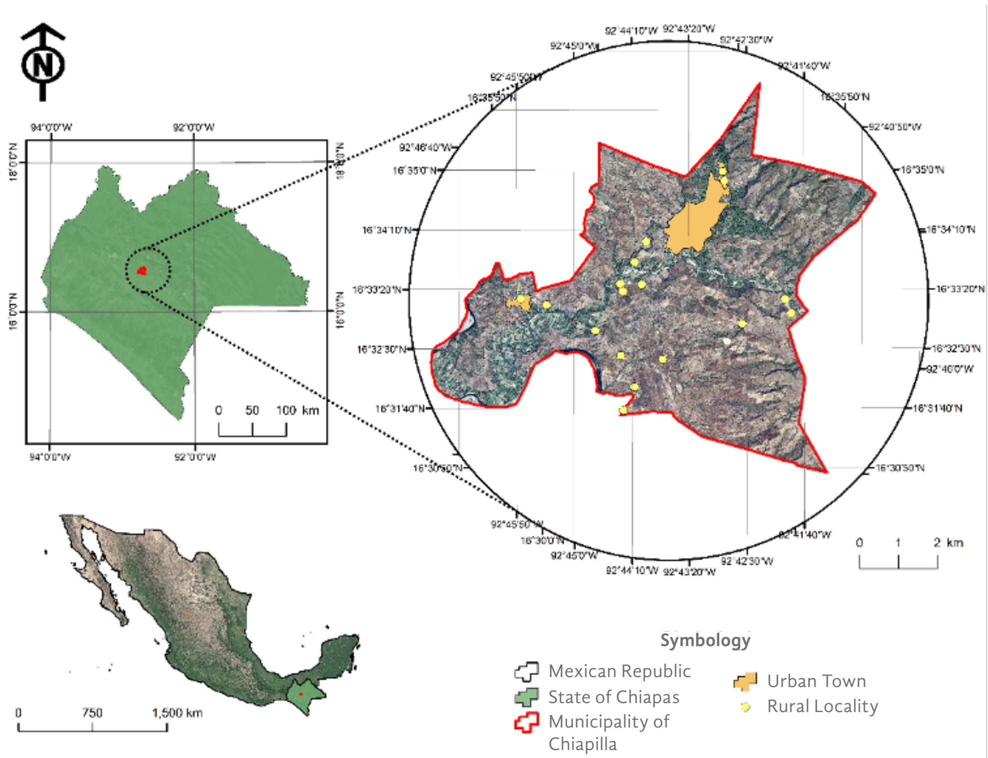

Figure 1. Research area

Collection of baseline data and housing selection

Initially, the INEGI databases were used, in addition to the City Hall of Chiapilla, Chiapas, to confirm the only visible socioeconomic stratum in which waste sampling would be carried out. Subsequently, as indicated by NMX-AA-061-1985 (Ministry of Commerce and Industrial Development [SECOFI], 1985d), to work with a confidence level of 90%, at least 80 houses were determined as pre-samples within the capital, which were numbered on a plan of the study area, and chosen through random numbers produced by statistical software.

Before taking samples in each home, we proceeded to tour the study area, visiting the inhabitants of the selected houses to explain the reason for the sampling, in addition to collecting general information on urban cleaning services. The fieldwork began on Wednesday, June 15, 2022, delivering a polyethylene bag daily, which had to be filled with the waste generated in the house, and collected the next day for further analysis. This operation was repeated until June 21, 2022, when the fieldwork was completed.

It is important to note that the collection of samples was carried out at 7:00 am every day, except for some households where there was no one at home. In addition, the cleaning operation was considered, which consisted of collecting the waste stored the day before the start of the studies, to avoid biases in subsequent sampling.

The analysis of outlier data of *per capita* waste production rates was performed considering the Dixon r22 criterion for samples larger than 14 elements within the MINITAB software. The equations and critical values of the aforementioned exclusion criterion can be found in Davis and McCueen (2005).

Concerning non-household generation (commercial and service), databases shown in Heredia et al. (2007) and Alvarado et al. (2009), which contain waste generation rates by type of commercial establishment, were used. Additionally, information from the National Statistical Directory of Economic Units (DENUE) of INEGI (2023), was used to identify the number of establishments within the capital of Chiapilla, Chiapas. **Table 1** presents a classification of economic units suggested by Araiza et al. (2017a).

Table 1
Establishments and economic units that may be analyzed

Economic units	Description
Commercial	This classification includes both small and large establishments, where necessities and other goods are sold. Among the main establishments are self-service stores, commercial establishments of various types, as well as grocery stores, and meat and vegetable stores.
Services	In this classification are the establishments that assist society, regarding transportation, paperwork, and others. The establishments correspond to public and private offices, cultural and religious centers, as well as gas stations and hotels.
Specials	It is made up of educational centers, medical units, and land terminals.
Others	In the latter classification, the green areas of parks and gardens were grouped.

Determination of the composition of residues and volumetric weights

After collecting the bags of waste from each house/room sampled, they were taken to the workspace assigned by the City Hall, where each bag was weighed and recorded in a database, and the per capita generation rate was obtained based on **Equation 1**.

$$GPD_R = \frac{mBolsa_R}{Hab_{viv}} \quad (1)$$

Where GPD_R is the per capita household generation rate in kg/hab-day; $mBolsa_R$ is the weight of waste within each bag in kg; Hab_{viv} is the number of inhabitants in each dwelling of the day sampled.

Subsequently, the waste from each bag was placed on the floor and mixed as indicated in NMX-AA-015-1985 (SECOFI, 1985a), applying the quartering method, which consists of dividing the waste (into four parts) until obtaining an adequate portion for the subsequent steps. With the support of a 200 L container and following what is described in NMX-AA-019-1985 (SECOFI, 19852b) and **Equation 2**, the operation was carried out to determine the volumetric weight of the waste.

$$\rho_R = \frac{m_{cm}(lleno) - m_{cm}(vacío)}{V_{cm}\ x\ N_{llenado}} \quad (2)$$

Where ρ_R is the density of waste in kg/m³; m_{cm} (*lleno*) is the weight of the full sampling container (kg); m_{cm} (vacio) is the weight of the empty sampling container (kg); V_{cm} is the volume of the sampling container (0.2 m³); $N_{llenado}$ is the fill level of the sampling container (%).

Finally, to characterize or quantify the sub-products, a portion of approximately 50 kg from quarrying was used. In this activity, the residues were placed on a table, categorizing them based on the fractions and components listed in **Table 2**, in addition to what is indicated in NMX-AA-022-1985 (SECOFI, 1985c). It is important to note that the weight percentage of each of the sub-products was determined through **Equation 3**.

$$P_{sub} = \frac{m_{sub}}{m_T} \quad (3)$$

Where P_{sub} is the percentage of the sub-product considered; m_{sub} is the weight of the sub-product considered in kg, discounting the weight of the bag or container used in the weighing; m_T is the total weight of the sample in kg (50 kg or close to that value).

Table 2
Component of the MSW fractions.

Fraction	Components
Organic	Fraction of rapid biodegradability which includes food and gardening waste, as well as pieces of wood.
Paper and cardboard	This includes printing paper, magazine or waxed paper, newspaper, cardboard, and waxed cardboard.
Plastics[a]	In this fraction, pet, HDPE, LDPE, PP, PS, PVC, and mixtures thereof were incorporated into the plastics.
Glass	Two categories were considered: transparent and color
Metals	This includes aluminum in cans and profiles, as well as metals in both can and piece form.
Hazardous[b]	It includes all materials that have CRETIB characteristics, such as syringes, batteries, and medicines.
Technology	Any equipment or part from a household appliance is included.
Not usable	This fraction includes paper and sanitary napkins, as well as other sub-products such as rubber, earthenware and ceramics, construction materials, and fine items.

Note: [a] PET (terephthalate polyethylene), HDPE (high-density polyethylene), LDPE (low-density polyethylene), PP (polypropylene), PS (polystyrene), PVC (polyvinyl chloride).
[b] CRETIB (corrosive, reactive, explosive, toxic, flammable, and infectious biological).

$$GT_R = GD_R + GND_R \tag{4}$$

$$GPU_R = \frac{GT_R}{PT} \tag{5}$$

$$GS_R = GPU_R \ x \ P_s \tag{6}$$

Where GT_R is the total waste generation of the study area in tons/day; GD_R is the rate of waste production from the household source in tons/day; GND_R is the rate of waste production from the non-household source (for example, schools and small businesses) in ton/day; GPU_R is the urban per capita generation in kg/hab-day; PT is the total population of the study area; GS_R is the rate of waste production by sector, colony, or another type of area in ton/day; P_s is the population of each sector, colony, or any other area. **Equation 4** is useful for clearly identifying domiciliary and non-domiciliary sources, while Equation 5 allows the per capita rate to be obtained. **Equation 6** allows us to calculate waste production rates but at the generating source level.

RESULTS AND DISCUSSION

Statistical analysis of per capita household generation

In this study of waste generation, it was possible to work with 86 homes, which participated by delivering the samples with waste during the 8 days that the field activities lasted (including the cleaning operation). After the weighings, obtaining volumetric weights, and characterization of residues, the database was examined by applying an atypical data exclusion analysis, specifically the Dixon r22 criterion (for samples greater than 14 elements), within the MINITAB statistical package (**Figure 2**).

Through the aforementioned exclusion criterion, no data was removed because the value of the test statistic and the p-value are higher than the r22 value of Dixon and α respectively. Therefore, the statistics of the sample were obtained, obtaining an average per capita generation of 0.615 kg/house-day, a median of 0.580 kg/house-day, and a standard deviation of 0.289 kg/house-day. In addition, the calculation of the actual sample size yielded a value of 56, so the 86 pre-samples with which we worked during the study were accepted. This was done considering a sampling error of 0.05 kg/house-day and a percentile of the student t distribution corresponding to the 90% confidence level.

Finally, the reliability analysis indicated that the statistics of the sample can be used as the population parameters since the null hypothesis that the sample mean does not differ from the population mean is accepted (H_0:X =µ vs. H1:X ≠µ). The above, through the p-value obtained, which is higher than the chosen significance value (0.99 > 0.05), considers a 95% confidence level and a two-sided test.

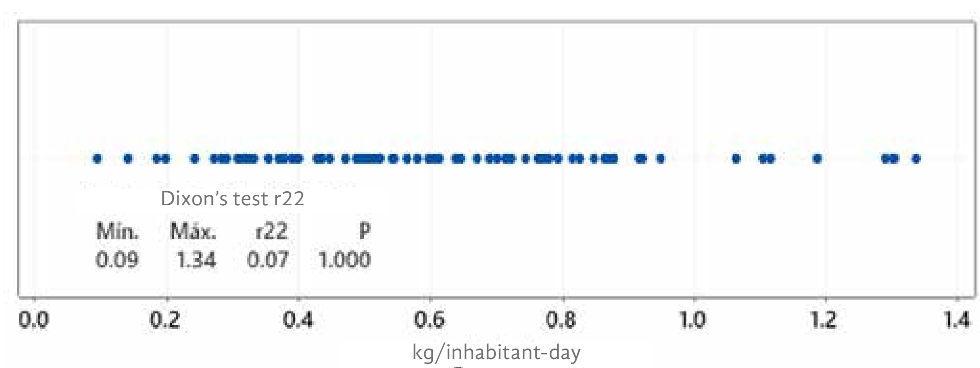

Figure 2. Outliers and application of the exclusion criterion

Household and non-household waste production

Table 3 shows the per capita household generation per day, obtained through the study carried out. A standard deviation of 0.046 kg/house-day is observed concerning the global average rate obtained of 0.615 kg/house-day. It is important to mention that this value is slightly below the national average of 0.653 kg/inhabitant-day, and also below the per capita generation value for small localities of 0.642 kg/inhabitant-day (<10 thousand inhabitants), both data reported by SEMARNAT (2020).

Concerning other studies carried out in Chiapas, the average obtained in this study is higher than the figures reported by Alvarado et al. (2009), Araiza et al. (2015), Araiza et al. (2017a), and Araiza et al. (2017b), for municipalities such as Chiapa de Corzo, Las Margaritas, Berriozábal, and Villaflores respectively, which range between 0.3 and 0.5 kg/inhabitant-day. These differences may be due to the timing of the studies, since according to Jaramillo (2002), normally waste production rates tend to increase annually at a rate of 1 to 2%.

Table 3
Household per capita generation rates obtained in generation study

Day	kg/inhabitant-day average per day	Global average kg/inhabitant-day	Standard deviation kg/inhabitant-day
15/06/2022	0.680		
16/06/2022	0.628		
17/06/2022	0.672		
18/06/2022	0.604	0.615	0.046 kg/inhabitant-day
19/06/2022	0.577		
20/06/2022	0.565		
21/06/2022	0.584		

Regarding the production of non-household waste, according to the information described in the INEGI's Directory of Economic Units (2023), Chiapilla, Chiapas has 205 establishments (**Table 4**), which presented a waste generation rate of around 0.516 tons/day, equivalent to a per capita rate of 0.118 kg/inhabitant-day. It should be noted that commercial economic units, particularly grocery stores and small stores predominate in the study area since they correspond to 36.59% of the total economic units. In contrast, fruit and vegetable stores (1.95%), as well as medical units (1.46%), and educational centers (3.90%) are the economic units with the lowest presence.

Table 4
Waste production from non-domestic sources

Economic units		No. of units	Generation per unit (kg/day)	Total generation (ton/day)
Commercial	Local commercial establishments	47	3.5	0.165
	Small grocery store	75	0.925	0.069
	Butcher shop	13	2.43	0.032
	Fruit and vegetable stores	4	3.92	0.016
	Miscellaneous	18	0.803	0.014
Services	Public/private/cultural offices	18	1.05	0.019
	Restaurants/Food	19	5.96	0.113
Specials	Schools	8	0.059/alumno	0.081
	Medical Units	3	0.92/consultorio	0.003
Others	Parks and gardens (m^2)	402	0.00993/m^2	0.004
	Total	205	--	0.516

Note: The area of parks and gardens is not being considered in the sum of economic units.

Generation per urban capita

With the data on household and non-household generation obtained previously, it can be established that the municipality of Chiapilla, Chiapas, generates around 3.2 tons/day (with statistical figures for 2020), that is, an equivalent to 0.733 kg/inhabitant-day in urban per capita generation and 0.615 kg/inhabitant-day in household per capita generation. It should be noted that this last figure is lower than the national average of SEMARNAT (2020) but higher than the data reported in other studies carried out in Chiapas (see **Table 5**), which, as previously indicated, may be due to climatic and temporal aspects, as well as local economies of the sites where such studies were applied. According to GTZ (2003), other factors could be involved in altering waste production rates, such as household income levels, consumption patterns, population growth, or even urbanization rates. All this information is relevant because it can be used in waste management plans or programs for both household and non-household sources. The population growth factor is usually the most commonly used in all studies related to waste since it provides useful information for future projections (Araiza & Rojas, 2020). Cultural aspects also tend to affect waste production rates, depending on the number of patron saint festivals or events throughout the year. Finally, urbanization also affects waste rates, since the greater the urbanization, the greater the access to new products or services that reach the communities and affect these waste production patterns.

Table 5
Waste production by generating source in Chiapilla, Chiapas

Source	Chiapilla		Promedio nacional[a]	Chiapa de Corzo[b]	Las Margaritas[c]	Berriozábal[d]	Villaflores[e]
	kg/hab-día	ton/día			kg/hab-día		
Household	0.615	2.684	0.653	0.487	0.346	0.456	0.495
Non-household	0.118	0.516	0.291	0.300	0.300	0.163	0.212
Total	0.733	3.200	0.944	0.787	0.646	0.619	0.707

Source: a SEMARNAT (2020); b Alvarado et al. (2009); c Araiza et al. (2015); d Araiza et al. (2017a); eAraiza et al. (2017b)

Spatially, the sources of waste production (household and non-household) are located from the northeast to the southeast, along the main road that crosses the municipal capital (**Figure 3a**). The area with a low presence of waste production sources (**Figure 3b**), is characterized by the existence of vacant lots, scattered houses, lack of paved roads, etc. This influences the fact that the most representative economic units are small grocery stores. On the other hand, the areas with a high presence of waste production sources are highly concentrated in the middle part of the municipal capital (**Figure 3c**), very close to the central park. This area is characterized by the presence of typical houses, administrative offices, large and small commercial establishments, as well as medical and school units. Finally, the zone with moderate (medium) presence of waste production sources of all types covers most of the study area (**Figure 3d**).

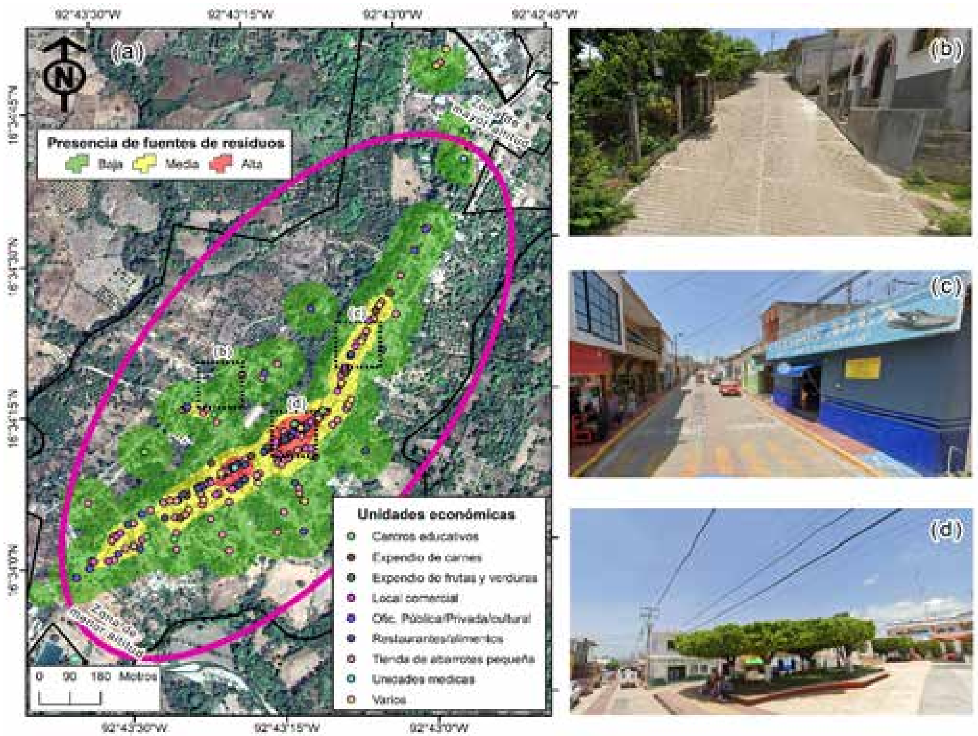

Figure 3. Sources of waste production: a) distribution of sources, b) area with low presence, c) area with medium presence, d) area with high presence

Waste composition

Figure 4 and **Table 6** show the typology of sub-products generated in the municipality of Chiapilla. It is observed that the organic fraction has the highest percentages, particularly food waste at 35.50%, followed by garden waste at 22.91%. Other sub-products such as plastics (7.38%) continue to increase, particularly PET (1.02%), HDPE (1.50%), and LDPE (2.83%). Paper and cardboard fractions, as well as glass and metals, have a very low presence, with percentages ranging between 1 and 3%.

Of all the waste generated in Chiapilla, 81.41% is material that can be recovered or used through some recycling mechanism so as not to be sent directly to final disposal and thus extend the useful life of the local sanitary landfill.

Finally, the fraction of hazardous and technological waste appears to a lesser extent, with a share of 1.15%. This type of sub-product, according to Araiza et al. (2017a), will require some kind of control or treatment mechanism in the future, especially due to the degree of hazardousness they add to the mixture with conventional or household waste.

Table 6

Percentage composition of domestic solid waste from Chiapilla, Chiapas

Fraction	Percentage %	Components	Percentage %
Organic	65.70	Food waste	35.49
		Garden waste	22.91
		Wood	0.35
		Animal bones	0.35
		Seeds and hard shells	6.60
Paper and card-board	4.31	Cardboard	2.57
		Waxed cardboard/Tetrapak	0.52
		Waxed paper/magazine	0.40
		Printing paper	0.48
		Newspaper	0.34
Plastics [a]	7.38	HDPE (high-density polyethylene)	1.50
		LDPE (low-density polyethylene)	2.83
		PET (polyethylene terephthalate)	1.02
		PP (polypropylene)	1.00
		PVC (polyvinyl chloride)	0.07
		PS (styrofoam)	0.28
		Miscellaneous plastics	0.68
Glasses	2.94	Stained glass	0.52
		Transparent glass	2.42
Metals	1.08	Aluminum (cans and paper)	0.42
		Cans of other metals	0.25
		Ferrous materials	0.41
Hazardous	0.61	Hazardous Waste (syringes, batteries, medicines)	0.61
Technology	0.54	Technological waste	0.54
Not usable	17.44	Disposable diapers / sanitary napkins	6.71
		Toilet paper	5.16
		Leather shoes	0.51
		Rag (natural and synthetic)	1.93
		Earthenware and ceramics	0.40
		Rubber	0.01
		Construction waste	0.18
		Fine waste	2.45
		Hair	0.09
			0.00
Total	**100.00**		**100.00**

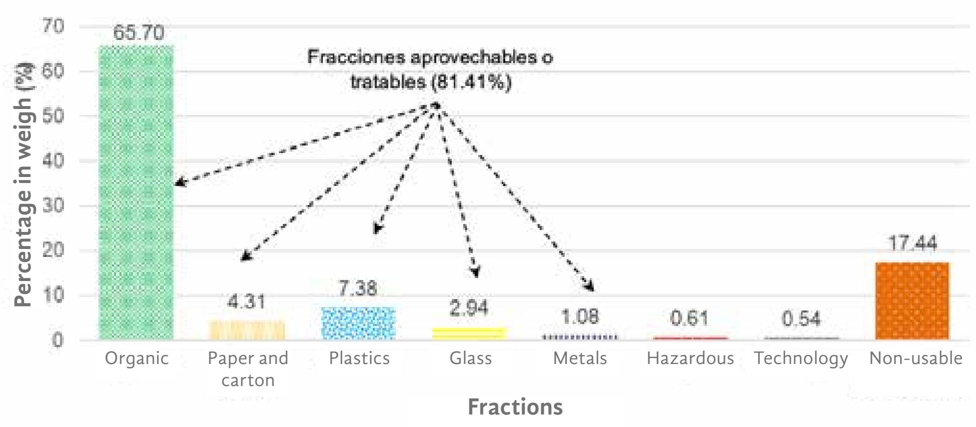

Figure 4. Main solid waste fractions generated in Chiapilla, Chiapas

As for the volumetric weight, the value obtained was 234.07 kg/m³, which is a high value compared to the 140.44 kg/m³ and 128.06 kg/m³ reported by SEMARNAT (2020), as a national average and for small towns (<10,000 inhabitants). This is possibly due to the time of year in which the study was carried out, which was when the first heavy rains appeared, which incorporated water or humidity into the samples, regardless of the humidity contributed by the organic matter present in the waste. According to Colomer and Gallardo (2007), the humidity of the waste ranges between 35 and 65% and the factors that mainly influence the percentage of water in the waste are the content of organic matter, the origin, how they are presented, and the climate of the region.

Environmental improvement strategies for solid waste

Currently, the Chiapilla City Hall lacks much information on the elements involved in waste management, such as data on the urban population served by the cleaning service, the lengths traveled by the collection and sweeping routes, and the service times associated with the collection, among others. This prevents an in-depth analysis of aspects related to the efficiency, quality, and costs of those services. Therefore, one of the first strategies is precisely aimed at promoting municipal authorities to approach academia (educational institutions), to develop studies similar to this work, trying to update the figures of waste generation or carrying out environmental diagnoses. Today there are academic works that cover several small and large municipalities in Chiapas (González, 2021; Cirilo, 2021; Hernández, 2024), but there are still several more missing, given the number of existing municipalities and localities (124 municipalities and more than 20 localities). Much of the work to be carried out must also be focused on implementing emerging waste management technologies, such as large-scale treatment of organic waste or implementing unconventional methods of waste storage and collection, for example, using motorized equipment instead of specialized vehicles, and building high-volume containers with regional materials. On the other hand, it is necessary to promote the development of a municipal regulation related to the management of MSW, since currently according to Araiza (2019), in several municipalities of the state of Chiapas, including Chiapilla, there is a lack of any municipal regulation of constant application in terms of waste.

Another strategy that has gained relevance in recent years is the establishment of operating bodies for waste management. In the Official Journal of the State of Oaxaca POEO (2018) and SEMARNAT (2023), the functioning of such organisms has been reported, mainly paying attention to the stages of collection and final disposal. Through these operating agencies, what is sought is to have finances independent of the City Halls, but with the approval or partial control of them. This will allow it to operate similarly to how private companies do it, that is, through a payment or fee for the service, which makes self-financing possible.

Regarding the current situation of the municipality of Chiapilla, it is important to establish environmental education campaigns by the municipal government, which should be focused mainly on children and women, considering that they are the basis of academic and cultural formation in society. These campaigns must be aimed at the implementation of waste separation practices in homes and schools, as well as the reuse of the sub-products with the greatest presence in Chiapilla's solid waste, such as organic matter or plastics. These activities will allow the establishment of temporary storage mechanisms and also directly influence consumption habits and behaviors related to waste production.

Finally, it is important to seek a radical change in the way waste management policy or hierarchy is applied, not only in Chiapilla but in all municipalities in Mexico. According to the United Nations Environment Programme (UNEP, 2013) and Sáenz and Urdaneta (2014), these policies or hierarchies throughout Latin America are currently aimed at ensuring that conventional collection systems prevail, where organic and inorganic waste are mixed and are disposed of in landfills or open-air dumps, so minimization through recycling and waste treatment is left aside. However, a vision similar to the European one should be sought, where the waste management policy or hierarchy is reversed, that is, looking for minimization, having as a last stage or less favorable option, the final disposal through Sanitary Landfills. In addition, waste recovery and reuse as an energy source are also proposed.

CONCLUSIONS

In this work, the results obtained from a study of the generation and quantification of MSW sub-products prepared in the municipality of Chiapilla, Chiapas, were presented. The main objective of the work was to generate figures and data on solid waste, which municipal authorities can use to design works, plans, and programs on waste management.

The work carried out made it possible to meet the objective set since it was possible to determine the per capita generation rates for the source of urban (0.733 kg/inhabitant-day), domiciliary (0.615 kg/inhabitant-day), and non-domiciliary (0.118 kg/inhabitant-day) production. On the other hand, through the study of waste composition, it was found that the organic component presented the highest percentage (65.71%), followed by other sub-products such as plastics (7.38%), as well as paper and cardboard (4.31%). In addition, only 17.44% is non-usable material that should go directly to final disposal.

Some of the improvement strategies proposed in this work suggest that the City Hall seeks to collaborate with institutions of higher education to carry out more technical studies. In addition, it is also proposed to seek a radical change in the way of applying the waste management policy or hierarchy, in order to minimize and valorize waste. All these actions can serve to improve the current conditions in the municipality in terms of waste management.

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Application of an electrochemical process to treat liquid waste from GRAM staining tests

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— Abstract—

The experimental activities of teaching or research laboratories in higher education institutions can lead to the generation of wastewater that is complex to treat due to its high organic load and low biodegradability, such as those from Gram stain tests (wastewater composed of by the mixture of different dyes such as methyl orange, methylene blue, and gentian violet, among others). For the treatment of these effluents, advanced oxidation processes (PAO) can be a good option as they can achieve complete mineralization of the contaminants, as is the case of Anodic Oxidation (AO). Thus, the effectiveness of OA was tested using two types of electrodes; graphite as cathode and boron-doped diamond (BDD) as anode. The efficiency of the process was tested following the behavior of the chemical oxygen demand (COD) and color as response variables. The tests were carried out under a 3^2-experimental design, that is, different current intensities (0.10, 0.20, and 0.30 A) and pH values (3, 5, and 7). The influent started with initial COD and Color concentrations of 623 mg/L and 234 Pt-Co, respectively. Of the treatments tested, the best was at pH 7 and 0.30 A, with 100% removals in both parameters and up to 96.7% in suspended solids, for a reaction time of 90 minutes. In this way, OA proved to be efficient in oxidizing contaminants present in liquid waste from Gram Stain tests, so it can be a real treatment option for this complex mixture of dye waste generated in school environments.

Keywords:

Anodic oxidation; BDD electrode; Gram stain tests; laboratory wastewater.

In recent years, the publication of numerous studies carried out on bodies of water have warned of the presence of a variety of chemical products such as phenols, sulfides, and chromium, among others, as well as refractory organic compounds present in industrial effluents, such as dyes from wastewater from the textile industry. The latter, especially azo dyes, have a direct and negative effect on aquatic systems, even at low concentrations (Bermeo & Tinoco 2016; Hanane et al., 2020). Azo dyes are composed of two nitrogen molecules joined by a double bond, with high chemical stability and low biodegradability so when faced with this type of molecules, authors such as Barrera-Andrade et al. (2023) and Brdaric et al. (2024), mention that conventional treatment methods such as adsorption, flocculation, activated sludge, among others, are not efficient for decolorizing wastewater effluents. One option for the treatment of this type of compound is the so-called advanced oxidation process (AOP) (Nidheesh et al., 2018).

Among the different treatments that make up the AOP is anodic oxidation (AO), which consists of the generation of sufficient amounts of hydroxyl radicals (•OH) from water oxidation (Velázquez 2015; Xie et al., 2022). Essentially, authors such as Moreira et al. (2017) and Sánchez et al. (2020) point out the characteristics of these radicals; firstly, they represent the second most reactive species in nature, i.e., they have a redox potential of 2.8 V; secondly, they react non-selectively with most organic compounds, therefore, mineralization of the contaminants can be achieved, which will also depend on the type of electrode used and the contaminants treated. One of the most effective electrodes to achieve the combustion of pollutants are the so-called boron-doped diamond anodes (DDB), which have a high overpotential value for oxygen evolution, thereby favoring complete oxidation mechanisms up to CO_2 (Klidi et al., 2018).

AOPs can provide complete mineralization of contaminants in the problem water, as is the case with AO. This is a completely ecological process where there is no transfer of pollutants or sludge production (Sanchez et al., 2020). AO is a process where organic species and electrodes interact when an electron transfer occurs, this can occur at the anode by the generation of active oxygen physisorbed (•OH), or chemisorbed to obtain oxygen in metal oxides (Barrera-Díaz et al., 2014; Bermeo & Tinoco, 2016).

The AO process has been tested in problem waters contaminated with dyes, such is the case of the study reported by Yingying et al. (2021), who tested the removal of azo dyes such as crystal violet, with Ti/BDD electrodes with current densities between 2.5 y 15 mA cm^{-2}, under constant agitation and neutral pH, and with 95% TOC removals. Another study is the one performed by La Rosa and Ponce (2007), where the color removal of methyl orange was evaluated using Ti/Co_3O_4, Ti/PbO_2, and graphite electrodes, with a current density of 2.5 mA cm^{-2} and different pH values (2, 5, and 8). NaCl at 2% was used as the supporting electrolyte. In general, these tests showed color removal above 80%. Results obtained with other types of dyes are also reported, as in the case of the study conducted by Petrucci et al. (2015), using anodic oxidation applied to green dye 19, achieved in 15 minutes of reaction 100% color and 53% TOC removals using DDB electrodes, under the following conditions: current intensity of 300 mA, pH 7, and with 100 mg/L Na_2SO_4 as electrolyte support. In the case of the application of AOP in wastewater from Gram staining tests, as far as the literature review was possible, only the work of Granda-Ramirez et al. (2018) is reported, who applied heterogeneous photocatalysis with TiO_2, working with 10% diluted samples. The reaction time was 2 h and the COD was reduced by 40% and the color by 75%.

Thus, in the present study, unlike most of the reported works, where the AOPs have been applied to a specific dye, the objective of the present document was to evaluate the efficiency of COD and color removal through the OA method, for a mixture of liquid wastes from the Gram stain tests performed in the Environmental Engineering teaching laboratory of the Universidad de Ciencias y Artes de Chiapas (UNICACH). This mixture is mainly composed of dyes such as methylene blue, crystal violet, iodine, safranin, lactophenol blue, and methyl orange, as well as other compounds such as acetone and alcohol.

METHODOLOGY

Characterization of problem water

For this study, the problem water generated semi-annually in the laboratory as a by-product of the Gram staining microbiology practices was characterized with the following parameters: COD, color, total suspended solids (TSS), and pH. The COD test was quantified using the closed reflux micro method, digesting the sample at 150°C for 2 hours, and then reading at 620 nm in a HACH DR-5000 spectrophotometer. A HACH DR/890 colorimeter was used to determine color, and the gravimetric method was used to determine SST. Finally, the pH was only adjusted towards the beginning of the process and was re-determined at the end of the process, using the HI 3220 HANNA equipment. All parameters analyzed were carried out following standardized methods (APHA, 2012).

Experimental tests

Electrodegradation tests were carried out in an undivided electrolytic cell (150 mL beaker) operated under a batch regime. The system consisted of a plate at the top to hold the electrodes, where the anode (working electrode) and cathode (wear electrode) were made of boron-doped diamond and graphite, respectively. The dimensions of both were equivalent, i.e., 2.5 cm wide, 5 cm high, and 1.15 mm thick. The electrodes were placed parallel to each other 2 cm apart and with a submerged area of 6 cm^2. We made a hole at the top of the support plate that allowed the sample volume needed for color and COD measurement to be removed.

The current was provided by a power source brand EXTECH model 382270, in which cables and alligators were used to conduct the current to the electrodes. The electrolyte medium was maintained on a CORNING PC420D plate with constant agitation for 2 hours (Figure 1). For pH adjustments, a H_2SO_4 al 10% solution was used.

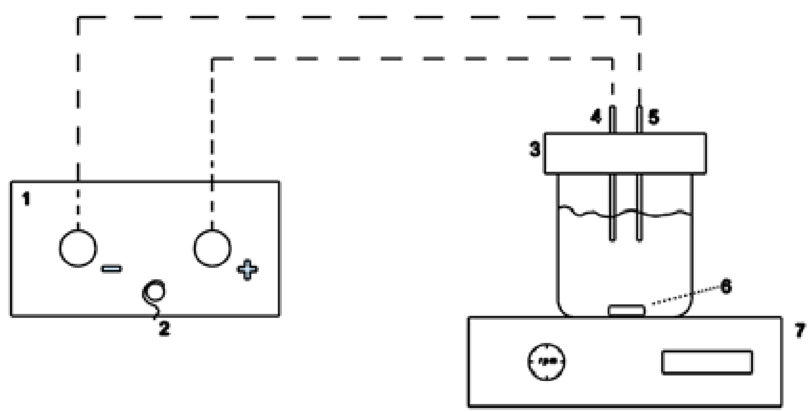

Figure 1. Experimental assembly of the electrochemical process. Where: 1. Power supply, 2. Ground wire, 3. Electrode adapter, 4. Anode (DDB), 5. Cathode (Graphite), 6. Magneto, 7. Stirring grill

Experimental design and data analysis

An experimental design of 3x3 was carried out, taking as study variables the current intensity (*i*) and the pH, each with three levels (Table 1). Levels were established as reported in other studies (Yingying et al., 2021, and Barrera-Díaz et al., 2014). The agitation speed was managed as a fixed factor at 300 rpm, a speed selected based on the report by Sánchez et al. (2020) and Chiliquinga et al. (2020).

Table 1
Experimental design used for the anodic oxidation process. Where: I (Current intensity), A (Ampere)

		pH		
		3	5	7
I (A)	0.10	T_1	T_2	T_3
	0.20	T_4	T_5	T_6
	0.30	T_7	T_8	T_9

The sample volume used was 100 mL for each test, under a 1:50 dilution, which was selected after preliminary tests, additionally, to make the application of the process more feasible, it was worked at room temperature. Finally, to favor the flow of electric current in the electrolytic medium, 0.05 M sodium sulfate was added. This electrolytic agent under this concentration, according to Rubí et al. (2023), favors the removal of color and organic matter (COD and TOC) in the reaction medium, as also shown by what was reported by Yungying et al. (2021), who evaluated the effect of different types of electrolytes on the removal of contaminants, and sodium sulfate was the best of them. It is important to mention that preliminary tests carried out with and without the induction of electric current and electrolyte support, allowed to see the influence of both factors for the electrochemical process to be carried out.

Regarding the response variables (color and COD), equation 1 was used to determine the removal efficiencies achieved, starting from the results of initial concentration (C_i) and final concentration (C_f). The results obtained were analyzed using the statistical program SigmaPlot 12.0, using an analysis of variance where the confidence interval was 95 % and each treatment was carried out in triplicate. In each case, the analysis was performed after checking the assumptions of normality (Shapiro-Wilk), independence, and homoscedasticity. When the analysis showed the existence of a significant difference between treatments, the multiple comparison procedure (Tukey's test) was performed.

$$\% \text{ Remoción} = [(C_i - C_f) / C_i] \times 100 \quad \text{Ec. (1)}$$

Where:
C_i = *Initial concentration*
C_f = *Final concentration*

RESULTS AND ANALYSIS

Characterization of problem water

The results of the physicochemical characterization of the problem water used in the tests under 1:50 dilution are shown in Table 2, as well as their comparison with values reported by other authors.

Table 2
Physicochemical characterization of the problem water (mixture of residues from the Gram staining technique)

Parameters	Units	UNICACH's problem water	Nidheesh et al., (2018)	Yusuf and Reza (2012)
		Gram stain	Textile wastewater	Black Dye 5
pH	--	9.3	9.5- 12.5	10.17
Conductivity	µs/cm	1320	NR	NR
Color	Pt-Co	234	NR	100
DQO	mg/L	613	1835-3828	NR
SST	mg/L	450	60-416	NR

Note: NR: Not reported.

From Table 2 it can be seen that the pH value obtained (9.3) is similar to that found by Nidheesh et al. (2018) and close to what was reported by Yusuf and Reza (2012), who also carried out tests on the elimination of dyes by an oxidation process. In all cases, the pH values are in the basic range.

In appearance, the hue of the laboratory residue was purple and slightly viscous (somewhat characteristic of basic substances), with a COD reading of 613 mg/L and 234 Pt-Co in color. In the case of COD, the value shown in Table 2, was lower than that reported by Nidheesh et al. (2018), otherwise in the color, where the reported value is higher than that mentioned by Yusuf and Reza (2012) although the value of the problem water becomes much higher if we start from its concentrated value.

In general, it is observed that Gram staining residues represent a complex problem water with important values in both COD and color, finding a good part of its contaminants in suspended form.

COD Behavior and Removal

For COD removal results, Table 3 shows that the differences in mean values between most treatment groups are greater than would be expected by chance; that is, there is a statistically significant difference according to the analysis of variance performed (GL = 8, $\alpha = 0.009$, F = 3.950).

Table 3

Mean and standard deviation (SD) of COD removal percentage

	Treatments								
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**
	pH 3, 0.10 A	pH 5, 0.10 A	pH 7, 0.10 A	pH 3, 0.20 A	pH 5, 0.20 A	pH 7, 0.20 A	pH 3, 0.30 A	pH 5, 0.30 A	pH 7, 0.30 A
Mean	63.000	33.333	77.000	76.333	71.667	70.333	81.000	85.000	88.333
SD	26.889	3.055	4.359	34.298	24.786	25.146	3.000	25.981	20.207

The test procedure shown in Table 4, revealed that of 36 comparisons made, significant differences were obtained in 5 of them, where the results obtained under this test are statistically significant when presenting P values ≤0.05.

Table 4

COD Multiple Pairwise Comparison Procedures (Tukey's Test)

Comparison	Average differences	*P*	P<0.050
T9 pH 7, 0.30 A vs. T2 pH5, 0.10 A	55.000	0.005	Si
T8 pH 5, 0.30 A vs. T2 pH5, 0.10 A	51.667	0.009	Si
T7 pH 3, 0.30 A vs. T2 pH5, 0.10 A	47.667	0.018	Si
T3 pH 7, 0.10 A vs. T2 pH5, 0.10 A	43.667	0.035	Si
T4 pH 3, 0.20 A vs. T2 pH5, 0.10 A	43.000	0.039	Si

Regarding the behavior in the removal of the COD parameter, Figure 2 shows a tendency to improve the removals in this parameter as the current intensity was increased, mainly for the most favorable reaction time (90 min) where maximum removals were achieved (100%), that is, Figure 2c (pH 7 at 0.30 A). This shows current intensity as one of the operating parameters that has the greatest impact on the degradation of complex organic molecules (González et al. 2011; Cruz 2013), being able to favor the interaction of organic species and electrodes, through the transfer of electrons. Mechanisms that, according to Bermeo and Tinoco (2016), come to occur at the anode, mainly with physisorbed hydroxyl radicals (•OH).

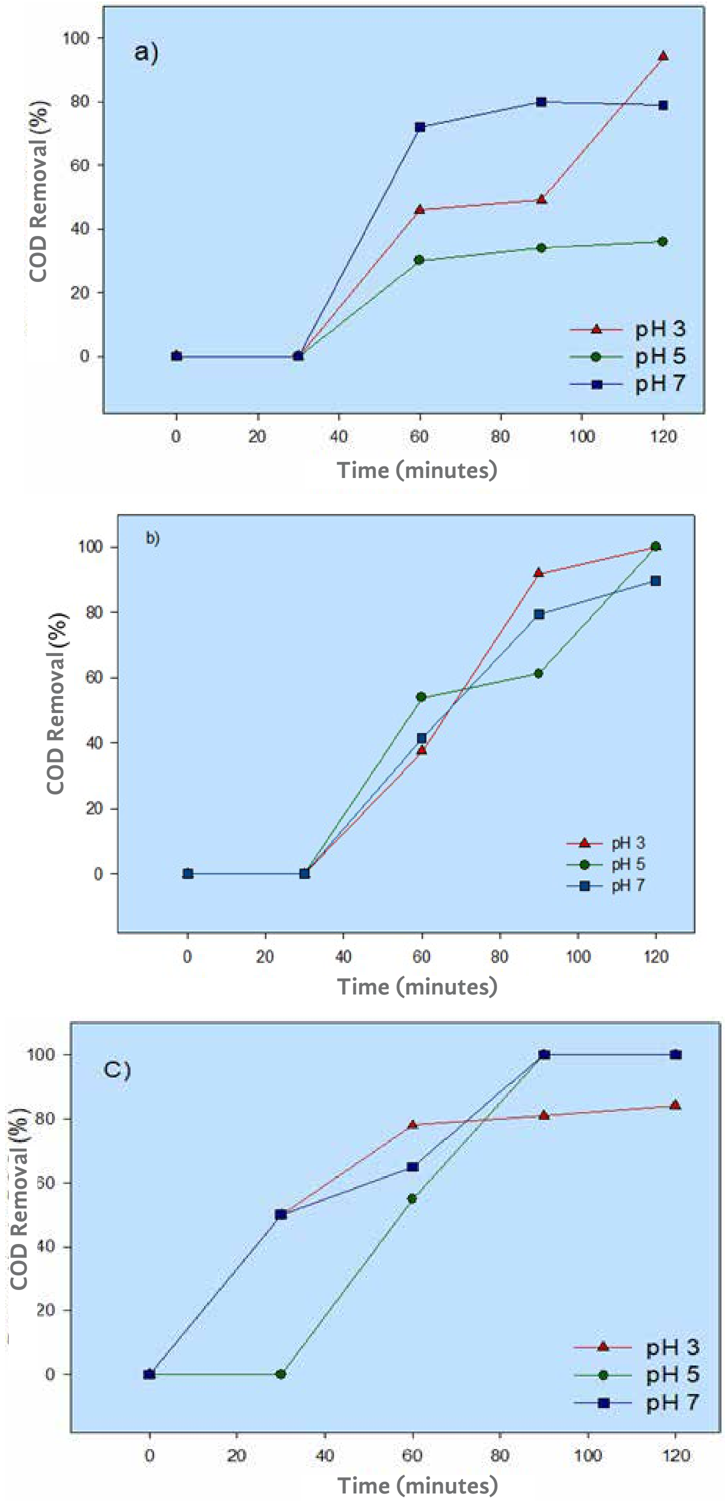

Figure 2. Removal of COD at different pH values and current intensities: a) 0.10 A, b) 0.20 A y c) 0.30 A

Figure 2a (0.10A) shows that the highest COD removal (94%) was obtained at pH 3 around 120 minutes of reaction. The remaining two treatments at pH 5 and 7 were below 80%.

For condition 0.20A (Figure 2b), in the treatments at pH 3 and 5, a 100% COD removal was achieved, with a final pH of 4, and for the treatment at pH 7, although the pH value in the final effluent remained neutral, the removal achieved was lower (89% COD).

Figure 2c shows that the highest removal (100%) was achieved at pH 5 and 7 and with only 90 minutes of reaction. In general, the results obtained for the best treatments (100% COD removal), reflect higher removals than those obtained in other studies, such as those reported by Bermeo and Tinoco (2016), who achieved slightly lower removals (96% COD), when working with synthetic water from the textile industry, or the study reported by Yingying et al. (2021) who report removals of the azo dye AV7 below 75% COD removal.

Behavior and color removal.

For the color removal results, an analysis of variance was also applied as shown in Table 5. Evidence of significant difference between treatments was observed in this analysis (GL = 8, $\alpha = 0.013$, F = 3.120).

Table 5

Mean and standard deviation (SD) of color removal percentage

	Treatments								
	T1	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**
	pH 3, 0.10 A	pH 5, 0.10 A	pH 7, 0.10 A	pH 3, 0.20 A	pH 5, 0.20 A	pH 7, 0.20 A	pH 3, 0.30 A	pH 5, 0.30 A	pH 7, 0.30 A
Mean	48.500	16.250	31.500	52.000	58.250	62.000	63.750	62.000	80.750
SD	23.331	4.272	19.192	20.050	31.298	21.894	20.966	19.579	24.102

Thus, the source of variation of the significance level "P" indicates that in some of the means there is a significant difference since P=0.013, in short, the significance level is less than 0.05. To isolate the group or groups that differed from the others, the Tukey test was used (Table 6).

Table 6

Multiple pairwise comparison procedures for color removal (Tukey test)

Comparison	Average differences	P	P<0.050
T9: pH 7, 0.30 A vs. T2: pH 5, 0.10 A	64.500	0.006	Si

In this sense, the analysis of variance performed on the 36 comparisons allows us to see that the difference between some of the removal percentages achieved by the treatments evaluated is significant in only one comparison. According to the analysis using Tukey's test, it was observed that there is a significant difference between the means of the comparisons in the treatment T9 vs T2; that is, pH 7, 0.30 A vs. pH 5, 0.10 A.

In the case of the removal of the color parameter, Figure 3 shows that at low current intensity, the results were below 70%. The opposite was the case with the rest of the current intensities, where the results were above 80% removal.

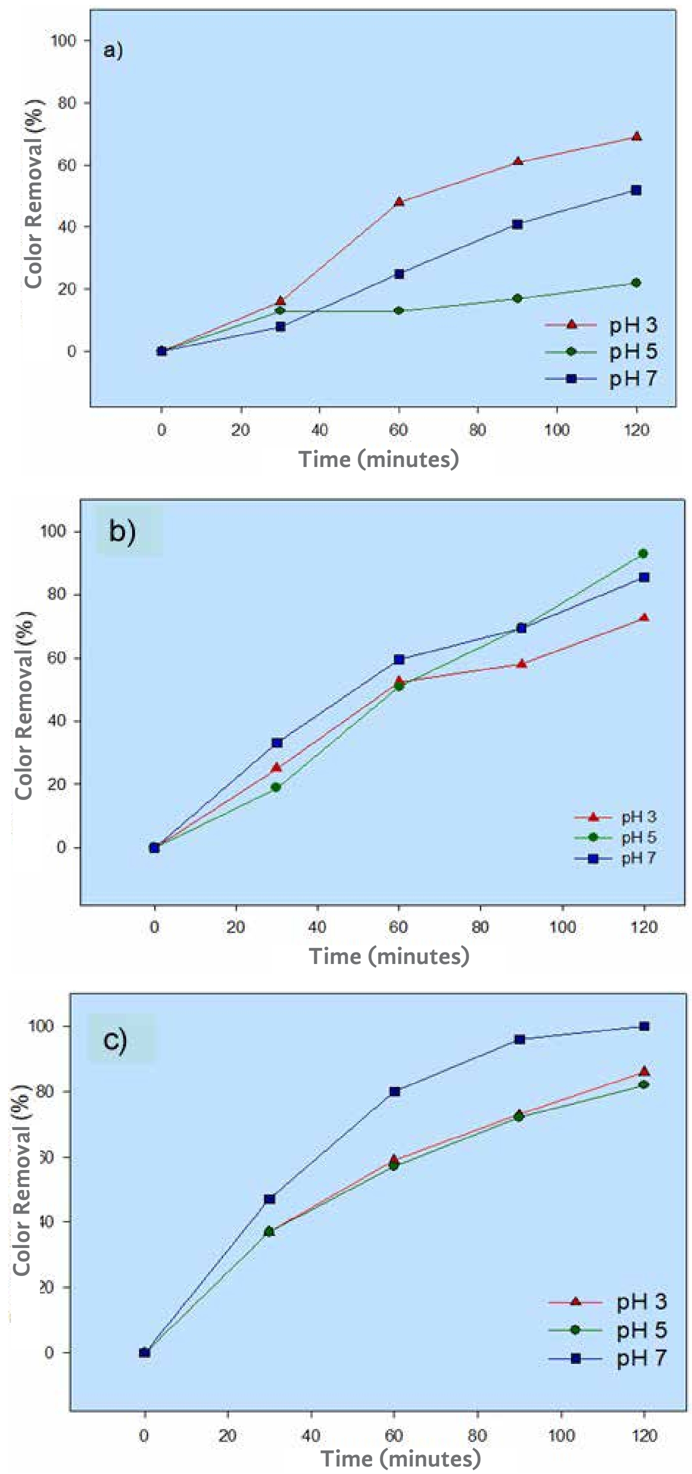

Figure 3. Color removal at different current intensities a) 0.10 A, b) 0.20 A, and c) 0.30 A

From Figure 3, it can be seen that the 3 treatments tested at a current intensity of 0.10 A (Figure 3a) show the lowest color removal efficiencies, and in general in the range of 22 to 69.26%.

For Figure 3b (current intensity of 0.20 A), it can be seen that for a reaction time of 120 minutes and at pH 5 and 7, the highest removals were recorded, i.e., 93 and 85%, respectively.

Finally, for Figure 3c (current intensity of 0.30 A), the maximum removals (100%) were obtained at pH 7, for the 90 and 120-minute reaction times. As with COD, the influence that current intensity can have on the degradation of complex organic molecules can also be seen with this parameter (González et al. 2011; Cruz 2013).

In general, in the decomposition of complex organic molecules, the •OH produced in the reaction medium, according to authors such as Barrera-Andrade et al. (2023) and Milam and Planalp (2024), are effective in the decomposition of dyes such as methylene blue, present in the dye mixture that characterizes Gram staining residues. The process begins by adding hydroxyl radical to the ring or the oxidation of the sulfur atom. After several additions of hydroxyl radicals to the phenyl rings, the ring structure may break down into phenolic moieties, giving way to further oxidations up to possible mineralization of the molecule (CO_2 and H_2O).

On the other hand, the analysis of the final characterization of the influent and effluent was carried out for the best combinations of pH and the different current intensities. Results are shown in Table 7.

Table 7

Characterization of wastewater (influent and effluent)

			a pH 3 (0.10 A)		b pH 5 (0.20 A)		c pH 7 (0.30 A)	
Parameters	Unit	Influent	Effluent	Removal %	Effluent	Removal %	Effluent	Removal %
pH	---	---	3.4	---	7	---	5	---
Color	(Pt-Co)	234	69.26	70.4	85	63.7	0	100
DQO	(mg/L)	612	36.72	94	61	90	0	100
SST	(mg/L)	450	390	13.3	75	83.3	15	96.7

From the table, it is observed that both the color and COD recorded 100% removals under the combination of pH 7 and 0.30 A, when recording values of 0 towards the end of the treatment. It also highlights the low presence of SST in the final effluent (15 mg/L). The removals achieved in the present study were much higher than those reported in the only work found (Granda-Ramírez et al. 2018), where a PAO such as heterogeneous photocatalysis with TiO_2 has been applied to the residues of the Gram staining test, and only 40% of the COD and 75% of the color were removed.

Behavior of the evaluated parameters and the statistical error obtained

The results of the color removal and COD concerning the error obtained are shown in Figures 4 and 5.

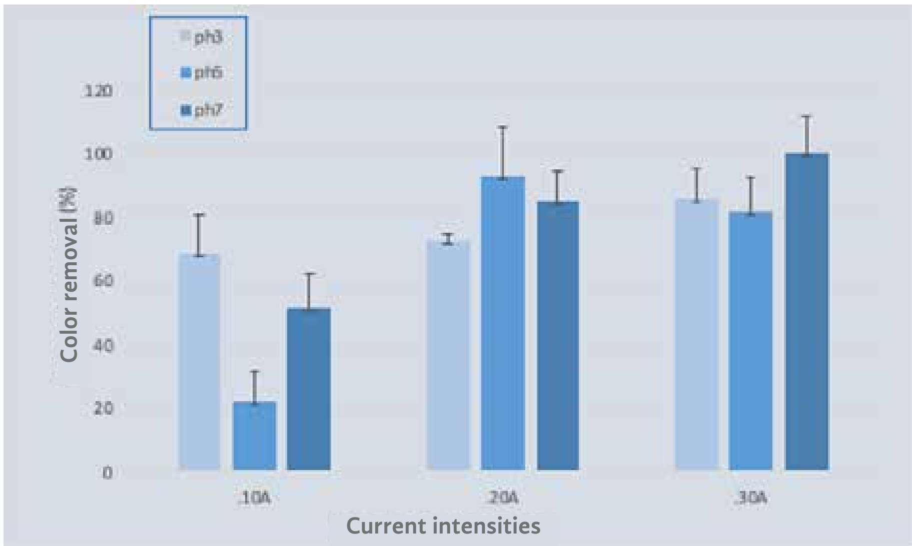

Figure 4. Color removal with the error obtained

As can be seen and under the conditions evaluated, the color removal values are not dispersed, they are even more concentrated at the pH 3 value under 0.20 A. In any case, it is convenient to highlight the direct relationship between the color removal and the applied current intensity; in fact, the higher the current intensity, the color removal result was more significant.

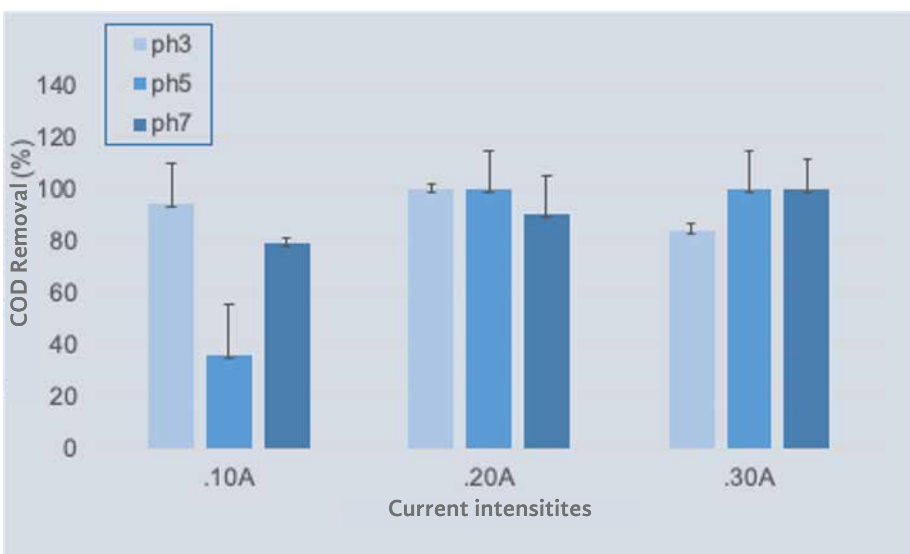

Figure 5. Removal in COD with the error obtained

For the COD removal treatability tests, it was observed that for the conditions evaluated (0.10 A and pH 7, 0.20 A, and pH 3, and 0.30 A and pH 3), the error values obtained were concentrated and the removals were above 80%.

CONCLUSIONS

The OA using the DDB electrode as an anode and the graphite electrode as a cathode, proved to be efficient in oxidizing the contaminants present in liquid waste from the Gram staining tests, so it can be a real treatment option for this complex mixture of dyes generated in school environments.

The ANOVA demonstrated the existence of significant differences between treatments. Tukey's test showed that the best removal conditions were 100% in COD and color, and 96.7% in SST when the system was operated with 300 mA and neutral pH.

Finally, considering that the UNICACH Environmental Engineering teaching laboratory generates an average of 2 L of Gram staining liquid waste every six months, it would be necessary to treat around 100 L of the already diluted test water, which could be discharged with values of zero mg/L in COD and zero Pt-Co units in color under the best conditions found in this study.

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Waste Destination: A view of its impacts

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— Abstract—

The generation of Municipal Solid Waste (MSW) reflects the culture of a society, and inadequate management of it can have a negative impact on public health and the environment. In Mexico, approximately 120,128 tons of USW are generated per day (SEMARNAT, 2020). There are 2,203 registered Final Disposal Sites (FDS), of which 87% are uncontrolled sites, with sanitary landfills being the minority. The adverse effects of inadequate final disposal of MSW include air and water pollution, methane and leachate emissions, landscape degradation, and the proliferation of diseases due to the transmission vectors they harbor. This document aims to provide an overview of MSW disposal in Mexico, as well as its main environmental and social impacts.

Keywords:

Urban solid waste; final disposal; environment.

The problem with waste began when humans stopped being nomads and settled in fixed places (Córdoba-Meriño et al. 2018). Since then, the complexity and impact of waste management have increased over time. Have you ever wondered what happens to the garbage we generate daily? For many people, it remains a mystery, as they often dispose of their waste without reflecting on their final destination. However, garbage does not magically disappear, it just changes places, and if not handled properly, it can cause serious damage to the environment.

In Mexico, the problem of garbage continues to increase, due to factors such as population growth, industrial development, technological advances, changes in consumption habits, and the increased use of disposable products with slow biodegradability (SEMARNAT, 2015). This situation has worsened in the post-pandemic context, due to new habits such as the growth of e-commerce, which has generated a greater amount of cardboard packaging, plastics, and other materials used in shipments, as well as the high consumption of personal protection supplies such as antibacterial gel and face masks (Das et al. 2021; Oceana, 2023).

Final waste disposal represents a major challenge due to the high costs associated with the construction, operation, and maintenance of sites suitable for final disposal. Improper management can have serious consequences for both the environment and public health. Soil pollution, and the damage of aquifers and surface water bodies, are just some of the problems that can arise as a result of poor management (Jaramillo, 2002).

This work aims to explore the different aspects of municipal solid waste (MSW) management in Mexico. The structure of the document is organized as follows:

1. **What is MSW?**
   The definition and classification of MSW will be presented.
2. **How many MSW are generated in Mexico?**
   Statistics on the amount of waste generated in the country will be presented.
3. **MSW final destination**.
   We will describe how MSW is managed in Mexico, detailing the types of disposal sites.
4. **Residues after final disposal**
   We will analyze the by-products generated after the waste disposal.
5. **Environmental and population impacts due to the inadequate disposal of MSW.**
   The negative effects of poor waste management on public health and the environment will be explored further.

6. **Final comments.**
   Conclusions and recommendations will be offered to improve waste management in Mexico.

METHODS

A review of academic and scientific sources, government reports, and statistical data on the final disposal of solid waste in Mexico was carried out. The search was conducted through platforms such as PubMed and Google Scholar.

We chose scientific articles in English and Spanish, reports from agencies such as the Secretariat of Environment and Natural History (SEMAHN), the Secretariat of Environment and Natural Resources (SEMARNAT), and statistical data provided by the National Institute of Statistics and Geography (INEGI).

Selection criteria were based on relevance, academic quality, and publication period, prioritizing those documents published between 2002 and 2024.

The search terms used were:

- Management of solid waste
- Environmental impact of waste
- COVID Waste Management
- Generation of waste
- Waste Legislation in Mexico

These combinations made it possible to address key aspects related to the management, impact, and regulation of solid waste.

1. WHAT IS MUNICIPAL SOLID WASTE?

As a result of the daily life of human beings, waste is generated, such as in homes and public, private, and recreational dependencies, among others (Tello-Espinoza, 2018). All our human activities, from the production and consumption of goods and services, inevitably generate waste. Housing construction, for example, in addition to construction material waste such as concrete, bricks, and wood, can also generate hazardous waste such as paints and solvents. Every day we use public or private transport, a service that generates waste derived from maintenance and operation, such as used oils, worn tires, and discarded batteries, among others.

In today's digital age, even the most remote places have telecommunications services. The installation and maintenance of telecommunications networks produce electronic and construction waste. In addition, electronic devices such as mobile phones, computers, and network equipment have relatively short life cycles, resulting in a constant accumulation of electronic waste (Oceana, 2023).

When the materials can no longer be used directly in the same activity where they were generated, they are considered waste. Although there are several definitions for the term "waste", in general, it is understood as any material that, once generated, is no longer useful to the person who generated it, which leads to the need to get rid of them.

The definition of solid waste, according to Tchobanoglous et al. (1994), is *"all waste arising from human and animal activities, which are normally solid and are disposed of as useless or not required"*. This concise definition states that any material that has lost its usefulness within the context in which it was generated becomes a waste, but may have potential as a secondary raw material in other processes. For example, used cooking oils can be collected and transformed into biodiesel by transesterification processes (Haq et al. 2021).

In Mexico, according to the General Law for the Prevention and Integral Management of Waste (LGPGIR), waste *"is any material or product that is discarded, which may be in a solid or semi-solid, liquid or gaseous state, contained in containers or deposits, and susceptible to valuation or subject to treatment or final disposal"*. These wastes are classified into municipal solid waste, special handling waste, and hazardous waste, according to their characteristics and origin.

According to Mexican Official Standard NOM-083-SEMARNAT-2003, municipal solid waste (MSW) is defined as:

> Waste generated in households, resulting from the disposal of materials used in their domestic activities, the products they consume and their containers, packaging, or wrappings; waste from any other activity in establishments or on public roads that generate waste with household characteristics, and waste resulting from the cleaning of public roads and places.

MSW includes a wide variety of materials, from organic materials such as food scraps and yard waste to containers, packaging, and wrappings used in daily activities, as well as textiles and urban cleaning waste, among others. These materials make up what is commonly known as trash.

2. HOW MUCH MUNICIPAL SOLID WASTE IS GENERATED IN MEXICO?

The generation of municipal solid waste (MSW) in Mexico is a common problem in all communities and its magnitude is directly related to the amount of waste generated (Tello-Espinoza, 2018). Over the last seven decades, there has been a remarkable increase in MSW generation. In 1950, per capita generation was 0.300 kg/inhab/day. However, by 2012, this daily volume almost tripled, reaching 0.852 kg per inhabitant (SEMARNAT, 2012). It is estimated that in 2020 the volume amounted to 0.944 kg. According to the National Census of Municipal Governments and Territorial Districts, which is conducted every two years, at the national level, total generation is estimated at 108,146 tons per day, compared to 99,770 tons per day estimated in 2012 (INEGI, 2023). Regarding the state of Chiapas, a daily generation of 5,188 tons is estimated, which represents 4.8% of the national total (SEMAHN, 2022).

The increase in MSW generation is attributed to several factors, such as the growth of urban areas, industrial development, technological advances, and changes in the population's consumption habits (Jaramillo, 2002). These factors contribute to the complexity of the problem, as the waste generated tends to have an increasingly less biodegradable composition and a greater amount of toxic compounds (Köfalusi & Aguilar, 2006).

The COVID-19 pandemic accentuated this problem by significantly increasing the generation of waste such as disposable masks, antibacterial gel containers, and other personal protective equipment (Das et al. 2021; Yousefi et al. 2021). According to NOM-087-SEMARNAT-SSA1-2002, these materials are mostly classified as Biological-Infectious Hazardous Waste (BIWW) in hospital settings, and a considerable part ended up being part of the MSW due to their massive use by the general population. This situation shows deficiencies in the separation and final disposal systems since many of these wastes do not receive adequate management, increasing the risks of environmental contamination and public health.

Taken together, these factors have contributed to progressive environmental deterioration, highlighting the urgent need to address the problem comprehensively and sustainably to mitigate its negative impact on the environment and public health.

Article 10 of the LGPGIR establishes that the integral management of MSW is under the responsibility of municipal governments, from collection to final disposal. However, in practice, municipalities lack technical and financial capacities which makes it difficult to implement effective measures to address this problem comprehensively.

3. THE FINAL DESTINATION OF MUNICIPAL SOLID WASTE

The final disposal of MSW refers to their permanent deposit when they are considered to have lost their value. However, it is important to note that not all MSW end up in the same destination, as this depends largely on the effectiveness of policies, infrastructure, and management capacity available in each municipality (Rodríguez & Montesillo, 2017). In addition, citizen culture in MSW management plays an important role, since it can influence the amount of waste generated, its disposal, participation in recycling programs, and the adoption of more sustainable practices in its management (Córdova-Merino et al. 2018; Kountouris,2022). In Mexico, many municipalities do not have adequate MSW management.

At the national level, there are 2,203 Final Disposal Sites (SDF) and Chiapas is among the states with the largest number of these sites, along with Chihuahua, Veracruz, and Oaxaca (Fig. 1, SEMARNAT, 2020). The most common final disposal practices are Sanitary Landfills (RS) and predominantly, Open Sky Landfills (TCA), commonly known as garbage dumps. These methods are described below.

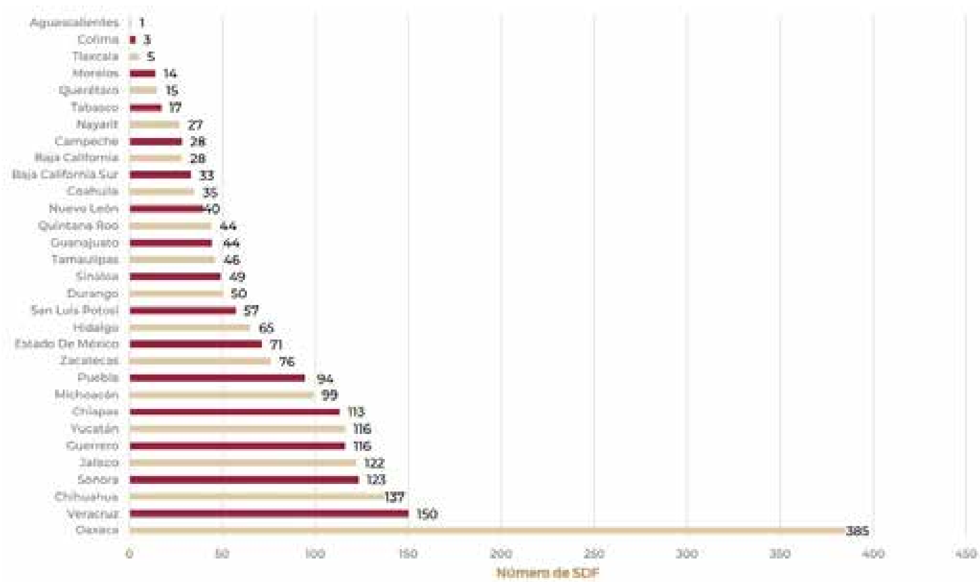

Figure 1. Sites of Final Disposal by the federative entity. Source: SEMARNAT, 2020

3.1 Sanitary Landfill (SL)

It is an engineering method designed to manage solid waste in a safe and controlled manner. In general terms, it consists of depositing the waste in waterproofed cells where they are compacted to reduce their volume and optimize the storage capacity of the site, daily they are coated with soil or other inert material to prevent the proliferation of sanitary vectors and bad odors. The by-products generated by the decomposition of waste must be properly managed to avoid environmental contamination (Jaramillo, 2002; Nájera-Aguilar et al. 2012). The Mexican regulation, NOM-083 SEMARNAT-2003, establishes the environmental specifications for the selection of the site, design, construction, operation, monitoring, decommissioning, and complementary works of an SL.

SL are a safer and less environmentally damaging alternative compared to uncontrolled final disposal methods that allow for more orderly and efficient management of MSW contributing to long-term environmental sustainability.

3.2 Open Sky Landfills (OSL)

It is the oldest method for MSW disposal, which consists of depositing them directly to soil without any type of coating or environmental control on the by-products caused by the decomposition of organic matter (Fig. 2). These sites are often set on fire frequently since the garbage contains and generates combustible substances (Cerda, 2007), therefore, it is an inappropriate practice due to the adverse effects on the environment and public health. Most OSL are clandestine and have spread throughout Mexican territory occupying ravines and riverbeds, lakes and lagoons, abandoned mines, swampy areas, wastelands, and geologically unstable areas (Rojas-Valencia & Sahagún-Aragón, 2022).

Image 2. Open Sky Landfill, Berriozabal, Chiapas. Source: Own

Of these disposal sites, MSW is the only environmentally acceptable, provided they are designed, constructed, and operated under current regulations to minimize environmental impacts and public health risks. Unfortunately, in our country, the most common practice continues to be the use of Open

Sky Landfill, with more than 87% of the FDS operating under this method (INEGI,2020) due to ease and low cost of operation.

Currently, there are some alternative methods for the final disposal of MSW, such as recycling, composting, incineration, and waste-to-energy production (Cabrera, 2022). These methods seek to reduce the amount of waste sent to landfills to prolong their useful life and promote more sustainable management.

4. RESIDUES AFTER FINAL DISPOSAL

The decomposition of municipal solid waste in any FDS inevitably generates other wastes or by-products, mainly biogases, and leachates:

4.1 Biogas

It is a gaseous mixture produced by the fermentation of the organic fraction of solid waste disposed in FDS, composed mainly of methane (405-55%) and carbon dioxide (40-50%). Minor amounts of nitrogen, hydrogen sulfide, hydrogen, and oxygen and traces of carbon monoxide, ammonia, and aromatic hydrocarbons (Vaverková, 2019). The production and composition of the biogas released depends on the waste composition, moisture content, temperature, and the FDS age, among others. It is generated during the anaerobic decomposition of organic matter that begins between one or two years after it has been deposited and continues for about 15-25 years (Köfalusi & Aguilar, 2006; Rojas-Valencia & Sahagún-Aragón, 2022).

4.2 Leachate

Liquids are generated by the decomposition of waste and the filtration of rainwater through them. They are considered highly polluting due to their variable and heterogeneous chemical and microbiological composition. The content of contaminants in leachates (biodegradable and refractory organic material, humic components, heavy metals, inorganic salts), varies with time, generally in the first years of decomposition there is a rapid increase and with the years there is a slow decrease that can be for more than 50 years (Costa et al., 2019; Vaverková, 2019). However, their composition and concentration may vary depending on the nature of the waste in the same way as in biogas production.

The main difference in emissions between FDS is that, in OSL, biogas, and leachate are released without control, which has environmental and social repercussions.

5. ENVIRONMENTAL AND POPULATION IMPACTS DUE TO INADEQUATE MSW DISPOSAL

Inadequate MSW disposal management generates multiple problems affecting both the environment and communities. The main impacts include soil and water pollution, greenhouse gas emissions, the proliferation of diseases such as malaria and dengue fever, the presence of foul odors, blockage of drains and sewers, and damage to wildlife, such as suffocation of animals in plastic bags (Abubakar et al. 2022).

The aesthetic quality of the environment near the disposal sites is seriously affected by dust and the dispersion of light waste, such as plastics and paper. In addition, odors from the decomposition of organic waste, mainly due to the presence of ammonia and hydrogen sulfide, worsen the quality of life of nearby communities, as prolonged exposure to these volatile compounds has been associated with potential health risks, such as respiratory irritation, cancer, and even damage to the central nervous system (Wu et al. 2018). The excessive accumulation of waste favors the proliferation of harmful fauna. In many cases, deliberate fires are set to reduce the volume of waste and prolong the life of disposal sites. However, these fires generate air and soil pollution due to the toxic gases, ash, and smoke produced (Manjunatha et al. 2024). In addition, they contribute to the emission of greenhouse gases such as CO_2 and CH_4, accelerating global warming (Köfalusi & Aguilar, 2006; Abubakar et al. 2022). On the other hand, groundwater and surface water are threatened by the constant production of leachate.

Image 3. Environmental and population impacts due to the inadequate disposal of MSW. Source: Own elaboration based on Jaramillo (2002), Köfalusi and Aguilar (2006), and Abubakar et al. (2022)

Inappropriate MSW management constitutes a critical challenge with social and environmental implications (Fig. 3), which requires immediate attention. Understanding the associated environmental risks is important to effectively address the problem. To mitigate these impacts, it is essential to adopt sustainable approaches that not only promote the reduction and proper treatment of waste, but also encourage the participation of all sectors involved: governments, businesses, and citizens. The implementation of efficient public policies, together with greater social awareness of the importance of proper MSW management, will contribute to the protection of the environment and the well-being of communities, preventing even more serious consequences in the future. Only through a collective effort will it be possible to achieve a healthier and more sustainable environment for future generations.

6. FINAL THOUGHTS

Urban solid waste management in Mexico is a growing challenge that requires urgent and concrete measures. With an estimated daily generation of 108,146 tons/day nationally and 5,188 tons/day in Chiapas, inadequate disposal systems have led to the proliferation of clandestine landfills and the accumulation of garbage in public spaces. This work shows the magnitude of the problem and the need to improve both the infrastructure for waste management and disposal and the strategies to reduce daily waste generation.

Promoting recycling, reuse, and reduction practices from the source can lead our country towards a circular economy model where resources remain in the production cycle as long as possible, aligning with the global goals of the UN Agenda 2030 and the Sustainable Development Goals (SDGs), especially SDG 12, which promotes responsible consumption and production.

While the government has a fundamental role in the creation of adequate infrastructure and public policies, the active participation of society is equally indispensable. Government policies should focus on implementing reduction, reuse, and recycling strategies, with special attention to sectors with high waste generation rates, such as industry and commerce. It is also essential to ensure strict compliance with environmental regulations, which are often ignored or insufficiently enforced.

Thus, this work contributes to the understanding of the challenges of urban solid waste management in Mexico, identifying the need to strengthen infrastructure and promote the circular economy as key strategies. To achieve this, a collective effort among all social actors is essential to build a cleaner, healthier, and more sustainable present for current and future generations.

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Spectral Characterization and True Color Analysis of Different Natural Dyes such as *Bixa Orellana, Brassica oleracea var. Capitata*, and *Indigofera suffruticosa*

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— Abstract—

This study evaluated the process of obtaining dyes from plant species such as *Bixa Orellana* (Achiote) and *Brassica oleracea, var. capitata* (red cabbage). The absorbances of the obtained dyes were compared with *Indigofera suffruticosa* (indigo) and methylene blue, commercially acquired, using ultraviolet (UV), visible (Vis), and near-infrared (IR) spectroscopy, achieving absorbances greater than 2.5 in the high-energy wavelength range, which is useful in the medical industry due to its disinfectant properties. Linear regression models were determined using dilutions of these dyes to obtain the true color, achieving determination coefficients greater than 95%.

Keywords:

Dyes; extraction; UV-Vis spectroscopy; true color.

The low availability of water for human consumption is one of the most significant health issues today since it is a resource used for supply, food, recreation, and economy, among others. In Mexico, about 80% of aquatic ecosystems have some degree of pollution. The main pollutants observed are organic matter, nutrients such as nitrogen and phosphorus, and microorganisms (fecal coliforms) (Hernández, et al. 2020). There are different conventional and unconventional techniques for the elimination of microorganisms in water such as the application of chemicals, UV sterilization, and reverse osmosis (Faroon, et al. 2023), for the first case and nanofiltration (Nasir, et al. 2022), electrocoagulation (Gamero, et al. 2020), photosensitization (Santos, et al. 2023), among others, as a second case. The latter represents a low-cost alternative for the disinfection of water using solar radiation and dyes, which are chemical structures used for their coloring properties. They are classified as natural by their vegetable, animal, or mineral origin (dyes) and artificial due to physical or chemical modifications, they absorb light and give color in the visible region of the spectrum (400-800 nm). Due to their characteristics, they are also used in substrates to give them color and can resist discoloration when exposed to water, oxidizing agents, sweat, and microbial attack, so they are also used in industries such as textiles, food, printing, cosmetics, medicine, plastics, concrete, and paper. One of the most widely used dyes in the industry is methylene blue, which is commonly applied to color silk, wool, cotton, and paper (Rodríguez-Basantes, et al. 2019).

This paper presents the extraction process of two different organic dyes, as well as the determination of the true color, comparing them with Indigofera suffruticosa and methylene blue.

MATERIALS AND METHOD

The procedure to follow for the extraction of the colorant is the selection of a determined mass of the chosen vegetal species (seeds or leaves), if this one is composed of leaves, it has to be cut to diminish the time of obtaining the colorant. Next, two extraction techniques are presented, the first uses water at boiling temperature with the chosen plant species and with constant agitation at 200 RPM for 10 minutes, it is allowed to cool and the liquid is filtered using filter paper, the extract is concentrated by boiling the solution or putting it in a water bath, this process is repeated in some cases up to 4 times to obtain the largest possible amount of dye. The second is using a solution of sodium hydroxide or potassium hydroxide (alkaline medium) at a concentration of 1.5% or also using concentrated ethyl alcohol to extract the dye under constant agitation at 150 RPM in times ranging from 10 minutes to 1 hour, depending on the plant species, in the case of using the alkaline medium, the solution is acidified using phosphoric acid at 10% (H_3PO_4) with constant agitation until reaching a pH between 2 and 2. 5, finally, the extract is concentrated by decanting the material and drying in an oven at an optimum temperature so that the properties of the dye are not modified. For its preservation, the concentrated material can be frozen or ethyl alcohol can be added in a 1:8 ratio (Rodríguez-Basantes, et al. 2019). The final mass of dye obtained is measured using an OHAUS analytical balance model PIONEER TJ2611 with a precision of 0.1 mg to determine the extraction efficiency.

The spectral analysis follows the procedure described in NMX-AA-017-SCFI-2021, for the measurement of true color in natural, waste, treated waste, and marine waters, using spectral absorption coefficients at three different wavelengths in the visible range of the spectrum (436, 525, and 620 nm) using

$$\propto (\lambda) = \frac{A}{d} f$$

Where A is the absorbance of the water sample at wavelength λ, d is the distance in mm of optical path through the cell containing the water sample and f is a factor to obtain the spectral coefficient in m^{-1} (f=1000). The study was carried out with a HACH model DR6000 UV/VIS spectrophotometer. The true color is expressed as a function of the spectral absorption coefficient at the analyzed wavelength, as well as the pH value of the sample. If the sample is diluted, the volume of water used in the final calculation of the true color is evaluated.

RESULTS

Three different raw materials such as indigo, annatto, and purple cabbage were used to obtain organic dyes, which were contrasted with methylene blue. The following is a description of the process of obtaining each of them.

For Indigo, from *Indigofera suffructicosa*, we had a colorant with a solid presentation, so for its preparation, it was ground to obtain granules smaller than 0.5 mm in diameter. Next, a mass of 800 mg of indigo was placed in 400 mL of distilled water and kept in agitation for 10 minutes at 200 RPM to homogenize the mixture until a concentration of 2 g/L was obtained, with an average pH of 7.0.

From this concentration, 9 dilutions were prepared, decreasing the concentration in periodic values, until a minimum concentration of 200 mg/L was reached.

In the case of *Bixa Orellana* (Annatto), two procedures were performed to obtain the dye, in the first one a mass of 100 g of annatto seeds was placed with 150 mL of distilled water in an Erlenmeyer flask, boiled at a temperature of 150°C with constant agitation at 200 RPM in a Thermo Scientific model Cimarec heating and stirring rack for 15 minutes, making sure that the seeds did not adhere to the walls of the flask. Once the time had elapsed, the mixture was filtered to eliminate the washed annatto seeds using a regular nylon mesh strainer. The liquid obtained was deposited in three porcelain capsules distributed in equal volumes for subsequent drying. Since the first process did not completely remove the colorant from the annatto seeds, we washed them a second time under the same conditions as the first one. The porcelain capsules with the liquid obtained were placed in a Biobase drying oven, model FCD-3000 Serials, previously conditioned at a temperature of 60°C for approximately 8 hours.

a) b)

Figure 1. Enlarged view of annatto seeds. a) first wash, b) second wash, the removal of dye between washes is observed by obtaining a larger dark surface on the seeds

Because the extract obtained, despite the washes performed, presented a thick consistency that inhibited the extraction process, it was necessary to use a larger volume of water, a smaller mass of annatto seeds, or a larger number of washes. Once the dye extraction process was completed, the mass and its removal efficiency were evaluated, obtaining 0.9397g of dye, which represents a removal efficiency of 93.32%.

For the second procedure, 10 g of annatto seed and 30 mL of an alkaline medium (NaOH or KOH) were used, both solutions at a concentration of 1.5%, the mixture was kept under constant stirring at 140 RPM for 1 hour, then it was left to digest for 24 hours, after which the seeds were separated and a second wash was carried out repeating the process described above. The extracts obtained for each wash were combined and acidified by adding drops of 10% phosphoric acid (H_3PO_4) with constant stirring AT 150 RPM until a pH of 2 to 2.5 was reached. Finally, the material for the separation of the seeds was decanted, allowing the liquid to dry for three days at room temperature in a controlled space. The mass obtained using sodium hydroxide was on average 1.2 g, while using potassium hydroxide it, was 1.8 g.

For *Brassica oleracea, var. capitata* (purple cabbage), 463.85g of purple cabbage (6 leaves) was finely chopped and divided into four blocks of approximately 115g. To each block contained in beakers, we added 460 mL of distilled water previously boiled for 30 minutes with magnetic stirring. Two batches were allowed to cool to room temperature; then 1/8 of their volume of concentrated ethyl alcohol was added for preservation and evaluation, and to prevent the proliferation of microorganisms. The other two batches were reduced by evaporation at an average temperature of 250°C for one hour, resulting in a decrease of 100 and 55 mL, respectively.

Absorbance

With the dyes obtained from each plant species, a concentration of these and a solution of methylene blue was determined in such a way that when measuring the absorbance they had values close to each other, obtaining the curves presented in Figure 2.

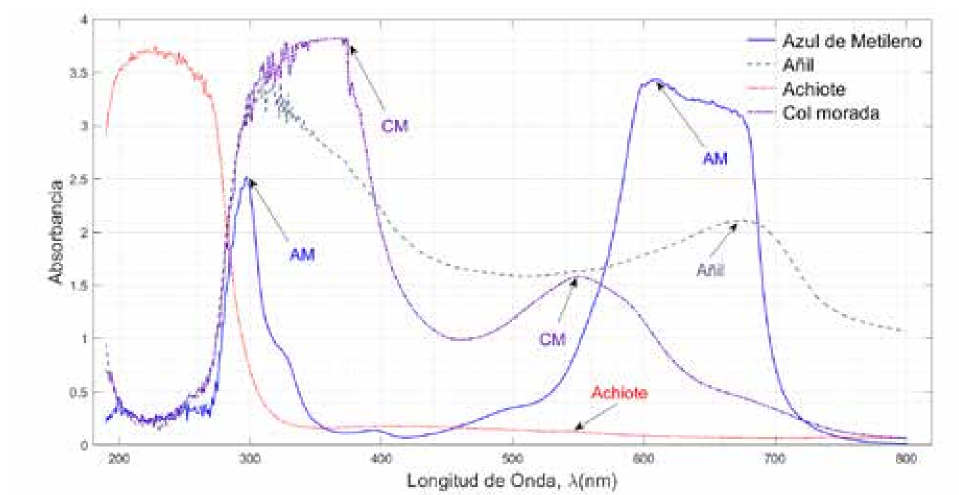

Figure 2. Absorbance curves of the dyes analyzed

From Figure 2, the highest absorbance for methylene blue at a concentration of 10 mg/L was at 610 nm, which indicates higher temperature but lower energy, similar to that observed in other works such as Amaya, 2023, which presented an analysis from 390 to 800 nm. However, in this case, a scan was performed from 190 nm presenting a second absorbance peak at 297 nm, which corresponds to a high frequency of light. This wavelength range with higher energy allows its use in medicine to eliminate microbial population, and in water treatment (Santos, et al. 2023). There was a higher absorbance around 310 nm and 675 nm for Indigo at a concentration of 2 g/L, according to what was observed by Basuki, 2018. In the case of annatto with a concentration of 22.5 mg/L, an absorbance peak was determined at a wavelength below 300 nm which corresponds to ranges of higher energy useful in medicine, the characteristic absorbance bands between 250, 370 and 500-545 nm are indicated for anthocyanins. The absorption of the latter band varies with the pH of the medium which makes it possible to detect the type of anthocyanin. The purple cabbage had two absorbance peaks at 370 nm and 550 nm, values close to those observed by Paez-Cartaya, 2018.

True Color

To determine the true color of the substances dissolved in water, the spectral absorption coefficient was calculated at 436, 525, and 620 nm, all samples when diluted in distilled water raised their pH to values close to 7.0. The calibration curve was then determined using methylene blue at different concentrations ranging from 0.1 to 10 mg/L.

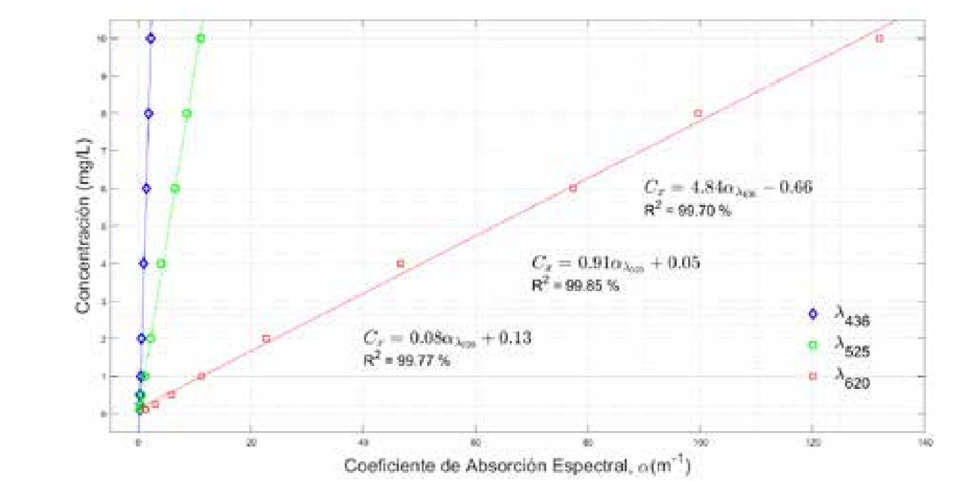

Figure 3. Calibration curve of Methylene Blue with the spectral absorption coefficient at different concentrations

Figure 3, presented the linear relationship between the spectral absorption coefficient and the dye concentration at different dilutions. The value of the spectral absorption coefficient for each wavelength represented the true color considering the dilutions made for each concentration. In the graph, different slopes were observed for each wavelength analyzed, the one corresponding to 620 nm which is the one at which the maximum absorbance of the dye was obtained, implies greater sensitivity of the analytical method due to the prolonged slope found and greater control of color gradients. A coefficient of determination R^2 greater than 99% was determined in all the wavelengths analyzed; which indicated a strong linear relationship between the variables. The expressions found will make it possible to ensure that the final application given to the dye is the desired one because the required tone or color will be exact by controlling the concentration of the same.

Figure 4 shows the indigo calibration curve, where no significant difference was observed between the wavelengths analyzed, which is inferred not to be within some maximum absorbance peak, so the true color will vary only in brightness.

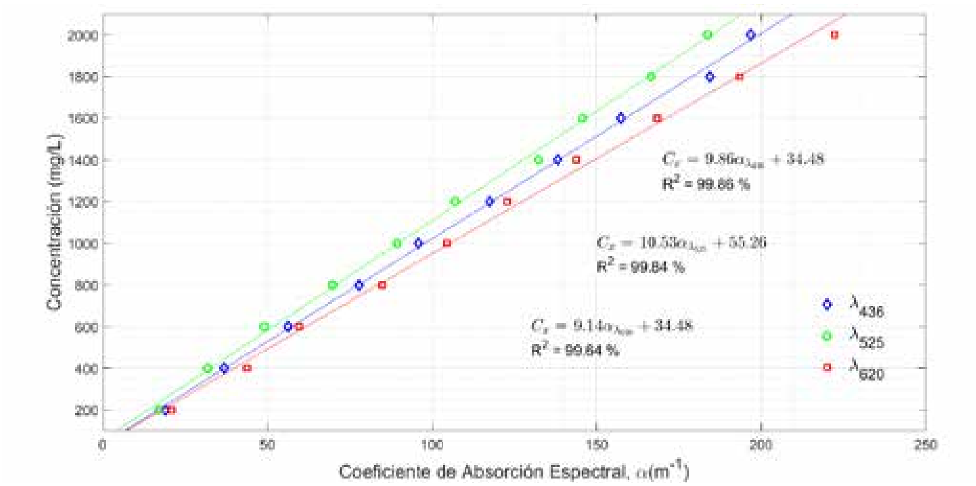

Figure 4. Indigo calibration curve with the spectral absorption coefficient at different concentrations

It should be noted that when the indigo was diluted in distilled water, it did not present a homogeneous solution, i.e., sedimentation or residues of indigo were observed scattered in the container, which implied variations in the concentration that depended on the initial conditions of the dye.

For the curve in Figure 5, 4 dilutions of the dye obtained from annatto were prepared decreasing the concentration from 22.5 to 12.5 mg/L, higher sensitivity was observed at 436 nm, in addition to the best approximation with an R^2 above 98%. There were also low values in the spectral absorption coefficient, which indicates that an intense color was obtained in the solution with low concentrations of annatto.

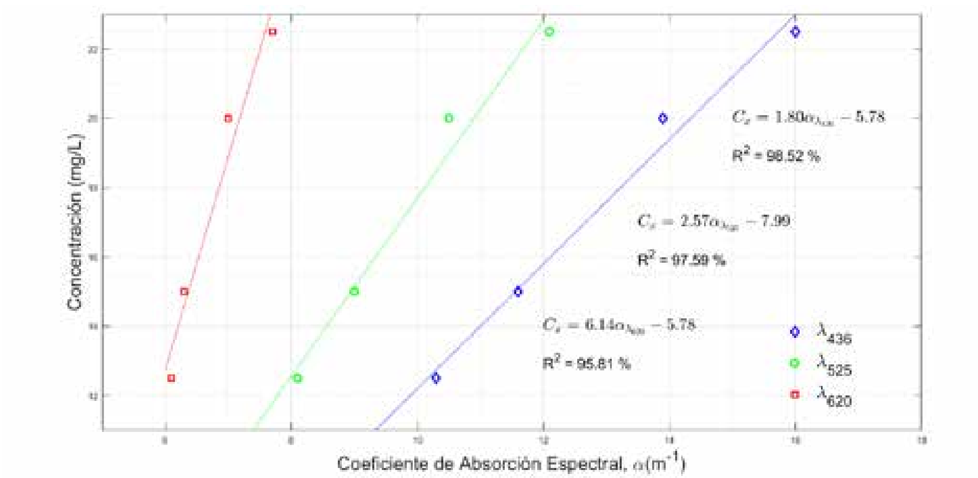

Figure 5. Calibration curve of the Annatto-based dye with the spectral absorption coefficient at different concentrations

For this dye, the obtaining method chosen was the second one based on sodium hydroxide at a concentration of 1.5% and phosphoric acid at 10%, because the first method presented sedimentation when diluted in water, while for the second one, a homogeneous mixture was obtained.

For the colorant obtained from purple cabbage, 10 dilutions were prepared, decreasing the initial concentration in periodic values until a minimum of 5% was obtained, as presented in Figure 6. Higher sensitivity was observed at 525 nm. It is important to point out that this dye has been proposed as a pH indicator due to its sensitivity through visible changes in color, which is effective in the development of biosensors for food preservation (Molina-Arteaga, et al. 2022).

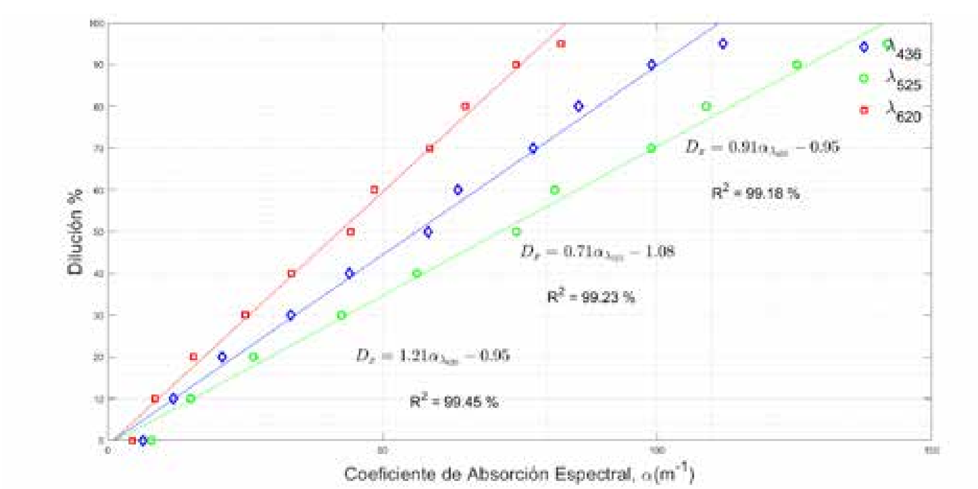

Figure 6. Calibration curve of the dye obtained from Purple Cabbage with the spectral absorption coefficient at different dilutions

With the equations obtained for each of the dyes, it was possible to determine the spectral absorption coefficient at an unknown concentration of these with an R^2 superior to 99% at the three wavelengths; only in the case of annatto was the coefficient of determination lower than 96% at 620 nm. These equations will help to simplify the monitoring system in the case of not having a spectrometer that scans the visible spectrum, by using a color sensor that evaluates the absorbances at wavelengths of 436, 525, and 620 nm, respectively.

CONCLUSIONS

Processes for obtaining water-soluble dyes were presented using potassium hydroxide and sodium hydroxide as solvents for the extraction of annatto colorant for its economic advantages and water for purple cabbage.

The absorbances of different organic dyes were determined at concentrations of 2 g/L and 12 mg/L, corresponding to indigo and annatto, respectively. The dyes analyzed showed high absorbances at wavelengths below 400 nm, which corresponds to high energy, making them viable in areas such as medicine and tertiary water treatment.

Linear relations were obtained between the spectral absorption coefficient and the concentrations of the dyes used, observing variations in the color gradient in the case of methylene blue and variations in brightness in the case of organic dyes.

Coefficients of determination R^2 greater than 99% were observed in most cases, indicating a high relation of the linear regression model to the actual data and allowing simplification of the true color procedure with a color detector covering the wavelengths proposed in NMX-AA-017-SCFI-2021.

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Environmental overview of the Mexican Caribbean as a growing hotel sector and wastewater generator; challenges and alternatives

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— Abstract—

The Mexican Caribbean hosts millions of tourists per year, which is an important source of jobs in the region. Hotel wastewater has high concentrations of fats and oils from kitchens and restaurants. These compounds cause several reactions with wastewater components and represent a problem in biological wastewater treatment processes, specifically filamentous bulking events. Filamentous bacteria such as *Thiothrix* spp., *Microthrix parvicella*, type 1701, *Gordonia* spp., and type 0041 causes settling problems, carrying solids to the effluent, causing poor quality of treated wastewater. This study aims to analyze those problems and to underline technology such as grease interceptors and dissolved air flotation systems (DAF), which represent efficient and economical technologies for removing fat and oil at the inlet of treatment systems. It was concluded that in addition to the use of technologies, strategic training programs should be included for staff and guests in general, to promote better kitchen practices and healthy food habits to reduce the consumption of fat and oils food.

Keywords:

Hospitality; tourism; wastewater; bulking; activated sludge.

TOURISM, HOSPITALITY IN THE MEXICAN CARIBBEAN, AND WASTEWATER

The Ministry of Tourism (SECTUR) states that the hotel sector in Mexico represents 28.7% of the gross domestic product of tourism. The country is in the 7th position worldwide in hotel infrastructure (International Hotel Consulting Services, 2022, Ministry of Tourism, 2022). By 2022, there was an investment of 215 billion pesos in 521 tourism projects, generating 115 direct and indirect jobs. The states with the highest amounts of investment were Nayarit, Mexico City, Baja California Sur, Yucatan, Quintana Roo, and Guerrero (Ministry of Tourism, 2022). In the period 2019-2023, the country's hotel infrastructure grew from 23,600 establishments to 25,500 and it is estimated that this trend will continue in the coming years (Statista, 2024).

As a tourist destination, the Mexican Caribbean area is a global powerhouse, due to its landscapes, cultural richness, and economic accessibility. It includes destinations such as Cancun, Puerto Morelos, Isla Mujeres, Cozumel, the Riviera Maya, Bacalar, and other destinations (SECTUR, 2015, 2023). After the lifting of social distancing caused by the COVID-19 pandemic, hotels in these popular destinations saw an increase in occupancy of 45.5%, with an influx of 13,530,307 tourists in 2021, to 19,680,330, representing an economic spill of 19,425.90 million dollars (SEDETUR-QR, 2022). That is why tourism represents one of the largest sources of income for the country, only surpassed by international remittances (SECTUR, 2023; Statista, 2024). It favors the empowerment, integration, and income generation of vulnerable populations such as rural communities and Indigenous peoples (International Hotel Consulting Services, 2022; SEDETUR-QR 2022; Statista, 2024).

In the environmental field, the hotel sector represents a pollution problem, being one of the most important sources of wastewater production in coastal areas, with varied characteristics. The growing demand for drinking water falls on services, ranging from filling hot tubs and pools, and artificial ponds to washing sheets, table linen, cleaning rooms, and cooking utensils, among other activities. All this required water, after being used, will become wastewater (Abdul Khader & Chinnamma, 2021; Estévez et al., 2022). In areas of tourist importance such as Cancun, it is estimated that the use of drinking water in hotels is around 550 L * guest $^{-1}$ * night $^{-1}$, although these estimates may vary depending on the nature of the tourist destination (Sánchez Gonzales, 2022; Santacruz de León & Santacruz de León, 2020). This volume exceeds the average water used in domestic activities, which is around 144 L * person $^{-1}$ * day $^{-1}$ (Estévez et al., 2022).

The Ministry of Tourism of the State of Quintana Roo (SEDETUR-QR, 2022) reports that, in Cancun alone, there are 207 hotels, with a total of 43,109 rooms, and by 2022 it had an influx of 6,786,004 tourists. For this same year, in the Caribbean area, there were a total of 1,331 hotels, distributed in 11 municipalities, which received 19,680,330 tourists (SEDETUR-QR, 2022). According to the National Tourism Development Fund (FONATUR, 2018), the city of Cancun, one of the most developed in the Caribbean, has the infrastructure to treat 4,707,798 m^3 * year $^{-1}$ of wastewater, considering only the wastewater discharged to the drainage and sewerage system, however, there is no detailed official information on per capita water consumption, wastewater generation by hotel complexes, or private infrastructure for wastewater treatment in the region (Biosilva A. C., 2015; Sánchez Gonzales, 2022).

It is important to size the wastewater treatment capacities in these developing cities, including those of each hotel, as the trend of population increase and tourism projects in the Mexican Caribbean, exacerbate the uncertainty about the wastewater treatment infrastructure, and whether it will be able to fully cover the adequate treatment of wastewater in the short term, since water bodies in the Caribbean currently receive discharges of contaminated water, representing a serious environmental and public health problem (Biosilva A. C., 2015).

Pollutants such as fats and oils, present in hotel wastewater, appear as one of the main problems, both in damage to infrastructure (pipes and sewerage), in the operation of wastewater treatment systems, and in the environment when wastewater does not receive adequate treatment. On the one hand, in the presence of Ca^{2+}, fat usually solidifies and adheres to the walls of pipes, which, over time, causes obstructions and bad odors, while oils, due to their hydrophobic chemical properties, form a layer on the surface of water bodies, preventing the passage of light and oxygen, affecting the biochemical processes of aquatic life (Khoury et al., 2023; Klaucans & Sams, 2018).

This text aims to analyze the scenario in which the Mexican Caribbean is located as a developing tourist destination and the challenges to be faced due to the amounts of wastewater generated and its characteristics, specifically fats and oils, as well as to highlight the problems that these compounds represent in conventional biological treatments, as well as the technologies and/or methodologies available to face these problems, which are directly related to the sustainability and rational use of the valuable water resource.

CHARACTERISTICS OF HOTEL WASTEWATER

In Mexico, before being discharged into the environment, wastewater must be treated to comply with applicable regulations and reduce contaminants such as total suspended solids (TSS), biochemical and chemical demand for oxygen (BOD5 and COD), fats and oils (GYAs), temperature, pH, nitrogen, phosphorus, and pathogenic microorganisms (fecal coliforms and *Escherichia coli*), to name a few. At the federal level, the official Mexican standard NOM-001-SEMARNAT-2021 establishes the limits of contaminants in wastewater discharges in receiving bodies owned by the nation, while NOM-002-SEMARNAT-1996 establishes the maximum permissible limits of contaminants in wastewater discharges to urban or municipal sewer systems (Official Mexican Standard NOM-001-SEMARNAT-2021, 2022; Official Mexican Standard NOM-002-SEMARNAT-1996, 1998). Hotels installed in the Mexican territory must comply with at least one of the aforementioned standards, depending on where their discharges go, for they must resort to some type of wastewater treatment process, however, 80-90% of the wastewater generated in the Mexican Caribbean is discharged without any treatment (Biosilva A. C., 2015).

The main sources of hotel wastewater generation (ARH) come from the services that guests require and from the corresponding areas to cover their needs. Bathrooms (WC), bathtubs/showers, sinks, kitchens/bars, and laundry are identified as the most important services (Abdul Khader & Chinnamma, 2021; Estévez et al., 2022).

Abdul Khader & Chinnamma (2021) point out that in hotel wastewater, the main contaminants are OSH, BOD, COD, and GYAs. In their study in a boutique hotel, they reported the following characteristics in the ARH; pH 5, BOD 170 mg/l, COD 350 mg/L, SST 350 mg/L, and GYAs 7 mg/L.

Estévez et al. (2022), determined in a study carried out for four- to five-star hotels in Spain, the characteristics of the ARHs for each generation source, and contrasted the pollutants when there are water-saving measures and when they are not considered, this information is illustrated in Table 1.

In the cited study, it was determined that the highest concentration of contaminants in ARH comes from laundry and toilet water mixing, when water-saving methods exist. In this same study, it can be observed that the concentration of pollutants decreases when the amount of water used is greater (without saving methods). In practice, this does not represent a benefit because when more wastewater is produced, larger capacity reservoirs are required for its collection and/or more efficient treatments, increasing operating costs (Cabrera Acevedo, 2011). Estévez et al. (2022) did not consider the concentration of fats and oils in their study. They pointed out nutrients that are a fundamental part of eutrophication processes such as nitrogen and phosphorus (Leader et al., 2005). In Mexico, these nutrients are regulated and indicated by wastewater regulations as contaminants that must be reduced to low concentrations so that the water can be discharged to the soil or bodies of water (Official Mexican Standard NOM-001-SEMARNAT-2021, 2022).

Table 1
Wastewater characteristics of 4 to 5-star hotels

Composition	Source of wastewater (with water-saving methods)				
(mg/L)	Tub/shower	sink	laundry	mixture	WC
Total Suspended Solids	80.27	(Stool, urine, toilet paper)	1131.84	248.46	1171.52
Chemical oxygen demand (COD)	432.23	421.43	4214.29	1030.16	1472.82
Total nitrogen	2.84	2.32	14.81	4.63	299.89
Total Phosphorus	0.10	1.38	2.65	0.79	36.43
Composition	Source of wastewater (without water-saving methods)				
(mg/L)	Tub/shower	sink	laundry	mixture	WC
Total Suspended Solids	37.46	(Stool, urine, toilet paper)	396.14	96.20	555.94
Chemical oxygen demand (COD)	201.71	116.67	1475.00	398.86	702.23
Total nitrogen	1.33	0.64	5.18	1.79	142.31
Total Phosphorus	0.05	0.38	0.93	0.31	17.29

Note. Average water consumption in hotels (100 - 249 rooms) with saving methods: 12.35 m^3 * day^{-1}. Without saving method: 31.89 m^3 * day^{-1}. Saving methods such as low-flow faucets, efficient toilets, efficient irrigation, pressure regulation systems, leak detection, and rainwater collection for irrigation. Source: edited with data from Estévez et al., (2022).

The data pointed out by Estévez et al. (2022) contrast with those reported by Pharmawati et al., (2018) who mention that the characteristics of ARH are similar to domiciliary ones, with the following parameters and values; BOD 110-400 mg/L, COD 250-1000 mg/L, TSS 100-350 mg/L, ammonia nitrogen (NH_3) 12-50 mg/L, and fats and oils (GYAs) 50-150 mg/L.

Differences in the physicochemical characteristics of wastewater vary from hotel to hotel, due to different factors, such as the nature of the services, the number of rooms, and their methods of water consumption. Of the studies mentioned above, little is said about the characteristics of the water from hotel kitchens and/or restaurants, specifically fats and oils. However, there is literature that addresses these contaminants studied in food establishments, whose characteristics complicate the treatment of ARH.

FATS AND OILS IN WASTEWATER

One of the great challenges in hotel wastewater treatment lies in fats and oils (GYAs), whose main source is restaurant and kitchen service activities, such as the use of oils, lard or shortenings, meat processing, sauces, broths, dressings, cheeses, butter, and fried food (Gurd et al., 2019). Some types of fats found in the modern diet are illustrated in Table 2, these make up the menus in hotel kitchens and restaurants.

GYAs will have different states (solids or viscous liquids) depending on the degree of saturation of their carbon chains and their length; when short-chain fatty acids predominate, fats tend to be "softer" with low melting points compared to those with long-chain fatty acids. For example, palm oils have a melting point ranging from 27 - 45 °C, while coconut oil has a range of 23 - 26 °C (Sharma et al., 2022). The chemical nature of fats, oils, and grease means that their presence in sewage systems causes clogging problems due to the formation of deposits.

Table 2

Fats present in the modern diet

Type of fat	Saturated	Monounsaturated	Polyunsaturated	Trans*
Common names	"Bad" fats	"Good" fats	"Good" fats	"Bad" fats
Chemistry	Without double bonds	With double bonds	With two or more double bonds	
Sources	- Meet fat - Whole milk, cheese, cream, butter - Baked goods (pancakes, cakes) - Deep-fried fast food - Palm and coconut oil	- Avocado, nuts (peanuts, almonds, hazelnuts, and nut spreads) - Margarine (canola or olive oil-based) - Canola, olive, and peanut oils	- Fish and seafood - Polyunsaturated margarine - Vegetable oils (soybean, sunflower, corn, and safflower oils) - Brazil nuts and seeds	-Pies, cookies, cakes, fried foods, milk, cheese, and beef and lamb cuts

Nota. *Trans fats only form naturally in the stomachs of sheep and cows, so they are present in small amounts in milk and in beef and lamb cuts. Source Sharma et al., (2022).

According to Table 2, it can be noted that the colloquial grouping of the fat groups present in foods is only referred to as "bad" because of its relation to health problems (metabolic or cardiovascular) when the daily diet is based on an abusive consumption of these foods. The inclusion of fats and oils in the diet is necessary, as they are an essential part of cellular components and metabolic processes. However, it is important to note that, although most of them have a "natural" origin, we must moderate their consumption and consume other foods of vegetable and animal origin.

In this context, five major GYAs groups of importance in the human diet can be pointed out, which are illustrated in Table 3.

Table 3
Main groups in fats and oils

Group	Description
Free Fatty Acids	Carboxylic acids with long hydrocarbon chains. They occur in their esterified form as a major component of lipids. The most common have from 8 to 22 carbon atoms in their chains, and one or more unsaturations (double bonds). In restaurants, free fatty acids represent a 15% concentration in their effluents, lowering the pH of the water.
Triacylglycerol	Grass acids are generally presented as esters of glycerol, known as triglycerides. They are non-polar and insoluble in water. Fats and oils are complex mixtures of triacylglycerols, whose composition varies depending on the organism of origin; animal or vegetable.
Wax ester	Waxes include various types of medium and long-chain compounds, including hydrocarbons (TCH_3), alcohols ($R\text{-}CH_2OH$), aldehydes (R-CHO), acids (R-COOH), and esters (R-COOR'). There are waxes of vegetable and animal origin.
Phospholipid	The amphiphilic nature of phospholipids provides them with properties of interest in the pharmaceutical, cosmetic, and food industries. Although these compounds are removed in the refining of oils, part of them end up being part of the mixtures in the GYAs in water treatment.
Sterols and sterol esters	Strictly speaking, sterols such as cholesterol are not lipids but have similar physical properties to fats and oils. These can be esterified to long-chain fatty acids by oxidation reactions, hence they are also grouped together with the other compounds that form GYAs in wastewater.

Note. Prepared with information from Husain et al., (2014).

Table 3 shows GYA's main characteristics present in basic foods of the human diet. As mentioned above, considerable amounts of food waste will be produced in hotel kitchens, and derived from utensil cleaning activities, or direct discharge of fats and oils, these compounds will end up in wastewater lines, which will mainly have two destinations, a wastewater treatment plant or a body of water or soil, allowing the reaction of these compounds with those found in the water.

CHEMICAL REACTIONS RELATED TO GYAS IN WASTEWATER

Husain et al., (2014) point out in detail the nature of the reactions involved in the process of frying food, mainly due to the content of salts in food and the nature of free radicals in cooking oils.

Free fatty acids are chemically active and are easily saponified in the presence of sodium hydroxide and potassium hydroxide, both of which act as strong metallic soap-generating agents. Sodium and potassium are found naturally in raw foods, and by frying them some sodium ions can be extracted by the free fatty acids present in frying oils, forming sodium oleate (sodium soaps). Sodium oleate reduces the surface tension between the frying oil and the thin layer of water on the surface of the fried food, causing polar lipids to migrate from the frying oil to the fried food. In addition, sodium soaps stimulate the foaming of frying oil and this accelerates oxidation. The oxidation reaction that is caused by heat, light, and heavy metals, is a chain of radical reactions that occur quickly during the frying of food.

First, the oil's peroxy-, alkoxy- and alkyl-free radicals react with oxygen or RH (see Equation 1)

Equation 1

$$R\cdot + O=O \rightarrow R\text{-}OO$$
$$R-OO + R-H \rightarrow R-OOH\cdot + R\cdot$$
$$R-O + R-H \rightarrow R-OH\cdot + R\cdot$$

The reaction is initiated by the attack on the oil's alkyl group, followed by a chain reaction, resulting in a hydroperoxide (-OOH) group in the chain (see Equation 2).

Equation 2

$$R-OOH \rightarrow R-O\cdot + \cdot OH$$
$$2R-OOH \rightarrow R-O\cdot + R-OO\cdot + H_2O$$

The resulting hydroperoxides are reacted again by the combination of two radicals to form aldehydes, ketones, and fatty acids (see Equation 3).

Equiation 3

$$R\cdot + R\cdot$$
$$R\cdot + R\text{-}O\cdot$$
$$R\cdot + R\text{-}OO\cdot$$
$$R\text{-}O\cdot + R\text{-}OO\cdot$$
$$R\text{-}OO\cdot + R\text{-}OO\cdot$$
$$R\text{-}O\cdot + R\text{-}O\cdot$$

These reactions during the frying of food generate free fatty acids, usually found in used oils, and are part of the GYAs content in wastewater. Subsequently, these free fatty acids will react with an alkali, such as sodium hydroxide to form metallic soap (see Equation 4).

Equation 4

$$R-COOH + NaOH \rightarrow R-COONa + H_2O$$

Likewise, small amounts of triacylglycerols are saponified (hydrolyzed) forming metal soaps.

Equation 5

$$C_3H_5(COOR)_3 + 3NaOH \rightarrow C_3H_5(OH)_3 + 3NaOOCR$$

Sodium contributes to the saponification of GYAs and produces hard soap, which is deposited in small layers in pipes, causing maintenance problems. Sodium content can increase in wastewater due to the use of salt in food preparation. Detergents and sanitizers also contain large amounts of sodium hydroxide ($NaOH$), which is a strong alkaline catalyst, which potentiates saponification reactions (Sultana et al., 2024a). Another relevant element is calcium, since its ions (Ca^{2+}) and free fatty acids also perform saponification reactions, forming calcium soaps. This reaction is mainly influenced by temperature and pH, and the sources of the reagents which significantly affect the strength, appearance, quantities, and physicochemical properties of GYAs deposits in pipelines (Sultana et al., 2024a; Yusuf et al., 2023).

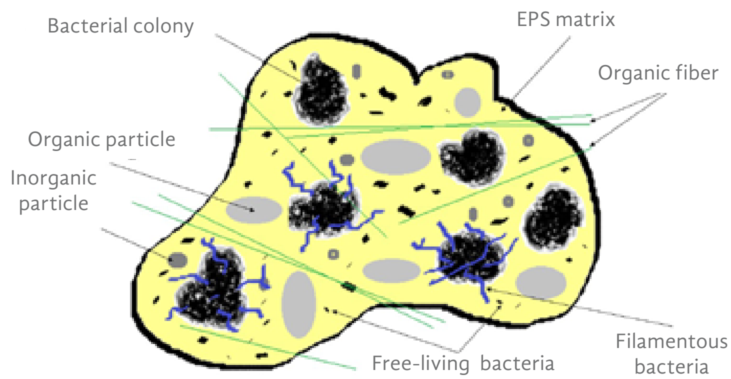
Wastewater from hotel kitchens and restaurants are waters rich in organic content, due to the content of GYAs. Their composition will be diverse by the type of menu handled, in addition to other factors such as kitchen cleaning practices (amount of water used, separation of solids, use of dishwashers and cleaning products, etc.) (Gurd et al., 2019). GYAs' problems can escalate to maintenance issues due to pipe plugging, but also negatively impact the water treatment process due to all the compounds derived from the GYA reactions that took place in the water collection system.

BIOLOGICAL WASTEWATER TREATMENT SYSTEMS

Typically, wastewater treatment systems are those processes in which wastewater solids are partially removed and/or transformed by the decomposition of complex, degradable organic solids to relatively stable or mineralized organic compounds (Sonune & Ghate, 2004). Wastewater treatment processes may vary depending on the type of water to be treated. According to the characteristics of hotel wastewater, one of the most common are conventional biological treatments, where microorganisms are used instead of chemicals to remove contaminants present in the wastewater, these methods intend to reduce the accumulation of chemicals and prevent eutrophication in water bodies (Schaider et al., 2017; von Sperling, 2007).

In biological wastewater treatment systems, most microorganisms are found in the form of microbial aggregates, such as sludge floc, biofilms, and granules. This is due to extracellular polymeric substances (EPS), a high molecular weight polymer complex, which has been observed in these media (Sheng et al., 2010). The presence of EPS influences the physicochemical properties of microbial aggregates, including structure, surface charge, flocculation, sedimentation properties, adsorption, and dewatering (Sheng et al., 2010).

Activated sludge processes are widely used in wastewater treatment plants (WWTP), where aeration units are used for the conversion of soluble organic compounds into settleable solids, followed by clarification processes, usually tanks where solids are separated from the liquid (Arcos A., 2013; Deepnarain et al., 2020). Ideally, aerobic processes are able to convert organic molecules into CO_2, H_2O, inorganic nutrients (N, P), biomass, and other products such as EPS. In activated sludge, the floc structure varies according to different factors, but commonly consists of bacterial colonies surrounded by an extracellular EPS network, in addition, the floc can include organic fibers and inorganic particles as seen in Figure 1 (Alrhmoun, 2014).



Note. Own elaboration with data from (J. Guo et al., 2014; Shchegolkova et al., 2016).

Figure 1. General structure of floc in activated sludge

It is common to find filamentous bacteria in the activated sludge floc, which can provide a support structure in the three-dimensional shape of the floc (Figueroa et al., 2015; Pacheco Salazar et al., 2003). Likewise, unicellular protozoa such as flagellates, amoebae, and ciliates can be observed, as well as complex organisms such as metazoans (rotifers), nematodes, and some worms, which are part of activated sludge systems (Curds, 1973; Isac et al., n.d.; Martin-Cereceda et al., 1996). Sedimentation efficiency is crucial in activated sludge WWTPs and governs the potential and capacity of the entire treatment system. Technically, the sludge sedimentation properties are described by the sludge volumetric index (SVI), which expresses the amount (in mL) occupied by one gram of solids suspended in the mixed liquor (SSTLM), usually in 1 L of sample for 30 minutes. When activated sludge has SVI values above 150 mL/g, it can be noted as sludge with '*bulking*', which hinders the whole activated sludge process (Deepnarain et al., 2020; Torrescano Spain, 2009).

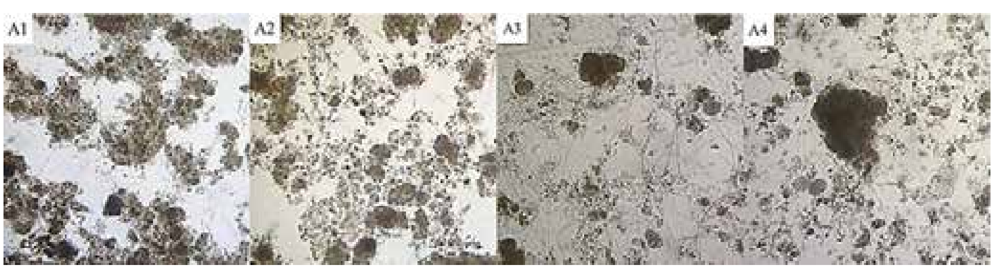
FILAMENTOUS MICROORGANISMS IN BIOLOGICAL SYSTEMS

Excessive growth of filamentous bacteria is associated with sedimentation and foaming problems. Sludge bulking is characterized by a growth of filamentous bacteria in the vicinity of the liquid floc medium, inhibiting the formation of dense segregates. Foaming is caused by sludge flocs floating to the surface of the aqueous medium, segregating into a relatively stable sludge layer at the water-air interface (Alrhmoun, 2014). An example of foaming is illustrated in Figure 2.

Note. Nilsson, (2015).

Figure 2. Example of foaming in a conventional biological treatment system

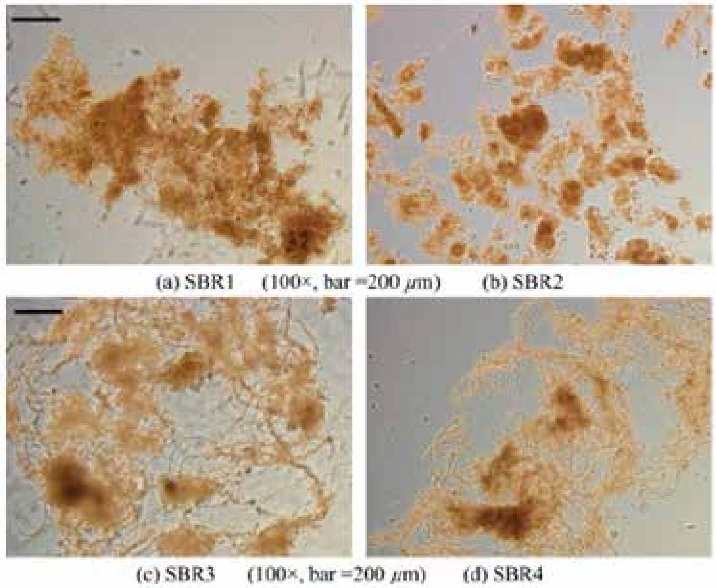
At the microscopic level, bulking can be identified when the floc presents scattered characteristics without aggregation and filamentous microorganisms are observed around the floc (J. Guo et al., 2014). In his study, Yao et al., (2019) illustrate in detail when the sludge presents filamentous bulking, in Figure 3, samples of a regular floc (Fig.3 A1 and A2) and another with filamentous bulking characteristics (Figure 3 A3 and A4) are observed.



Note. Edited from Yao et al., (2019).

Figure 3. Microscope view of floc types (100x)

On the other hand, Guo et al. (2014) analyzed the floc of sequenced batch reactors (SBR) at the laboratory level. Figure 4 shows the differences between a regular floc and a floc with the presence of filamentous microorganisms.



Note. SBR; Sequenced Batch Reactor. Source: edited from Guo et al., (2014).

Figure 4. Observation of floc in batch reactors

Figure 4 (a and b) shows flocs considered desirable in a good water treatment system, while Figure 4 (c and d) shows a characteristic floc with the presence of filamentous microorganisms. Guo and his team of collaborators reported that in the reactors that presented filamentous floc, the effluent had COD above 100 mg/L. The entrainment of solids and the low quality of the effluent are the results of having a sludge with bulking, this is supported by other studies, pointing to the problems of filamentous bulking as the most important in conventional biological processes of activated sludge (Aonofriesei & Petrosanu, 2007; Lu et al., 2023; Nilsson, 2015).

Several filamentous microorganisms causing bulking are noted in the literature. 021N- type sulfur bacteria and *Thiothrix spp*. are able to use organic substrates and reduced sulfur compounds as energy sources, together with heterotrophic bacteria adapted to sludge that receive high organic loads ("AM" Food/Microorganism ratios > 0.15 Kg of DBO5 Kg^{-1} SSTLM $día^{-1}$), for example, *Sphaerotilus* spp. and *Haliscomenobacter hydrossis*. In addition, species such as *Microthrix parvicella*, type 1701, *Gordonia* spp. and type 0041 for being responsible for filamentous bulking events (Alrhmoun, 2014; Aonofriesei & Petrosanu, 2007; Bjo et al., 2002; Deepnarain et al., 2020; Nilsson, 2015).

The proliferation of filamentous microorganisms is due to operation-related parameters such as low oxygen concentration, high AM ratio, N and P deficiencies, low pH, soluble residual DBO, and high concentrations of fats and oils (G. Liu et al., 2018; Pacheco Salazar et al., 2003). In this context, it can be noted that the presence of GYAs in ARHs enhances problems due to filamentous bulking in conventional biological treatments. Due to the physicochemical characteristics previously analyzed, waters from kitchens and restaurants have low pH, in addition to generating competition for dissolved oxygen in aerobic systems between GYAs and microorganisms that require this element for their breathing processes (Cabrera Acevedo, 2011; Nilsson, 2015).

WASTEWATER OVERVIEW OF HOTELS IN THE MEXICAN CARIBBEAN

In infrastructure, according to the Inventory of Municipal Potabilization and Wastewater Treatment Plants in Operation (National Water Commission, 2022), Quintana Roo has 29 municipal water treatment plants, but there is no information regarding how many hotels are connected to the municipal sewage network to send their wastewater to these plants, or if they have their own treatment plants.

In the matter of wastewater, the Law of Ecological Balance and Environmental Protection of the State of Quintana Roo, in its article 129 establishes that "when there are no municipal systems for the evacuation of municipal wastewater, the owners of hotels, subdivisions, condominiums, residences, industries, and similar, must install systems for the treatment and recycling of their wastewater, whether individual or communal, to satisfy the particular conditions determined by the competent authorities" (Law of Ecological Balance and Environmental Protection of the State of Quintana Roo, 2018). In this regard, hotels located in the Mexican Caribbean, which are in the territory of the state of Quintana Roo, are required to have a WWTP in their facilities. According to the research by Biosilva A. C., (2015), hotels with wastewater treatment infrastructure are operated by in-house staff or licensed companies. These hotels face significant challenges in the operation of their treatment plants which, as discussed, conventional biological processes are susceptible to inefficiency due to delicate operating conditions.

Deficiencies of dissolved oxygen in biological systems, due to an excess of GYAs and filamentous microorganisms, lead to an increase in energy consumption, due to the increased use of aerators, blowers, etc.

Problems also arise in the management of the biosolids generated in the process, starting with an increase in sludge concentration (SSTLM) in the aeration tanks, which subsequently require greater purges (removal in volume of sludge from the system) to maintain optimum levels of SSTLM * $m^{3\ -1}$ concentration in the bioreactors, and thus be able to improve oxygen dissolution so that the quality of the treated water is not compromised. This overproduction of sludge will result in a higher demand for inputs used in the dewatering process (flocculants and coagulants), and complications in the storage, removal, and final disposal of biosolids (Flores-Alsina et al., 2009; J. H. Guo et al., 2010; Y. Liu et al., 2020).

Figure 5 illustrates the overview of the current situation in the Mexican Caribbean analyzed in this text. This interrelation of components leads to a possible scenario; environmental imbalance, increased risks to public health, and lower water availability.

Figure 5. General scenario of the Mexican Caribbean and its environmental challenges

The protection of the environment and public health is the main objective to regulate wastewater discharges from hotels, because they represent a high risk of diseases, mainly pathogenic ones, and also cause a negative impact on ecosystems. Untreated ARHs contain bacteria, viruses, and parasites that can cause gastrointestinal and respiratory infections, among others. The risk increases when the points of wastewater discharges are at the following points:

- Agricultural areas; since irrigation water sources can be contaminated, and in this way reach crops (Werneck et al., 2017).
- Coastal areas or areas with rivers, streams, lakes, etc.; these areas are the ecological niches of various species, whose position in the trophic chain allows the pollutants to which they are exposed to reach humans (UN, 2017).

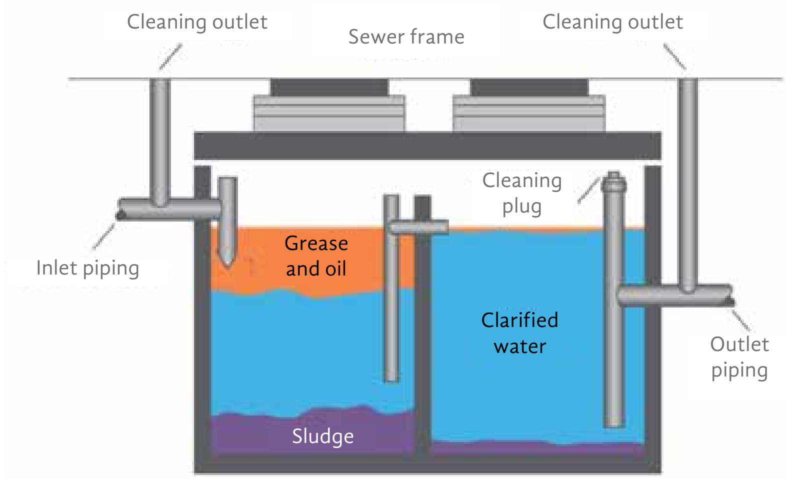
The effects of wastewater pollution are more severe in vulnerable groups, whether due to age; children and infants, as well as older adults, are more susceptible to disease, in addition to people with chronic diseases or disabilities. Not to mention that, in economically vulnerable populations, access to drinking water and good nutrition trigger health situations that, by adding the "pollution" factor, pose challenging scenarios for an already saturated public health system (UN, 2017).

The Caribbean area has karst soil, with formations of caverns, cenotes, and underground rivers, which easily exposes underground water bodies to contamination by wastewater discharges, which transports diseases to all fauna and flora (aquatic and terrestrial) that are close to the discharge sites, hand in hand with eutrophication in surface and underground bodies of water that receive high concentrations of organic matter. The above problems worsen the natural landscape, mainly in areas where economic exploitation is the landscape, as is tourism in this area (Biosilva A. C., 2015).

Hotel companies must take the necessary measures to improve their water treatment infrastructure, reduce water consumption, and improve their practices in food production and cleaning in their kitchens, with the goal of reducing operating and maintenance expenses of their facilities and their water treatment systems, all without losing the objective of complying with the demands required by Mexican regulations on wastewater, whose purpose is to preserve the integrity of the ecosystem, on which they directly depend. The technologies available in wastewater treatment are diverse, but they are efficient and affordable for the hotel sector, two main ones were identified, and are presented in this context as the window of opportunity to solve the problems that ARHs represent.

TECHNOLOGIES FOR COPING WITH FATS AND OILS

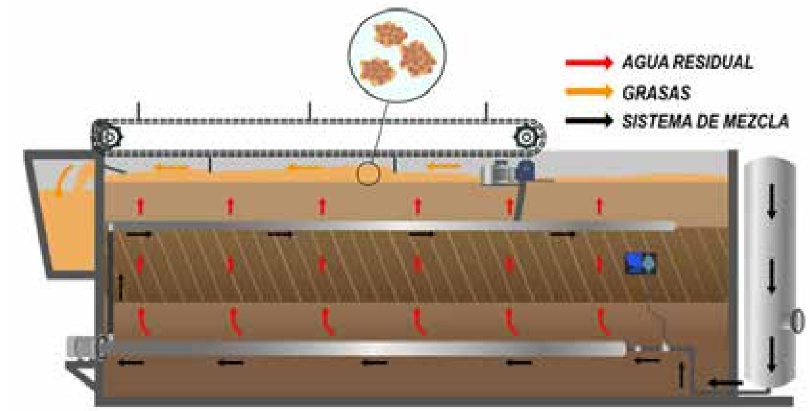
The most common and appropriate technologies are grease interceptors, which are installed in restaurants and kitchens, to prevent greases and oils from ending up in wastewater collection tanks, pipes, and finally in the WWTP. Typically a grease interceptor is a device installed in the hydraulic system to trap or intercept greases and oils from the water. The foundation is physical separation, while wastewater cools, GYAs harden, and food solids settle and form sludge. Water without GYAs and sedimentable solids advances to subsequent compartments and follows its flow until it reaches the treatment systems (Sultana et al., 2024b; Yusuf et al., 2023). A general schematic of a fat interceptor is illustrated in Figure 6.



Note. Liquid Environmental Solutions, (s/f).

Figure 6. Sketch of a grease interceptor system

The main disadvantage of a grease interceptor is that it requires constant removal of the materials that this device traps, or else they will end up in the hydraulic system and water treatment systems. This problem is solved by having a portfolio of suppliers that specialize in the removal of this waste, since, generally in hotels there are no spaces designed for the treatment of solids. The biggest advantage of these interceptors is that they handle higher flow rates than conventional grease traps and are ideal for the hotel sector that demands the preparation of large quantities of food, and consequently the cleaning of kitchen material in a short time. On the other hand, Dissolved Air Flotation (DAF) systems separate solid particles, such as GYAs, designed for industrial and urban wastewater clarification. The separation process is a physicochemical method where coagulants and micro or nano air bubbles are applied to separate solids on the water surface. It is very efficient and using the right operating parameters, TSS and GYAs removal can reach 90%, while BOD and COD reduction reach 40 to 55% (Palaniandy et al., 2010; Penetra et al., 1999; Rattanapan et al., 2011). This system improves the conventional water treatment process by minimizing the organic load that the bioreactors will receive, whose immediate benefits will be a greater dissolution of oxygen and less appearance of filamentous microorganisms, which will result in a better clarification of the treated wastewater, which can be reincorporated into the environment without complications. Figure 7 illustrates a general schematic of the DAF operation.



Note. (Synertech Water Resources, s/f).

Figura 7. Esquema general de un DAF

As shown in Figure 7, the fats are collected at the top and separated from the water for further treatment. DAFs stand out from other technologies due to their attractive low maintenance cost and energy consumption, and this can be adapted so that the collected grease can be sent to grease digestion sumps, and depending on the specialization of the facility, biogas can be generated (by anaerobic methods), or the digested grease can simply be mixed with the sludge purge to end up in the sludge dewatering process.

Technology in wastewater engineering offers different options to address problems arising from wastewater with excess fats, oils, and grease in conventional biological processes, but the situation can be addressed strategically. One strategy is to train personnel involved in the food preparation process (chefs, cooks) and kitchen cleaning (assistants, stewards), implementing methods for separating and recovering oils, which can be revalued in different ways. Another way, and perhaps the most complex, is for the population in general to reduce the consumption of fried foods or foods with high fat and oil content, which, on a large scale, would represent an improvement in eating habits, a decrease in cardiovascular diseases, and even overweight.

CONCLUSIONS

As a developing country, Mexico has a window of opportunity in the Caribbean to be a world leader in the hotel sector. At the same time, it faces a major challenge in maintaining a balance between the use and conservation of its natural resources, specifically water. In this paper, the characteristics of hotel wastewater were identified, as well as the main problems that they bring to wastewater treatment systems: filamentous bulking, which makes the operation of conventional biological systems difficult. Grease interceptors and DAFs were identified as functional technologies to directly decrease the concentration of fats and oils at the inlet of water treatment systems. Without neglecting training and awareness strategies for personnel and consumers to ensure the quality of the wastewater treatment systems, and at the same time maintain a balance between water use and conservation.

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Seismic hazard in the metropolitan area of Tuxtla Gutiérrez: two case studies

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— Abstract—

In the metropolitan area of Tuxtla Gutiérrez, made up of the municipalities of Tuxtla Gutiérrez, Chiapa de Corzo, Berriozábal, San Fernando, and Suchiapa, the interaction of human activity with natural features has given rise to dangerous scenarios in which the region presents different levels of vulnerability to seismic events. The consequences of the earthquakes that occurred in this southeastern region of the Mexican Republic have claimed lives, generating significant damage that has transcended the groups with the greatest degree of marginalization of the population. This research addresses historical damage and soil thicknesses as indicators of the site effect for analyzing the seismic hazard of two municipalities: Tuxtla Gutiérrez and Chiapa de Corzo. A multiparameter methodology (Moreno Ceballo et al., 2019, Moreno Ceballo et al., 2020) based on Geographic Information Systems was used, which included a documentary review and a field record of historical damage due to earthquakes in the two localities, the seismic microzonings of these cities that have fundamental periods of ground vibration that vary between 0.14 s and 0.39 s for Chiapa de Corzo (Salgado et al., 2004) and between 0.08 s and 1.33 s for Tuxtla Gutiérrez (González-Herrera et al., 2013, Narcía López et al., 2006). With the model used by Newmark and Rosenbluth (1976), the variation of sediment thicknesses that leads to the site effect in the area was obtained, considering an average shear wave velocity of 150 m/s. Finally, sediment thickness maps were prepared for both urban areas, ranging from 7.12 m to 14.62 m for Chiapa de Corzo and between 3 m and 46.78 m for Tuxtla Gutiérrez, and a spatial correlation was made with the historical damage caused by earthquakes in both localities.

Keywords:

Seismic amplification; map, seismic microzonation; seismic vulnerability.

In Mexico, much of the national territory presents a significant seismic risk, generated mainly by the earthquakes occurring on the Pacific Ocean coast, at the conjunction of the Cocos and North American tectonic plates. Chiapas is a region considerably prone to seismic activity, due to a unique feature in the rest of the Mexican Republic, in which three tectonic plates converge: the Cocos Plate, the North American Plate, and the Caribbean Plate (Figure 1).

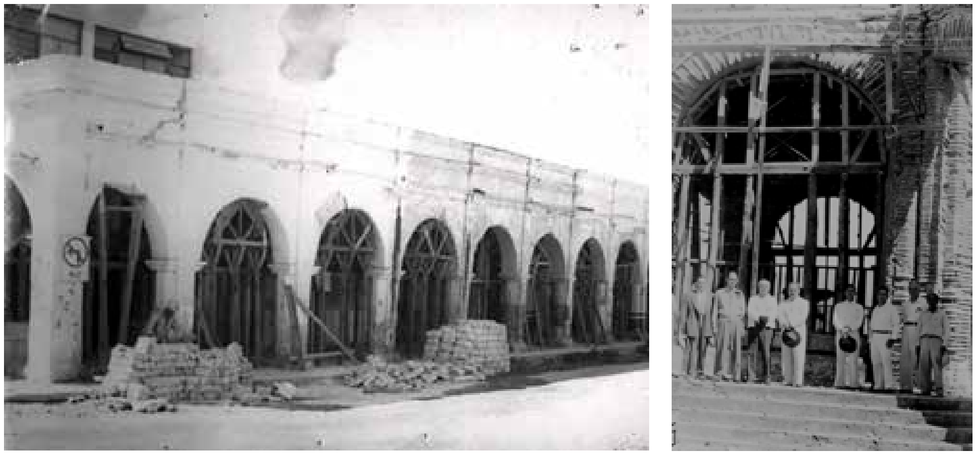
Note. (CENAPRED, 2006).

Figure 1. Tectonic plates that interact in the state of Chiapas with their respective movement direction

Chiapas is divided into four tectonic provinces: the province of the Inverse Fallas, the province of the Lateral Fallas, the Batolito de Chiapas, and the Motagua-Polochic Fallas (Guzmán & Meneses, 2000) and five seismogenic sources have also been identified (González-Herrera, 2014) that have originated the earthquakes that occurred in the region, the first being the subduction process of the Cocos plate under the North American Plate (Suárez & Singh, 1986; Pardo & Suárez, 1995). The second source is associated with the internal deformation of the subducted plate, which produces earthquakes ranging from 80 to 300 km deep, of the intra-plate type, such as the one that occurred on September 7, 2017, of 8.2 Mw. The third source corresponds to surface fault systems that have caused a cortical deformation, which originates tremors of moderate magnitude and depth (González-Herrera et al., 2015).

These earthquakes cause local damage, such as those that occurred in Chiapa de Corzo between July and October 1975 (Figure 2a and 2b) (Nadayapa, 2011). The presence of active volcanoes in the state (the Tacaná and the Chichonal or Chichón) and the left lateral faulting between the

North American Plate and the Caribbean Plate (González-Herrera, 2015) correspond to the fourth and fifth source, respectively.



a) b)

Note. (Nandayapa, 2011).

Figura 2. Damage to the portals and the fall of one of the ends of the arches of Chiapa de Corzo's colonial fountain

STUDY AREA

Metropolitan Areas (MA) are defined as a group of municipalities related to each other by a high degree of physical or functional integration on an inter-municipal or interstate basis. Another requirement to be classified as an MA is that the total population of the municipalities that comprise it is greater than 200 thousand inhabitants and that the urban locality or conurbation that gives rise to it has more than 100 thousand inhabitants (SEDATU, 2020).

The dynamics of development and economic growth experienced by some cities, such as Tuxtla Gutiérrez, have led them to exceed their municipal boundaries (INEGI, 2014), which has caused them to update their composition. In 2023, the document "Metrópolis de México 2020" was published, the result of a collaborative work between the National Population Council (CONAPO), the National Institute of Statistics and Geography (INEGI), and the Ministry of Agrarian, Territorial, and Urban Development (SEDATU), which defines 48 MAs in Mexico, comprised of 345 municipalities in which 67.6 million people reside.

Therefore, the Tuxtla Gutiérrez MA (Figure 3) is made up of this municipality (capital of the state of Chiapas), as well as Berriozábal, Chiapa de Corzo, Suchiapa, and San Fernando, as shown in Table 1.

Table 1
Municipalities that make up the Metropolitan Area of Tuxtla Gutiérrez

Municipalities	Surface area (Km^2)	Altitude	Number of Inhabitants
Tuxtla Gutiérrez	334.61	527	604,147
Chiapa de Corzo	829.98	509	112,075
Berriozábal	351.70	904	64,632
Suchiapa	283.66	460	25,627
San Fernando	359.26	912	41,793

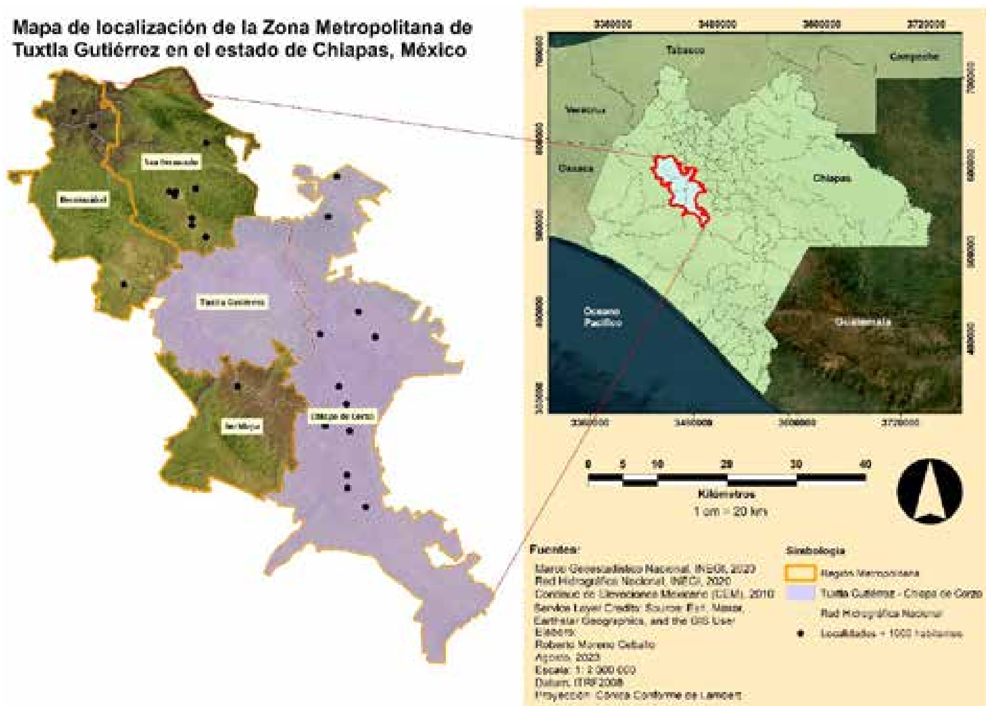


Figure 3. Location map of the Metropolitan Region of the state of Chiapas, Mexico

The MA of Tuxtla Gutiérrez has experienced significant growth in the period between 2010 and 2020, at the population level, it increased by more than 100 thousand inhabitants, which represents an increase of approximately 14 percent (Figure 4).

Figure 4. Population growth in the Metropolitan Area of Tuxtla Gutiérrez, according to the INEGI population censuses of 2010 and 2020, respectively

General characteristics of the study area

In the northern part of the region, the high mountain range with sloping slopes predominates, followed by a complex steep high mountain range; to the south of the region, the plateau with glens predominates, followed by the high mountain range with sloping slopes and in a smaller proportion of areas with typical canyons. In the eastern part of the region there is the valley of slopes stretched with homerio and high mountain range of steep slope; in the western part of the region the typical homerio predominates, in the center of the region there is the typical plateau and alluvial plain with homerio (Mullerried, 1957), in this area there is the Cañon del Sumidero, a large geoform product of a system of faults and geological fractures, in addition to the erosive action of the Grijalva River; the relief forms with little slope with hills, plateaus, and valleys predominate in the center, which represents approximately 60% of the territory.

The relief's height ranges from less than 30 m to 2,600 m above sea level (INEGI, 2004). In the study area, 8 soil units are generally presented, within which there is a greater percentage distribution of Litosol, Regosol, and Rendzina:

Table 2
Metropolitan Area Soil Units

Soil units	Percentage distribution
Litosol	38.04
Regosol	20.90
Rendzina	14.38
Vertisol	10.51
Luvisol	4.91
Acrisol	4.55
Feozem	3.54
Fluvisol	1.67
Body of water	0.93
Urban Area	0.58

Note. (INEGI. Topographic map scale 1:250,000 Series III. INEGI. Municipal Geostatistical Framework 2005).

In terms of geology, the surface of the MA has seven types of rock and is composed of tertiary soils, with three types predominating: limestone (34.46%), limonite-sandstone (29.01%), and shale-sandstone (16.55%). Also from Cretaceous soils: siltstone (7.35%) and alluvial (07.22%). Other varied soil compositions make up the remaining 05.40% of the region's land area (Secretary of the Treasury, 2017).

Seismicity in the region

The earthquakes that have occurred in the region have had a strong impact on the southeastern region of Mexico, with a considerable impact on the most marginalized groups of the population. According to the population and housing census conducted by INEGI in 2010, over 70% of the region's population has a medium to high level of marginalization. The analysis of the seismic hazard in a given region involves the management of a large amount of information. This paper presents the results obtained for two case studies: Tuxtla Gutiérrez and Chiapa de Corzo. Both sites were selected for the existence of buildings with high heritage value, for having a housing stock with a certain degree of deterioration, and for the presence of areas with a high degree of marginalization.

The effect of earthquakes in the aforementioned cities can be appreciated at different scales, at the state level because they have suffered major earthquakes that affected buildings that are part of the cultural heritage of humanity, as in the case of Chiapa de Corzo (earthquakes of October 1975), or the earthquake of October 1995 in Tuxtla Gutiérrez, and at the local level because of the characteristics of the soil and the levels of seismic amplification. The occurrence of large magnitude events (Figure 5), such as the one that occurred on September 07, 2017 (8.2 Mw), reiterates the need to conduct hazard studies in areas of extensive cultural richness.

Figure 5. Earthquakes occurring in the state of Chiapas between 1900 and 2022 with magnitude M>6

METHODOLOGY

For this research, a multi-parameter methodology was used (Moreno Ceballo et al., 2019, Moreno Ceballo et al., 2020) based on Geographic Information Systems, which contemplated the geological, edaphological characteristics, and the areas susceptible to flooding or floodplains were also determined. A database of historical earthquake damage in the region, much of it collected in the field between 2017 and 2020, was also used:

Documentary review and field data collection

Documentary review of the seismic events recorded in the study area, based on surveys applied to the population and semi-structured interviews with chroniclers and historians. This allowed a compilation of the damages presented with the occurrence of seismic events in the region, highlighting those that occurred on October 6, 1975 (for the case of Chiapa de Corzo) and the earthquake of September 7, 2017, of 8.2 Mw.

The historical damage databases were built by strengthening the documentary research with field work, where the use of the properties from 1975 to the present was also considered (Moreno-Ceballo et al., 2020). A GPS/GNSS navigator was used to geographically reference the buildings damaged by the seismic events considered for this work.

Flooded areas

Areas adjacent to riverbeds are very attractive for urban development, the use of such areas, without considering the natural limits necessary to evacuate floodwaters, has contributed to amplify the negative effect of floods, which in some cases leave tragic consequences (Arbeláez et al., 2002). Therefore, flood areas were identified due to the presence of major rivers that have historically affected urban areas in the study area, such as the floods caused by Hurricane Arthur in 2008 (Hernández, 2009) and Hurricane Matthew in 2010 (López, 2010) in Chiapa de Corzo.

Soil movement amplification is one of the main causes of significant damage in areas with poorly compacted sedimentary deposits. According to Schmudde (1968), the floodplain, a geomorphological form generally composed of unconsolidated material transported by rivers, favors this phenomenon. These soils increase seismic amplification, intensifying the effects of an earthquake. In general, the damage caused is related to variations in near-surface geologic materials and, in particular, these amplifications of ground motion are associated with recent and poorly consolidated sedimentary deposits (Tinsley & Fumal, 1985).

Degree of damage and determination of vulnerability

For the assignment of the degree of damage and determination of seismic vulnerability, the European Macroseismic Scale (EME) was used, which considers a description and graphic scheme, and defines qualitatively each of the five degrees of damage; where the degree of damage varies from degree 1, which corresponds to negligible damage, to degree 5, which is associated with the total collapse of the building (Grunthal, 1998), (Arellano et al., 2003), (Silva, 2006). The quality of the building was also analyzed taking into account the materials used and the areas of greatest seismic amplification were determined based on measurements of the fundamental periods of soil vibration and their subsequent comparison with the thickness of sediments and the use of the following variables: Soil science, geology, historical damage, seismic amplification.

Map production

Finally, maps containing information on historical seismic damage and sediment thickness were prepared for urban patches. In 1976, Newmark and Rosenbluth coined the expression relating sediment thickness to its fundamental period of vibration and shear-wave propagation velocity:

$$T = 4\sum_{i}^{n} \frac{hi}{\beta i} \quad (1)$$

Where T represents the natural period of the terrain, *h* is the thickness of the *ith* stratum, and β is the speed of propagation of shear waves. The number of sedimentary strata is represented by *n*. From this model, we can obtain the definitive equation with which the ArcMap software was fed in order to obtain the values that were subsequently interpolated:

$$h_i = \frac{(Tx\beta i)}{4}) \quad (2)$$

To estimate the sediment thicknesses under both urban patches, the model described above was used, in addition to the calculation of the natural periods of vibration of the soils. For this, an average β velocity of 150 m/s was used (Narcía et al., 2006). The periods used for Chiapa de Corzo correspond to those found by Salgado et al. (2004), while in the case of Tuxtla Gutiérrez, 285 measurements were used throughout the urban area (Figure 6).

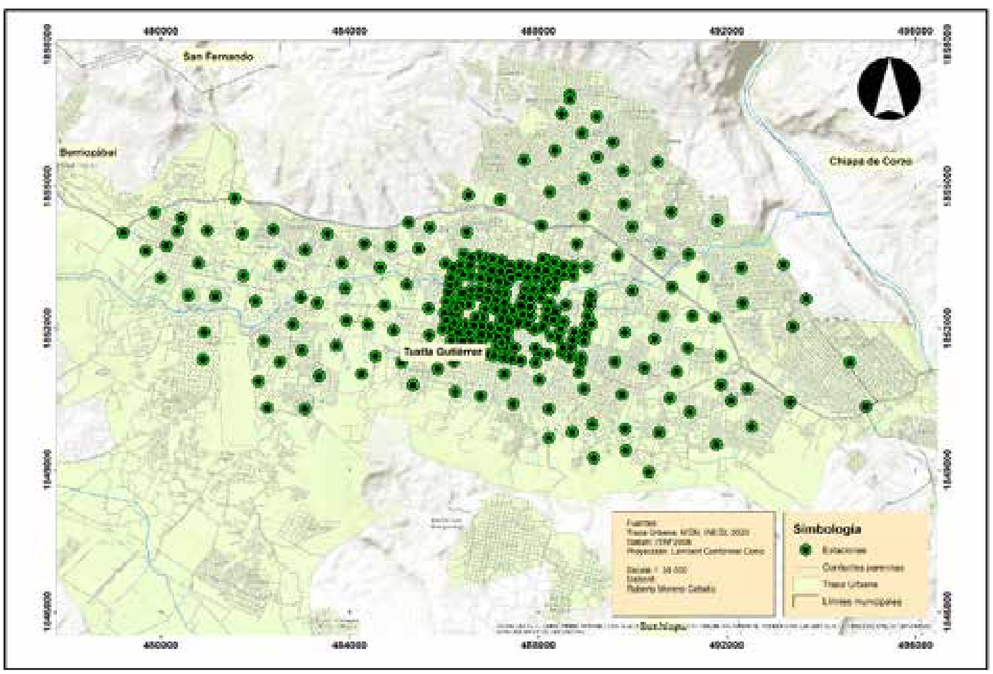


Figure 6. Location of the stations to measure the fundamental periods of environmental vibration in the municipal capital of Tuxtla Gutiérrez

CHIAPA DE CORZO

Chiapa de Corzo is located on federal highway 190, just 12 km from Tuxtla Gutiérrez, the capital of the state of Chiapas. The capital of the municipality is located on the limits of the Central Depression and the Central Highlands, its geographical coordinates are 16º 42"N and 93º 00" W (497920.00 m E and 1849152.00 m N, Zone 15 N), its altitude is 406 masl and has a territorial extension of 869.21 km² (INAFED, 2018). It borders to the north with the municipalities of Osumacinta, Soyaló, and Ixtapa; to the east with the municipalities of Ixtapa, Zinacantán, Acala, and Venustiano Carranza; to the south with the municipalities of Venustiano Carranza and Villa Corzo; to the west with the municipalities of Villa Corzo, Villaflores, Suchiapa, Tuxtla Gutiérrez, and Osumacinta (INEGI, 2008).

The municipality of Chiapa de Corzo has geological characteristics, where limestone predominates by 40.84%, Lutite – Sandstone (27.06%), Siltstone – Sandstone (13.22%), Limestone – Lutite (10.56%), Conglomerate (7.44%), Basic Intrusive Igneous (0.74%) and Sandstone – Conglomerate (0.12%) (INEGI, 2008).

As for the edaphological characteristics, the eastern portion of the population is made up of a calcareous Regosol, and in this area, there are some low ridges. The west side and a small portion to the south are in a Vertisol; likewise, another area to the southwest of the town is constituted by an eutric Fluvisol. To the south and southwest is the body of water that constitutes the Rio Grande de Chiapa or Rio Grijalva. Most of the historic center of Chiapa de Corzo is substantially flat (Salgado et al., 2004).

The map in Figure 7 illustrates the distribution of earthquake damage in the municipal capital of Chiapa de Corzo, where a concentration can be seen in the central area and the areas near the Grijalva River. Several important buildings have been repeatedly affected, such as the Temple of Calvary, the Church of Santo Domingo, the Church of San Jacinto, and some homes that survived both seismic events. The greatest number of affectations corresponds to traditional adobe houses, approximately 30% of the buildings surveyed during field work; it is important to specify that adobe generally presents poor structural behavior during the occurrence of natural phenomena such as earthquakes.

Amplification of local terrain may be due to the nature, composition, and morphology of the surface layers of soil. This local phenomenon of terrain behavior is known as the "local effect", "local response", or "site effect" (Rodríguez, 2005). The damage presented in the buildings is caused, to a large extent, by the amplification of soil movement, which is greater in areas constituted by deposits of soft and poorly compacted sediments, such as areas near the river bank.

Geomorphologically, the flood plain is a landform composed primarily of unconsolidated deposited material, derived from sediments transported by the river in question (Schmudde, 1968). The presence of this type of soil favors seismic amplification, causing a greater site effect in the event of an earthquake. For this reason, after a thorough documentary review, as well as the incorporation of Civil Protection reports, a map of the Maximum Extraordinary Water Level (NAME) for the municipal capital of Chiapa de Corzo was drawn up (Figure 8).

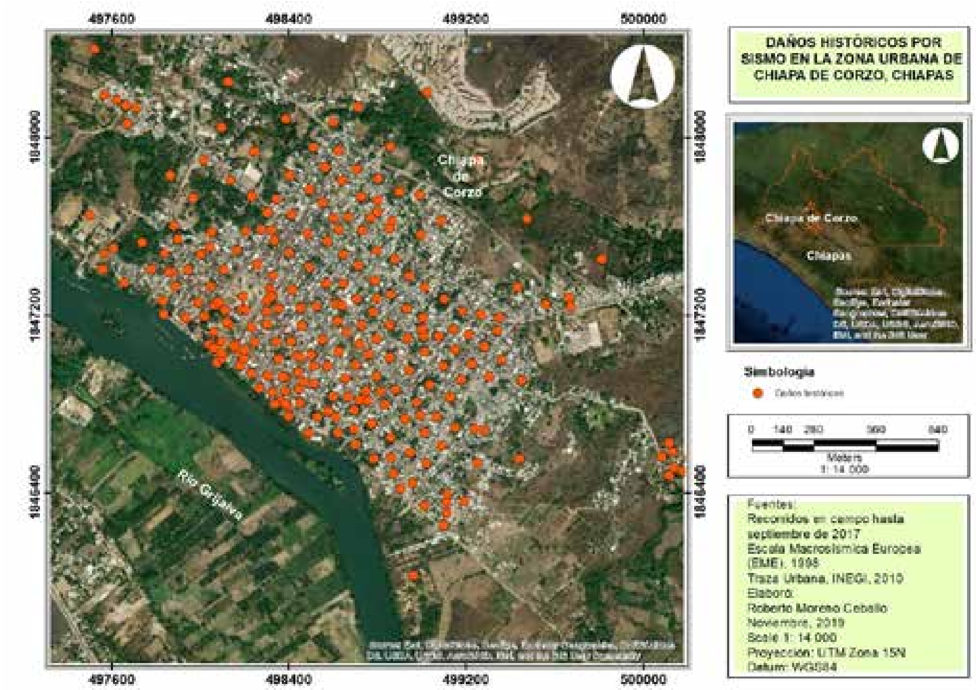


Figure 7. Location of historical damage in Chiapa de Corzo, Chiapas, in two seismic events

Overall, earthquake shaking damage is commonly related to variations in near-surface geologic materials and, in particular, these large amplifications of ground motion are associated with recent and poorly consolidated sedimentary deposits (Tinsley & Fumal, 1985).

Town development plans should consider the local seismic response of the subsoil, in order to define specific seismic-resistant structural design parameters, according to the seismic history of the region (IPCMIRD, 2010). This research mainly addresses the physical part within the analysis of seismic risk, studying the current state of the buildings and the construction process of vulnerability, mainly due to human intervention that, in the absence of technical advice, resort to self-construction processes or the use of materials that do not comply with the corresponding regulations.

Note. (Moreno-Ceballo et al., 2019).

Figure 8. Floodplain of the municipal capital of Chiapa de Corzo

In the region, the use of reinforced brick predominates, followed by adobe, which has traditionally been the most used material for housing walls in the area, due to its economy, ease of manufacture, construction, and thermal benefits (Moreno-Ceballo et al., 2019). With the occurrence of earthquakes that have locally affected Chiapa de Corzo (Table 3) and the state of Chiapas in general, it is imminent that local soil conditions are determinant in the structural response.

Table 3
Earthquakes that have affected Chiapa de Corzo

Date	Latitude	Length	Magnitude
05/06/1897	16.30	-95.40	7.4
19/04/1902	14.90	-91.50	7.5
23/09/1902	16.60	-92.60	7.7
14/01/1903	15.00	-93.00	7.6
09/12/1912	15.50	-93.00	7.0
30/03/1914	17.00	-92.00	7.2
10/12/1925	15.50	-92.50	7.0
28/06/1944	15.00	-92.50	7.1
26/09/1955	15.50	-92.50	6.9
09/11/1956	17.45	-94.08	6.3
29/04/1970	14.52	-92.60	7.3
05/10/1975	16.74	-92.92	4.8
10/09/1993	14.20	-92.80	7.2
14/03/1994	15.98	-92.43	6.8
21/10/1995	16.81	-93.47	7.1
18/11/2001	15.45	-93.60	6.3
16/01/2002	15.58	-93.60	6.3
07/09/2017	15.76	-93.70	8.2

Note. (Salgado et al., 2004; SSN, 2017).

This must be accompanied by the analysis of seismic amplification at the local level. In this research, we consider sediment thickness as an additional variable to understand the spatial behavior of the damage presented. For this purpose, the data obtained by Salgado and collaborators (2004) were used, which present fundamental vibration periods ranging from 0.14s to 0.39s (Figure 9).

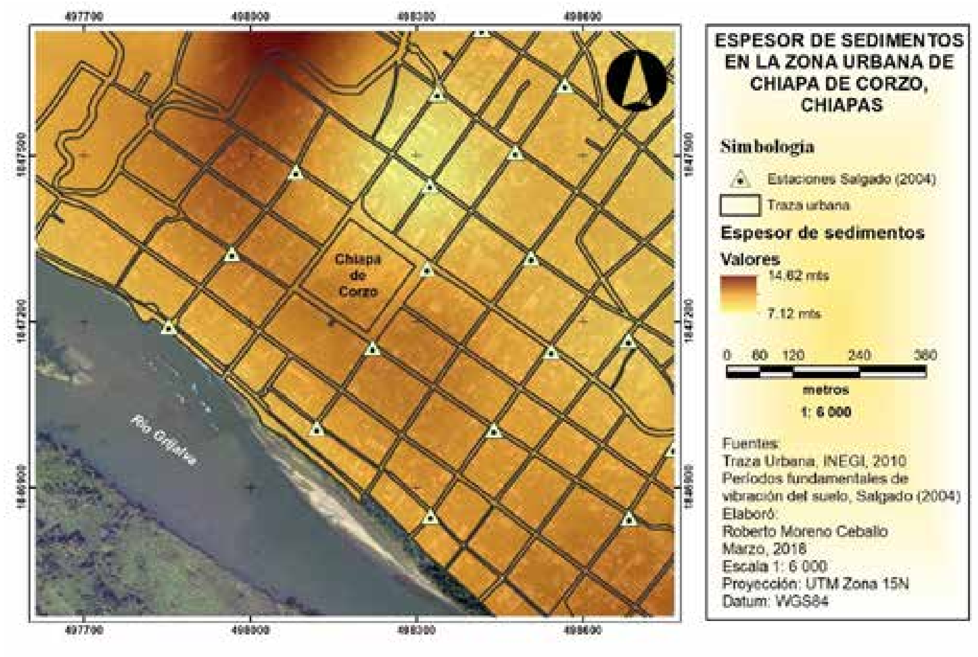


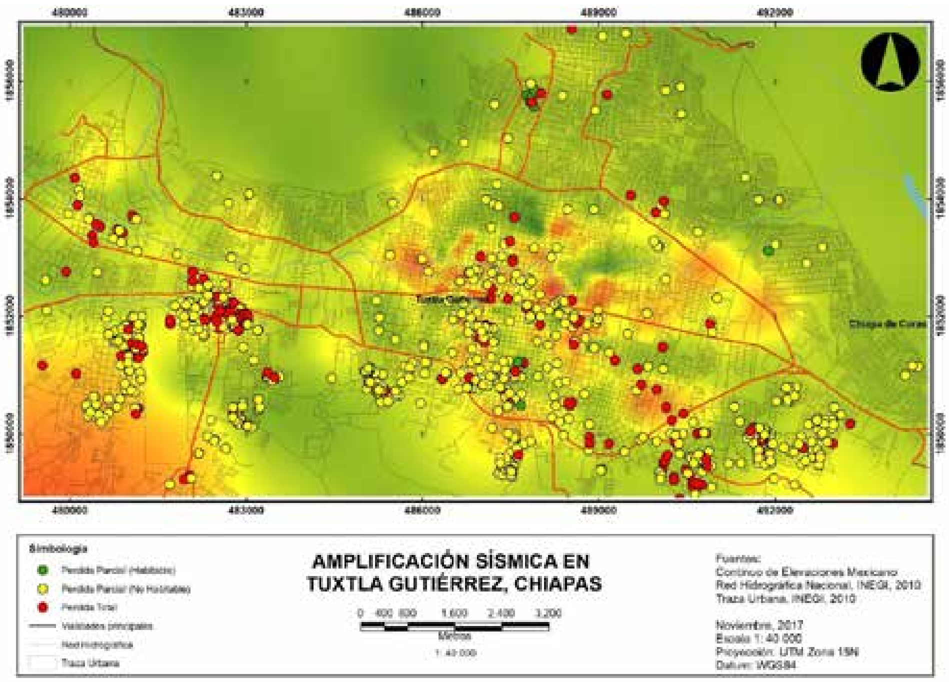
Figure 9. Sediment thickness map for the municipal capital of Chiapa de Corzo, Chiapas

TUXTLA GUTIÉRREZ

Located in the Central Depression of the state of Chiapas, it has mountainous relief to the north and south. Its territorial extension is 412.40 km², which represents 3.26% of the Central region and 0.55% of the state's surface. This city is bordered to the north by the municipalities of San Fernando and Usumacinta, to the east by Chiapa de Corzo, to the south by Suchiapa, and the west by Ocozocuautla and Berriozábal (CEIEG, 2010).

The municipal territory is made up of high mountain ranges with steep slopes, plains with alluvial deposits, and plateaus due to erosion; in the northern part, there is a set of mountain ranges whose altitude does not exceed 1,200 masl. The northern slope is stable and is made up of Upper Cretaceous limestone (Ocozocoautla-La Angostura formation), and corresponds to the flanks of the Mesa de la Animas. On the other hand, the southern slope is unstable by nature (Paz, 2012), since it corresponds to recent colluvium-type deposits, generated from materials detached from the edges of the Copoya karst table (Paz et al., 2011), which is composed of limestones and sandstones of the middle Eocene (San Juan formation) (Ferrusquia et al., 2000, cited in Paz-Tenorio et al., 2017).

The signal measured on the ground during the occurrence of a seismic event has different durations (Atakan et al., 1997; Lermo & Chávez-García, 1993), especially in those with an unstable composition. This is due to the change that seismic waves undergo as they pass through the different soil strata.



Note. (González et al., 2020).

Figure 10. Seismic amplification in Tuxtla Gutiérrez, Chiapas

Figure 10 presents a map of seismic amplification in Tuxtla Gutiérrez (González-Herrera et al., 2012), where the damages of the earthquake of September 7, 2017 (8.2 Mw) can also be observed, highlighting a significant number of total and partial losses caused by this phenomenon. When the materials and construction systems used are homogeneous, so is the vulnerability of the constructions; this means that the results are conditioned by the effects of the site (Moreno et al., 2019).

In addition, it is located within the Sabinal River basin and is immersed within the Hydrological Region Number 30, Grijalva-Usumacinta. It has a length of 407 km, of which 148.96 km are located in the municipality of Tuxtla Gutiérrez, which represents approximately 36%. It is born on the hill "El Chupadero", 5 km northwest of the municipality of Berriozábal (to the west) and runs 46.4 km to flow into the Grijalva River (east of the city of Tuxtla Gutiérrez) in the municipality of Chiapas de Corzo (García Benítez, et al., 2022). Figure 11 shows a map of the floodable areas in Tuxtla Gutiérrez, prepared from Municipal Civil Protection reports in the period between 2004 and 2016.

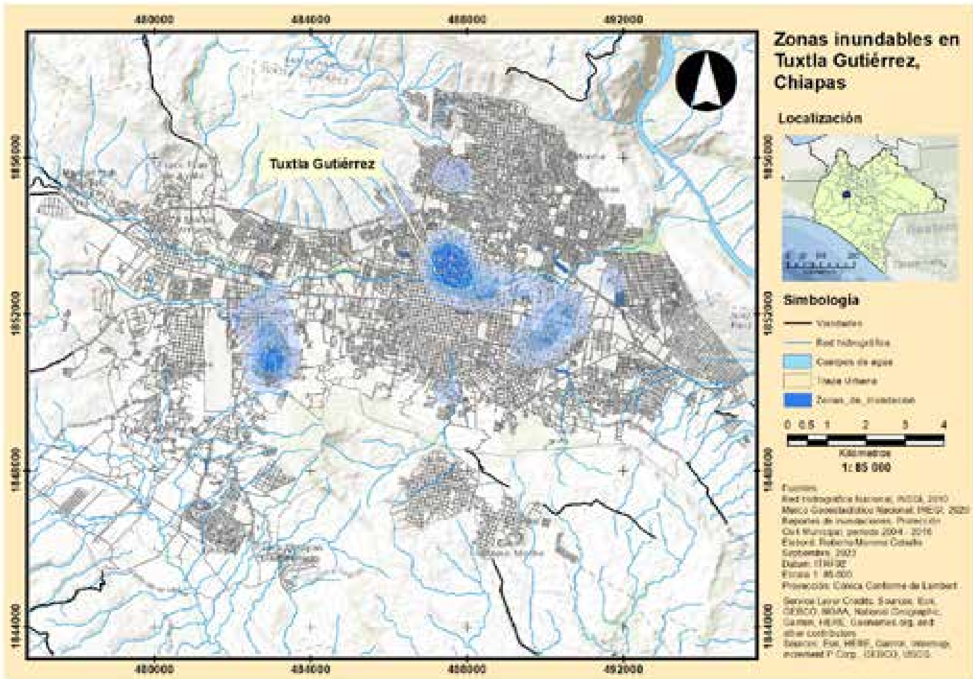


Figure 11. Tuxtla Gutiérrez's floodplain areas, map prepared from municipal Civil Protection flood reports in the period between 2004 and 2016

Finally, using the model proposed by Newmark and Rosenbluth in 1976, the sediment thicknesses (Figure 12) were obtained for Tuxtla Gutiérrez. The records were taken at 285 stations located at different points of the urban area (Figure 6); the periods obtained range from 0.08s to 1.33min. In addition, the spatial distribution of the damage caused by the earthquake of September 7, 2017, can be observed.

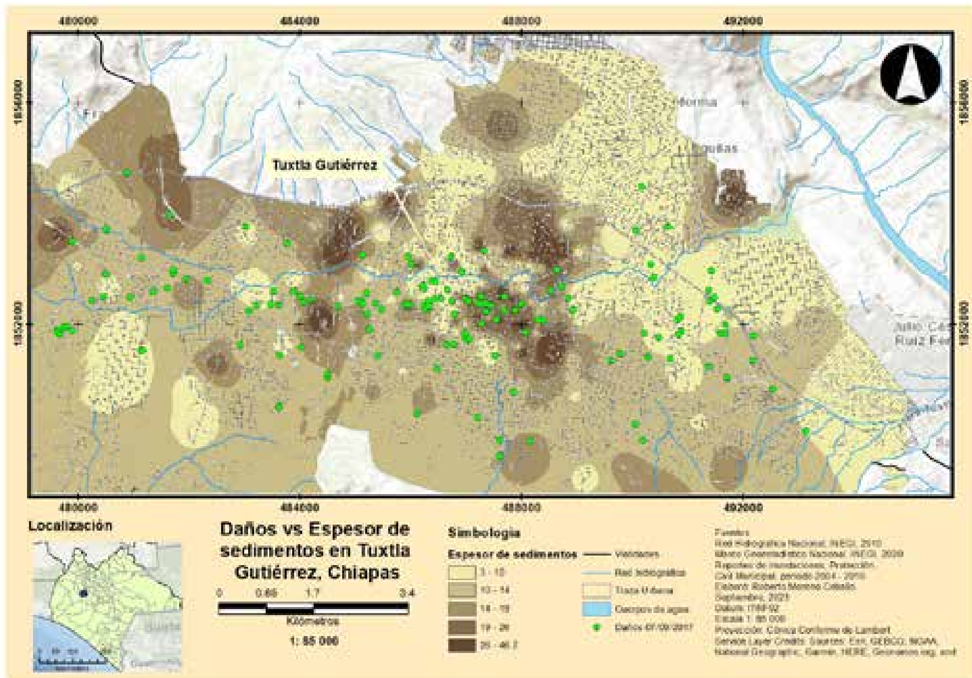


Figure 12. Thickness of sediments in Tuxtla Gutierrez, Chiapas

RESULTS

The development of sediment thickness maps and the analysis of seismic amplification in both urban areas allowed comparing the damage caused by earthquakes and, in turn, establishing a relationship with the areas of greatest impact. 198 blocks in Chiapa de Corzo were analyzed, and sediment thicknesses ranging from 7.12 m to 14.62 m were obtained (Figure 8). The city presents homogeneous constructive pathologies, which shows that the local conditions of the subsoil have been decisive in the location of the damage; it was also observed that the largest amount of these occur in areas between 8 and 12 meters thick of sediments and have been concentrated in the central area of the city and on the banks of the Grijalva River, that is, soft, poorly consolidated soils.

For Tuxtla Gutiérrez, thicknesses ranging between 3 m and 46.78 m were obtained (Figure 12) and a spatial correlation was made with the historical earthquake damage, finding that most of the damage is located in the central area and in the southwestern area of the city and is also located between 10 m and 20 m thick sediment. It is important to highlight the need to complement the results obtained in this work with current measurements located throughout the extension of the urban patch of both cities, since in recent years population growth has been considerable, also occupying areas considered at risk due to geological phenomena such as the southern slope of Tuxtla Gutiérrez (Paz-Tenorio, 2012).

CONCLUSIONS

Self-construction is a determining factor in the effects caused by the earthquakes that occurred in the study area. This has had consequences in groups with a high degree of marginalization of the population who, due to a lack of knowledge or resources, resort to this means to build their homes. Identifying existing threats and vulnerabilities in our community is an important task that will allow us to generate actions and ideas to reduce them through action plans.

The results presented here are part of an investigation related to the assessment of seismic vulnerability in the Metropolitan Area of Tuxtla Gutiérrez, using a methodology that allows preliminary zoning to be obtained using freely accessible information, which also allows it to be replicated in the rest of the cities of the MA.

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Water administration in rural and indigenous contexts: the case of the Association of Water Management Committees in the Municipality of Sitalá (APAMS)

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— Abstract—

The objective of this essay is to deepen the knowledge about community organizational experiences that ensure access to water in rural and indigenous contexts in Chiapas. Based on the case of the Asociación de Patronatos de Agua del Municipio de Sitalá (APAMS), we analyze the experience of more than four years of an organizational process that has involved various challenges and lessons learned, as a case that can inspire other organizational processes in Chiapas and southeastern Mexico. APAMS has promoted diverse actions within the communities, which have allowed it to legitimize its role as a spokesperson for community needs and proposals. Above all, it has placed Sitalá on the state stage, gradually advancing in the fulfillment of human rights to water and sanitation. Nevertheless, the association continues to confront multiple challenges, underscoring the ongoing imperative to enhance internal processes and external collaborations.

Keyswords:

Water management committees; community management; human rights; governance; sanitation.

This article is based on the author's work experience, about promoting, advising, and assisting in the construction of an organizational process of water boards in the municipality of Sitalá. The experience is based on being part of the work team of the civil association Cántaro Azul.[1] Therefore, it is an essay that is based on experiential learning over 4 years of linkage with community leaders and actors of various kinds that have been part of the organizational experience in question.

Access to water is a social necessity of vital importance for families and communities to be able to live in a dignified manner, as water is an essential element to ensure health and other associated rights, such as education, a healthy environment, among others. However, there is a gap in access to water for domestic use with notable differences between urban and rural areas. According to the United Nations Educational, Scientific and Cultural Organization (UNESCO), household drinking water coverage in Latin America reaches only 35% in rural areas, while coverage in urban areas reaches 90% (UNESCO, 2022).

Throughout the rural territories of Latin America and the Caribbean, there are community organizations that are born out of the collective need for water for the families' subsistence. These community organizations have improved the living conditions of the families they serve. However, the challenges they face are daunting. This is due to the fact that most of them operate with minimal or no collaboration from the government institutions responsible for providing basic water and sanitation services.

In the Latin American region, these community organizations are known as Community Water and Sanitation Service Organizations (OCSAS), which are defined as social structures that have emerged to support efforts to ensure water management (UNESCO, 2022). Several cases have been documented where OCSAS practice peer-to-peer strengthening, the development of articulated actions from the municipal to the international level, and undertake actions to increase the scope of results that would be less effective if each acted alone.

From my experience, under the imaginary of "OCSAS associativity", we can understand the articulation between OCSAS as the scaling up of the scope and capacities of action of community organizations, which generate their own mechanisms of linkage with other actors, depending on the agreements and needs, and which integrates a wide variety of community organizational forms.

1 Cántaro Azul is a civil association based in San Cristóbal de Las Casas, which has been working in municipalities in the Altos de Chiapas region for more than a decade; to learn more, please visit their website: https://www.cantaroazul.org/mision-y-vision.

This essay aims to contribute to the knowledge about the organizational processes of water committees and boards, and to the debate about the need to scale up collective action from the community bases in order to advance in guaranteeing human rights to water and sanitation, taking as reference the Chiapas case from the Asociación de Patronatos de Agua del Municipio de Sitalá (APAMS).

It is a priority to analyze the situation experienced by community organizations in relation to water, since in the recent decade a variety of challenges continue to prevail with respect to the implementation of the human rights to water and sanitation, where water governance continues to have utopian overtones in terms of the design and execution of public policies in accordance with the rural realities of Chiapas and Mexico.

STATUS OF COMMUNITY WATER MANAGEMENT IN MEXICO AND CHIAPAS

In several Caribbean, Central, and South American countries, the associativity of community organizations has been practiced with greater tradition. While in Mexico, there are few examples of this type, but with a long tradition of struggle in other contexts, such as resistance to large dams (which has led to the relocation of many communities) or to the excessive extraction and pollution by mining companies and other extractivist modalities.

In the rural experiences in Mexico, the associativity of community water organizations is being practiced as little of a strategy for scaling up advocacy processes and territorial strengthening of the agendas of these community organizations. However, community water management experiences in Mexico are becoming increasingly visible. Within the few existing cases, in indigenous and rural territories of Chiapas, processes are being developed based on the importance of the union between communities to achieve common objectives based on the felt needs regarding access to water and sanitation.

In the rural and indigenous territories of Chiapas, various social actors have carried out actions within the framework of community water management, with the main objective of achieving significant improvements in access to water. Understanding community water management as a collective practice that seeks to solve the problem of equitable access to water and sanitation services in order to meet the needs of families, collectives, and communities (own adaptation based on Cántaro Azul, 2023). In this entity, the crisis of access to water and sanitation services is notorious and has been a fundamental element in the situation of marginalization in which thousands of communities live. Between the Central Altiplano and the Northern Mountains, the scenario around community water management involves community representation structures known as "water committees"[2] which, with the support of their communities, have promoted and sustained collective actions to address water needs.

Water committees are generally part of an honorary community service (they do not receive a salary or economic gratification), as this is the main element that implies that the people in this type of position are renewed every year so that several inhabitants of the community comply with this type of services for the collective benefit. They are representative structures designated by community assemblies for a group of people to carry out the necessary tasks to make possible accessing water for the families of a community. Their work is normally focused on operational issues such as the care of springs and the maintenance of community water systems, but they also take on representation and negotiation functions before external actors (city hall, state or federal water sectors, among others). Some authors citing the characteristics of water committees in rural Chiapas are Murillo and Soares (2017).

However, local actions increasingly require the scaling up of processes to confront the multiple crises that affect water issues in rural and indigenous contexts. Given the need for greater outreach, the associativity of community water organizations is demonstrating several advantages as a mechanism to build collective work agendas at different scales, where water committees and boards of committees are key subjects in the development of solutions to address the problems affecting the population they represent.

Faced with the diverse challenges of the substantial implementation of the human right to water in Chiapas, inter-community organization processes are being developed, which have materialized in the form of "water committees associations". Particularly in the municipalities of Sitalá and Chenalhó, cases are developing where the water committees are assuming the need to organize among equals, considering the benefits of acting and strengthening collectively. Specifically, APAMS is the main actor in the present essay.

Commonly, when a water committee exists, it is largely due to the existence of community piped water systems. However, thousands of homes in the Tseltal and Tsotsil territories of Chiapas still do not have piped water service. In other cases, several of the water systems implemented by the Mexican government have become obsolete shortly after starting operations, reflecting the limited capacity of government institutions to ensure the sustainability of the systems installed.

2 In other areas of Chiapas, such as the Comité Plateau or the Central Depression, the name used is "water committees".

Thus, in various collective analyses, together with civil society organizations (CSOs), the water boards have been defining proposals for better social conditions to make substantial progress in solving community needs. Among the analyses carried out, the importance of promoting and strengthening collaborative relations with the Mexican State stands out, especially with municipal councils and other government agencies that have jurisdiction over water and sanitation services; in other words, collaboration with these agencies is sought because it is their obligation to develop actions, according to the legal frameworks at the federal and state levels.

The creation of water committees associations is based on the importance of the rural sector having a legitimate representation in the spaces for reaching agreements with key actors of the governmental entities. Based on this situation, community management of water and sanitation is recognized as a series of solutions based on organized citizenship.

APAMS INTEGRATION PROCESS

The situation in Sitalá indicates that 59% of the municipality's population lacks access to water and drainage in their homes, and 69% are in a situation of extreme poverty (Secretaría de Bienestar, 2024). What can be observed in the territory shows an even more serious situation, due to the fact that several of the water systems installed in recent decades have become obsolete and without follow-up by the competent authorities; this has been corroborated in several visits to the territory over the past several years, and contrasted with the testimonies of various community actors in dozens of workshops and exchanges of experiences over the past several years.

In the recent history of Sitalá, the fact that a few decades ago land tenure prevailed in the hands of a small group of landowners who held significant power in the social and political life of this territory stands out. This situation was gradually changing through social mobilizations that modified land tenure conditions, the most recent stage being the armed uprising of the EZLN, where several groups from Sitalá managed to obtain land to found their own communities (Bobrow-Strain, 2015).

In this context of remarkable changes in recent decades, APAMS was created in 2019 with the will of various community leaders who decided to organize to seek solutions to the difficult situation they live in terms of lack of basic water and sanitation services, linked to a historical omission of municipal councils that have not prioritized attention to rural communities and have not been able to position Sitalá before state and federal agencies.

In the same scenario of the creation of APAMS, various initiatives of civil society organizations converged, which in 2019 were developing a territorial alliance project called "Alianza Crecer Juntos por Sitalá", where three organizations in particular were working on the strategic axis called "Water and Territory" (Cántaro Azul, Cooperación and Organización Integral para el Desarrollo Rural AC. (CONIDER) and **Diseño y Capacitación para el Desarrollo y las Microfinanzas** (DICADEM). This alliance was visualizing the possibility of promoting organizational processes among water committees, in work sessions where Cántaro Azul positioned the ideas around the strengthening of the water boards at the intercommunity level, which would entail reaching agreements so that the actions and proposals of the community water managers could have an impact on the decisions and actions of government institutions.

In December 2019, the first municipal assembly for water was held in the municipal capital of Sitalá, where representatives of several communities attended, some of them where Cántaro Azul has worked, several others where CONIDER and DICADEM have had a greater focus on community work, and, at the same time, more than half of these community representatives participated, in that year, in another organizational process known as the dialogue space "*Tsoblej Slekubtesel Sitalá*".[3] As an agreement of this first assembly, it was decided to promote the municipal articulation of community leaders in order to seek solutions to the various water-related problems of the communities they represented. Thus began the organizational process that today defines itself as APAMS.

After the first municipal assembly, three more assemblies were held, which had both a resolutive and formative character, where the decision-making mechanisms and the priority issues to be addressed in the assemblies began to take shape depending on the objectives that were agreed upon by the water committees. Ideally, the assemblies should have been monthly, but the rhythm was interrupted due to the health contingency of the COVID-19 pandemic. Having a break between April and August 2020. The micro-regional assemblies were held once again in September, October, and November of the same year.

In December 2020, the First Municipal Listening Forum on water and sanitation was held in Sitalá. This was the first experience of strategic action where preparation sessions had to be held to plan several of the details for the dialogue that was expected to be held with different governmental institutions, including the Municipal Council. The event was co-convened by Cántaro Azul, CONIDER, and DICADEM, under the "Water and Territory" working group of the Alianza Crecer Juntos por Sitalá.

3 The broad participation of community leaders who were part of the "Tsoblej Slekubtesel Sitalá" is due to the fact that the internal process of this dialogue space resulted in the collective analysis that the main problem to be solved in the territory of Sitalá is access to water for Sitalá families (followed by other problems related to health, sanitation, the coffee market, and others).

The objective of the Forum was to promote a direct dialogue between the community and government sectors to link needs, initiatives, and proposals for collaboration among the participating actors. As for government institutions, delegates and representatives of the following institutions were present: National Water Commission (CONAGUA), the State Water Institute (INESA), the State Human Rights Commission (CEDH), the Roads and Hydraulic Infrastructure Commission (CCeIH), among others. One of the factors to achieve good attendance was the fact that a visit by the CONAGUA's sub-director to a couple of localities of Sitalá was organized weeks before, where he accompanied INESA. The result of the Listening Forum dialogue was the signing of voluntary agreements to promote strategic actions to advance the fulfillment of the human rights to water and sanitation for the communities associated with APAMS.

While planning the First Listening Forum, in the micro-regional assemblies of October 2020, they identified that the organizational process of water committees needed to have its own name, leaving it as a decision to keep its current name (APAMS) and defining who would be the community spokespersons in the dialogue with government institutions. With the passage of time, the APAMS representation structure would take on the current name of the Board of Directors.

One of the most important achievements of the first Listening Forum was to position Sitalá and APAMS on the institutional radar, since before this event, Sitalá was largely unknown in the scope of territorial knowledge of public servants, despite being at the top of the statistics of social marginalization. As an example of this, in 2021, we were able to develop collaborations with INESA, through which we managed to manage more than 400 home water filters, which benefited an equal number of households distributed in 13 rural localities of Sitalá. It should be noted that initially, Sitalá was not included in the list of municipalities prioritized by INESA, but it was taken up by the people who represented this Institute in the First Listening Forum.

At the beginning of APAMS (2019-2020), it is worth mentioning the *Tsoblej Slekubtesel Sitalá* as a fundamental element in the creation of APAMS, since, from the first municipal water assembly, they attended the call, contributing a large proportion of the participants, being active in convening water boards or other types of representation of the communities where they came from. And being promoters within their communities about the importance of having a stronger community organization that has the ability to promote significant changes to address the problems around water, sanitation, health, family economies, and other strategic issues that they identified in their internal analysis.

APAMS ORGANIZATIONAL STRUCTURE AND COMMUNITY CONTEXT

Currently, the APAMS is made up of 35 rural Tseltal communities. Amount that has been fluctuating since 2019, having greater stability from 2022. Some communities, through their water boards, have decided not to stick with the APAMS, while several others have joined at different times. Each community associated with the APAMS has a water board that represents them in municipal assemblies. These water boards are responsible for representing the needs and interests of their community before the APAMS and before external actors such as government institutions. While, in communities where they have piped water systems, they carry out maintenance and improvement actions throughout the water system, including the catchment area; within their communities, they are the ones who convene community assemblies in case of having to make important decisions about water, in coordination with the main community authority, which is normally the Municipal Rural Agent, in cases where there is an agrarian authority (ejido commissioning).

It should be noted that many communities that joined the APAMS in 2019 and 2020, did not have water boards, but were represented by the municipal agent or the ejidal commissioner, and even by leaders who participated in a personal capacity due to their interest in the subject (but without formal designation of their community assembly). The increase in the number of water boards happened gradually, the most important moment being the promotion of community assemblies in 2021, between the APAMS and the Crecer Juntos Alliance, where some communities formalized the creation of their water boards through community assembly minutes.

The assembly of water boards is the space where the most important decisions about the APAMS are made. Each associated water board has a voice and a vote. While the Board of Directors is responsible for representing the needs, agreements, and proposals of the APAMS, as well as attending to the actions and strategic links with external actors, both governmental and other civil society actors, such as the APAMCH (Association of Water Boards of the Municipality of Chenalhó) and other structures representing Chiapas' water boards and committees. Therefore, the way in which the assemblies of water boards are developed is largely inspired by the mechanisms of community assemblies, such as decision-making spaces.

The organizational process of the APAMS has developed in a challenging context where social dynamics occur within rural communities that in many cases have led to divisionism. Mainly, due to the intervention capacity of political parties and government programs that are executed without the care to promote social cohesion, achieving the opposite due to the prevalence of particular interests before the collective well-being, which implies contradictions with respect to the social objectives of government programs and political parties. Proof of this, in the recent prioritization exercises for the official mechanism of COPLADEM (Planning Committee for Municipal Development), housing construction has been prioritized due to a long tradition of political parties that have promoted direct agreements with some community groups in order to capitalize on the highest possible number of votes in municipal elections.

This is one of the greatest challenges that APAMS has had because, in 2021, there was little possibility of changing the local political modes of prioritizing needs before COPLADEM. While recently (2024), it is expected to have greater advocacy capacity, it remains to be seen to what extent water and sanitation could be among the main needs prioritized in COPLADEM.

Likewise, the gender issue remains very challenging, while in rural communities, the participation of women has not been given sufficient value. Generally, men do not take into account women's opinions and proposals regarding the problem of water (which is repeated in several other aspects of domestic and community life). However, in recent years, in the spaces of the APAMS there has been progress in the assessment of women's role, the clearest action being the fact that the main position of representation of the APAMS was designated for a woman, based on the decisions of the assembly of water boards. In addition, it is also notable that, since 2021, the number of communities that have integrated at least one woman into water boards has grown.

Regarding the structuring of water boards, in 2021, it should be noted that in 15 communities, the assemblies decided to integrate at least one woman into water boards, an unprecedented situation. This is an achievement of the constant promotion of reflections on women's role in community life. Reflections that have been facilitated by the organizations that make up the Alianza Crecer Juntos por Sitalá; for example, they have reflected on how women live the consequences of the lack of access to water on a daily basis. Currently, in the year 2024, there are 20 communities that have integrated at least one woman into the water boards teams; one of the main objectives for this year is to sustain this number, since this year the majority of the water boards teams associated with APAMS will be renewed.

2022-2024 APAMS STRATEGIC ACTIONS

One of the key processes of APAMS was the generation of its Management Plan. The Plan was developed through a series of workshops in 2022, concluding the drafting of the document in March 2023.[4] The Plan's general objective is to promote that the authorities responsible for guaranteeing the human rights to water and sanitation carry out the necessary actions to make infrastructure possible based on the priorities agreed upon by the APAMS, so that communities can enjoy their rights. While the objectives of the construction process[5] of this Plan were: a) Identify and prioritize the water and sanitation infrastructure needs in the communities; b) Organize the demands of the communities regarding access to water and sanitation; c) Promote the participation of the communities and their representatives in decision-making; d) Ensure follow-up on the agreements reached at the APAMS assemblies.

This plan is aimed primarily at government entities such as the Municipal Council, the National Water Commission, the Roads and Hydraulic Infrastructure Commission of the state of Chiapas, and the National Institute of Indigenous Peoples, seeking to generate and strengthen collaborative relationships to guarantee the human rights to water and sanitation.

One of the most outstanding characteristics of the APAMS Management Plan construction process was the reaching of agreements as to which communities would be prioritized first, as opposed to which would be prioritized last. This implied dialogue in which the felt needs of each community were made explicit, but also opened the opportunity to understand that some communities were living a more worrying situation due to the daily complications of not having some factor that would reduce the situation of marginalization. This led some communities to believe that their community could be left in a position of waiting for the communities with the greatest lags in terms of access to water to be taken into account.

The communities that ceded positions had one or more of the following factors: a) they had a community system (although with critical aspects of its operation), b) they had household storage systems in some degree of progress, c) although they depended heavily on water hauling, they had a surface source a few kilometers from the community or even complemented with wells within the community. Among other criteria that were discussed among the water boards.

With a Management Plan in place, APAMS mobilized to request dialogues with different governmental agencies, starting at the municipal level

4 An important element in the construction of the Management Plan was the project of the civil association CONIDER, which formally integrated this initiative into its 2021-2023 project financed by the Gonzalo Río Arronte Foundation. While all the organizations integrated in the Alianza Crecer Juntos made strategic contributions throughout the collective building process as a commitment to the continued strengthening of APAMS.

5 The process involved monthly workshops between August 2022 and January 2023, as well as the generation of community agreements promoted by the water committees before each community assembly, to substantiate the need and interest in developing a collective plan at the APAMS scale.

and going up to federal agencies. During the period from April to December 2023, the company generated various trades, approaches to government actors, and positioning the issue in events and media at regional and national levels. However, practically no significant actions have been taken by government agencies, despite the fact that we have tried to make the problems visible in collaboration with community representatives from other municipalities, such as Berriozábal, Chenalhó, Tenejapa, La Trinitaria, among others.

The strategic action with the greatest media coverage has been the development of the “Agenda Chiapas por el Agua”,[6] which seeks to lay the foundations for developing a Water Justice Plan for Chiapas. This Agenda was built based on the community voice of different municipalities, including Sitalá, for which meetings were held for the interaction and positioning of community needs and proposals, as well as those of youth and children. In particular, APAMS contributed to the September and November 2023 meetings; while in the latter, there was a more intentional participation of the Tsoblej Slekubtesel Sitalá.

Within the municipal context of Sitalá, based on the experience of APAMS in the year 2023, by the beginning of 2024, the APAMS Board of Directors decided to promote a strengthening of ties with community-based organizations with which there were varying degrees of alliance and rapprochement. Between February and May of this year, we were able to strengthen and amplify a community alliance that takes up the organizational mechanisms of the Tsoblej Slekubtesel Sitalá, integrating other community-based organizations, which are: the local group of the state midwives movement *Nich Ixim*, organization of craftswomen *Luchiyej Antsetic ta Sitalá*, municipal organization of honey makers, and the municipal security council (the latter is independent of the municipal government, which takes up the social vision of the local nucleus that previously called itself MODEVITE).[7]

The first action that the Tsoblej Slekubtesel Sitalá community alliance has taken is to approach the candidates for the municipal presidency within the framework of this year's elections. This resulted in the signing of collaboration agreements that represent a first step to be taken again now that it is known which of the candidates won the municipal presidency. Within the signed agreements it is stated that the new municipal council commits to “define as a municipal priority the attention to the improvement of

6 For a detailed description of the Chiapas Agenda for Water, see: https://www.cantaroazul.org/agenda-chiapas-por-el-agua

7 MODEVITE stands for Movement in Defense of Life and Territory. This movement is still in force in Chiapas

water and sanitation services for the communities associated in the Tsoblej Slekubtesel Sitalá, starting with actions at the community level in the communities prioritized in the Management Plan of the Association of Water Patronages of the Municipality of Sitalá" (Minutes of agreements, between the candidate to municipal presidency for the political party MORENA and the municipal social structures integrated in the Tsoblej Slekubtesel Sitalá, 2024; internal document). Among other agreements, we will seek to materialize various actions to move forward with greater clarity in the fulfillment of the human rights to water and sanitation, as well as other rights, for the benefit of the communities and families that need them most.

However, this is not the first time that written agreements have been reached between APAMS and government agencies. Therefore, it will be essential to follow up with close collaboration with various stakeholders. The academy is one of the sectors with the least presence in this type of initiative for the promotion of water governance.

APAMS CONTRIBUTION TO RURAL DEVELOPMENT IN CHIAPAS

APAMS is a clear reference of the possibilities of community-based organizations for the structuring of proposals to improve conditions in rural life with a social justice perspective. In a few years, APAMS has begun its journey in the territory of Sitalá to build greater opportunities to develop activities with water boards, which positively impact in various ways, especially in improving the coverage and quality of water and sanitation infrastructure.

Community water management, materialized in actions coordinated by water boards, is a mechanism for social participation that has existed in various rural territories in Chiapas for many generations, but is little recognized in legal and institutional frameworks, and faces enormous challenges for its sustainability in different contexts. Therefore, it is urgent to generate public policies and social agreements that strengthen it in order to achieve progress in the fulfillment of the various rights associated with water and sanitation.

In the localities of Sitalá there are examples of the invaluable work of the water boards, but it is also recognized that in many ways the water boards are overwhelmed by the economic, social, technical, and administrative challenges involved in sustaining water and sanitation services in rural communities.

It is important to deepen the knowledge about these organizational expressions that are building proposals for the solution of water and sanitation problems. As well as providing solid proposals, based on local and empirical knowledge, for the strengthening of social subjects that can form social organizations to position the rural sector in the scenario of territorial governance of water and sanitation.

In 2022, the experience of APAMS inspired several water boards in the municipality of Chenalhó, who, at the end of the same year, formalized the creation of their own organizational process, calling themselves the Association of Water Boards of the Municipality of Chenalhó (APAMCH). These water boards of Chenalhó had different approaches with APAMS representatives in events and exchanges of experience, being the most outstanding: the First State Listening Forum held in June 2022 and the Interstate Meeting of Community Water Management held in September 2022.

In this scenario, the organizational processes of water boards and committees have emerged in recent years with the potential to articulate actions between organized civil society and the government sector. Such is the fact of the current collective dream of diverse community representations that are promoting actions towards a water justice plan for Chiapas. This effort will have greater scope to the extent that various sectors of society join in, such as academia, which could contribute not only to the documentation of problems or the design of alternative technologies, but also to the development of community outreach projects with a participatory action research approach.

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A C A D E M I C S
P A P E R S

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Environmental Engineering Educational Program of the Faculty of Engineering, Universidad de Ciencias y Artes de Chiapas 20th anniversary

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This issue of the Journal Espacio I+D Innovación más Desarrollo of the Universidad Autónoma de Chiapas commemorates the twenty years of creation of the degree in Environmental Engineering, an educational program of the Faculty of Engineering at the Universidad de Ciencias y Artes de Chiapas - UNICACH. We want to share some of the results and contributions of its graduates, researchers, and collaborators. Over the years, they have managed to create a community that remains current in the face of the challenges of climate change, monitoring compliance with environmental legislation and regulations for the equitable administration of the valuable natural resources provided by our entity and the region for the world. Various social organizations and governments recognize the crucial importance of environmental engineering professionals in the protection and restoration of the environment, which highlights their important role as the current metaphor "healers of the planet".

Since its inception, the program has trained high-quality, competent, and ethical human resources at the undergraduate and graduate levels. Along the way, ties of friendship and collaboration have been strengthened with academics and researchers from various higher education institutions, such as UNACH, who today contribute to the publication of this issue for academic and scientific dissemination purposes. We greatly appreciate the collaboration of its graduates who continue their specialization or work in institutions such as the Tecnológico Nacional de México through the Instituto Tecnológico de Tapachula and the Instituto Tecnológico de Tuxtla Gutiérrez, the Universidad Autónoma de Chiapas, the Municipal Civil Protection Secretariat of Tuxtla Gutiérrez, the Fundación Cántaro Azul A.C., and, of course, the Universidad de Ciencias y Artes de Chiapas.

This issue includes 7 articles, most of which converge on environmental problems and natural phenomena of high concern to society and that continue to be a challenge in the search for joint solutions, about the management of urban solid waste, the generation of wastewater in different economic sectors, the governance of water resources in communities and alternatives for their disinfection, the treatment of complex wastewater, and seismic risk in the metropolitan area. The contribution of each article is reflected in aspects that affect society in general and show the need to continue addressing these challenges, taking into account the social, academic, business, scientific, and government sectors in a comprehensive way.

The approach on the inadequate disposal of solid waste that is generated in each house, workplace, or public space by each inhabitant in our state, as well as its management, are clearly presented in "Waste Destination: A view of its impacts", which provides a global vision on the final garbage disposal in Mexico, as well as its main environmental and social impacts. "Study of Generation of Municipal Solid Waste in the Municipality of Chiapilla, Chiapas" presents in detail the per capita generation and composition of waste, as well as management strategies that include the modification of local regulations and the importance of environmental education campaigns, to improve the current conditions for the study site.

The issue of water resources is of urgent and relevant importance both locally and internationally, requiring the permanent efforts of each sector of society. In this order, some of the authors of this publication address issues that deal from community organization in the rural and indigenous context that ensure access to water in their context, which has allowed progress in the fulfillment of the human rights to water and sanitation, such as "The case of the Association of Water Management Committees in the Municipality of Sitalá". As well as the explanation of the impacts of pollutants such as fats and oils in wastewater from the hotel sector in the Mexican Caribbean, in addition to its challenges, alternatives, and recommendations for reducing its impact. Another scenario that discloses corrective strategies in wastewater treatment is the article "Application of an electrochemical process to treat liquid waste from GRAM staining tests" where the authors present the treatability tests for a very complex wastewater to treat given its high organic load and low biodegradability, this process can be a real treatment option for complex mixtures of dye residues. Another related alternative in the reduction of impacts on water is the obtaining of organic dyes that can be obtained at low cost and that contribute with a disinfectant action in water, this issue is shown in the article "Spectral Characterization and True Color Analysis of Different Natural Dyes such as *Bixa Orellana* and *Brassica oleracea var. Capitata* compared to *Indigofera suffruticosa* and *methylene blue*".

Finally, this issue presents "Seismic hazard in the metropolitan area of Tuxtla Gutiérrez: two case studies", where the authors seek to contribute to the understanding of seismic hazard in the Metropolitan Area of Tuxtla Gutierrez, through the analysis of historical damage and soil characteristics as a fundamental element in the site effect in the region, using a methodology based on Geographic Information Systems. Maps are presented that can be used as key tools for risk management and urban planning in the region.

The works presented in this publication show only a small part of the wide diversity of problems related to the environment, its preservation, conservation, management, and administration of natural resources that do not compromise their availability for future generations and where the role of environmental engineering occupies a relevant and necessary place to contribute to the public and private order.

Figure 1

Figure 2

In commemoration of the 20th anniversary of the Environmental Engineering educational program of the UNICACH's Faculty of Engineering, we would like to express our deepest gratitude to the 29 generations of graduates for taking the spirit of our degree beyond the classroom and transforming it into concrete actions that transform the world through their success and commitment as a reflection of the quality and dedication of the effort in their academic training. To the directors who have believed in the educational program and have been key to positioning our degree as a driver of change. To the teachers for being the backbone of this achievement, who have inspired generations of environmental engineers to work for a sustainable future with their teaching and commitment. To the administrative staff, whose constant support and daily effort allow us to keep everything going enthusiastically and fundamentally for our community.

Thank you for being part of this history and building a legacy that will continue to positively and favorably impact our society and the environment.