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Current state of environmental contamination in the Oaxacan Mixtec Region

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Abstract: Objective: To present a systematic review of studies that evaluate the impact caused by urban solid waste generated in the Oaxacan Mixtec region. **Results:** The analysis of the research results consulted in the following databases: Red de Revistas Científicas de América Latina y el Caribe (Redalyc), Scientific Electronic Library Online (Scielo), Dialnet, EBSCO and Consorcio Nacional de Recursos de Información Científica y Tecnológica (CONRICYT), show that pollution is a problem that has been gradually increasing globally, which has led to the presence of foreign organisms and substances that interfere with and damage the health of people, natural resources and the ecological balance; It is worth mentioning that the impact on communities caused by the inadequate generation and management of solid waste significantly alters the ecosystem of the areas surrounding the disposal sites. It is important to note that there is legislation in this area that specifically classifies the different disposal sites and entrusts the municipalities with the integral management of urban solid waste, but this legislation is not correctly applied despite the fact that this problem has become very important in the last two decades in governmental spheres. **Conclusions:** Mexico faces the challenge of resolving environmental problems in order to reach a level of sustainability and sustainability in the medium term. The generation rates of urban solid waste continue to increase because we live in a society that has drastically modified its consumption habits. The degradation of the environment and natural resources for the Oaxacan Mixtec region is classified in ranges from unstable-critical to critical, causing pressure on natural resources, which is why we must have an adequate management and disposal of municipal solid waste, to achieve this it is necessary to have the support of society, governments and society in general, this synergy is necessary to reduce the extraction of resources used to produce them obtaining economic, social and environmental benefits in the long term for the region.

Keywords: environmental contamination; solid waste; integrated solid waste management

1. Introduction

The problem of the environment must be analyzed not without first studying the economic growth of countries. The problem of environmental conservation (EoE) is related to economic growth. From the point of view of economic theory, as economies grow, they become more concerned about the state of the environment and the preservation of natural resources; Thus, there is a positive relationship between economic growth and the preservation of natural resources [1], it is generally assumed that richer economies damage and destroy natural resources faster than poorer economies, given their consumption, i.e., environmental degradation tends to increase at a faster rate than poorer economies, environmental degradation tends to increase as the economic structure of a country or region shifts from an agricultural to an industrial economy, and subsequently, this degradation tends to decrease as it shifts from an intensive industrial sector to a service-based economy [2], meaning that economic

powers occupy developing countries as their factories and cheap labor. It is commonly believed that the quality of the environment can only be improved by escaping the industrialization process [3], the reality is that rich economies invest more resources in research and development, which translates into technological progress that allows replacing obsolete technologies with others that are more compatible with the environment [1].

Pollution is one of the most serious problems worldwide and is a silent threat to life [4]. The causes that provoke the contamination of a site are very diverse. Some of the most common are the improper disposal of Municipal Solid Waste (MSW), Special Management Waste (SMW) and Hazardous Waste (HW) in vacant lots, warehouses, warehouses and industrial yards; leakage of materials or HW from subway tanks and containers, pipes and pipelines; leaching of materials in storage sites and where production activities are carried out, or from landfills and open dumps, and accidental spills of chemical substances during transportation [5].

Air pollution can be defined as the undesirable modification of the environment caused by the introduction of physical, chemical or biological agents in greater quantities, which is harmful to human health, damages natural resources or alters the ecological balance [6], soil pollution can be understood as chemical degradation and, therefore, as a process or processes that lead to loss of productivity; this happens when the soil receives toxic substances in concentrations that exceed its natural self-purification capacity. Drinking water is threatened by the continuous pollution generated by human activity and by the decrease in water resources as a consequence of global warming [7]. 97.2% of the water on planet Earth is saline and only 2.5% is fresh water; of that 2.5%, 30% is groundwater, 68% is in glaciers and other snow layers and only 1.2% is surface water found in rivers, lakes and other forms of surface water [8].

According to the Drinking Water report by the World Health Organization in 2017, 71% of the world's population (5.3 billion people) has access to safe drinking water and this percentage will continue to decrease, so it is predicted that by 2025 half of the population will be living in water problem areas [9]. The high contamination of fresh water translates into public health problems that affect not only human and animal populations, but also the natural environment in general. High infant morbidity and mortality rates from acute diarrheal disease is a clear example of the results of water contamination. An estimated 1.8 billion people worldwide consume water contaminated with feces [10].

The production and consumption of goods and services inevitably generate some type of waste, which can be solid (of either an organic or inorganic nature), liquid (including those that are discharged dissolved as part of wastewater) and those that escape in the form of gases, all of which, depending on their composition, rate of generation and management, can have very diverse effects on the population and the environment. The importance of the issue of waste generation and management involves not only the environmental and public health effects derived from its generation and management, but also, from another angle, the use of natural resources [11].

In Mexico, according to the most recent figure published in 2015, MSW generation reached 53.1million tons, which represented an increase of 61.2% with

respect to 2003 (10.24 million tons more generated in that period, if these figures are expressed per inhabitant, it reached 1. The increase in the generation of urban solid waste can be explained as a result of multiple factors, among the most important of which are urban growth, industrial development, technological modifications and changes in the population's consumption patterns. In Mexico, as in the case of many other countries, the growth in the generation of solid waste goes hand in hand with the growth of private final consumption and the national GDP [12].

With the post-war era and the subsequent accelerated industrialization in the world, a process of environmental deterioration began, but it is especially since the seventies in the last century that this process has expanded, having global repercussions in the loss of biodiversity with an impact on human societies [13].

2. The Oaxacan Mixteca

Oaxaca is located between 15°38'30" and 18°42'30" North latitude and 93°38'30" and 98°30'30" West longitude, located in the southwest of the Mexican territory, bordering the states of Veracruz and Puebla to the north, the Pacific Ocean to the south, the state of Chiapas to the east and Guerrero to the west; The current political division of the state of Oaxaca is complex, as it is divided into eight geographic and cultural regions, with 570 municipalities divided into 30 districts, which are home to just over 11 thousand communities; the regions of Oaxaca are: Cañada, Costa, Istmo, Mixteca, Papaloapan, Sierra Sur, Sierra Norte and Valles Centrales [14,15]. The Mixtec region in the state of Oaxaca is located northwest of the state capital, bordering to the north with the state of Puebla, to the west with the state of Guerrero, to the south and southeast with the districts of Putla de Guerrero and Sola: Putla de Guerrero and Sola de Vega, belonging to the Sierra Sur region; Zaachila and Etla, both corresponding to the Valles Centrales region and, Cuicatlán and Teotitlán, which make up the Cañada region [16].

The Mixteca is located in a west-east direction, from the border between Guerrero and Oaxaca to the Valley of Oaxaca and, in a north-south direction, from the south of Puebla to the Pacific Ocean [17]. The Mixtec region is subdivided into three: Mixteca Alta, Mixteca Baja and Mixteca de la Costa, its administrative political division comprises 7 districts made up of 155 municipalities and 2098 localities are registered, covering an area of approximately 40,000 square kilometers which occupy a third of the Oaxacan territory, at the confluence of the Sierra Madre del Sur and the Sierra de Oaxaca, see **Figures 1** and **2** [18–20]. The Oaxacan Mixteca is the most depressed region in the province of Oaxaca, as it has social and ecological limitations that restrict its economic development [21,22].



Figure 1. Regions into which the state of Oaxaca is divided. Extracted from animal gourmet.

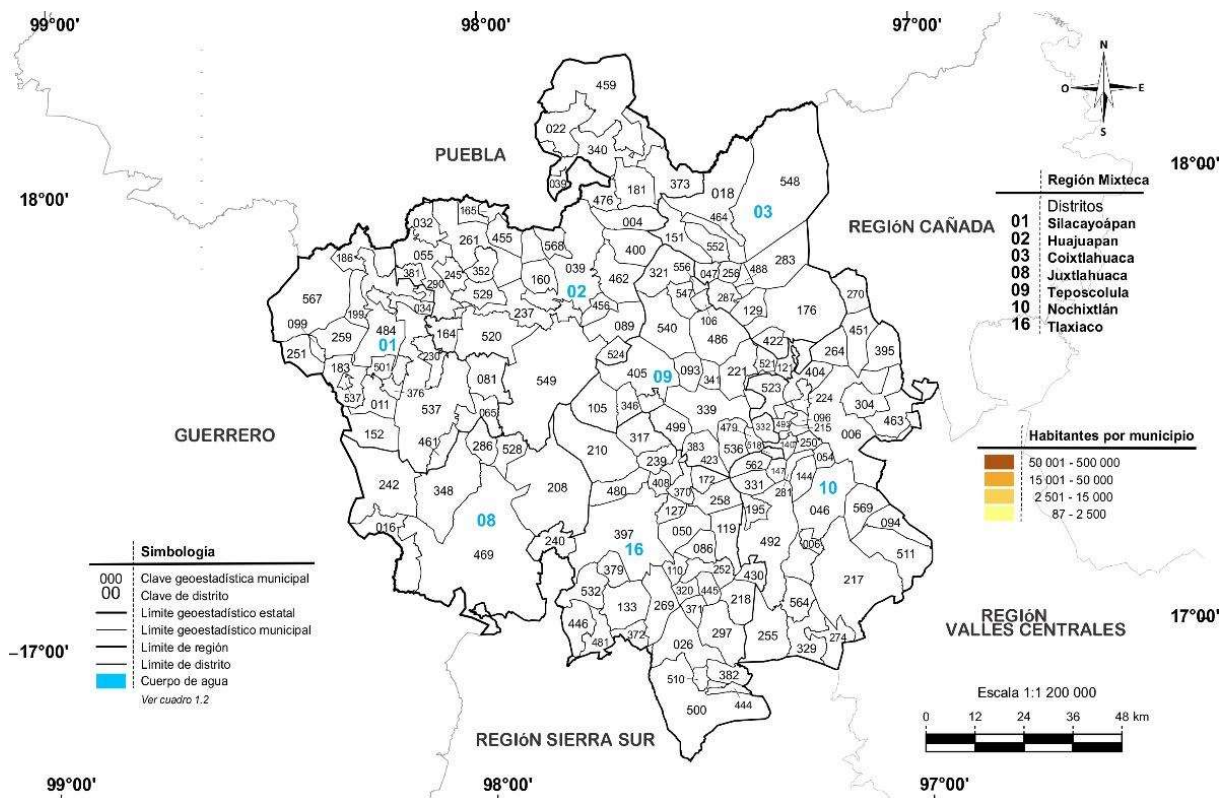


Figure 2. Oaxacan Mixtec Region by districts and municipalities, based on INEGI.

3. Environmental contamination

Pollution is one of the most serious problems worldwide. Growing urbanization, industry, agriculture with excessive use of pesticides and fertilizers, deforestation, energy production and consumption habits have produced an enormous amount of substances that contaminate water, soil, vegetation and the atmosphere and are a silent threat to life [4]. Mexico, like many countries in the world, faces the challenge of addressing and solving a series of environmental problems that could be major obstacles to achieving sustainability in the future. Climate change, the loss of ecosystems and their biodiversity, as well as the scarcity and contamination of water

resources are perhaps some of the most important, but not the only ones [12]. The precarious state in which an important part of Waste Management is found, especially with regard to the treatment and disposal of solid waste, is especially noteworthy; for this reason it is necessary to find measures and urgent solutions for improvement, with acceptable and sustainable environmental and economic criteria [23,24]. In Oaxaca, soil degradation is linked to different processes and levels, it is the result of both climatic variations and human activities. The most notable is the loss of hectares due to chemical degradation, which in the state reaches 1 million 678 thousand 622 hectares, representing almost 5% of the national chemical degradation [25]. The degradation of the environment and natural resources for the Mixtec region is classified in ranges from unstable-critical to critical, according to the map of the Geography Institute of the UNAM in the 2012 trend scenario. Degradation is a reflection of a set of adverse practices that negatively affect the quality of the soil, ecosystems (especially forests and jungles) and water [26]. The Mixteca, with an area of 15,671.08 km², is the fourth most populated region of Oaxaca, with 155 municipalities and 2098 localities, it has 12% of the inhabitants of the state, 465,991.00 inhabitants, although the region has a high concentration of population centers, it is combined with a notable dispersion of its localities with less than 2500 people [18,27,28]. The reality of this dispersion leads the inhabitants of these towns to use their environment as a way of life, generating pressure on natural resources (water, soil and forests), as well as higher costs for water supply, drainage, wastewater treatment, garbage collection, etc. At the same time, there is a drive to expand urban areas, impacting the environment [26]. The causes of the pressure on the environment and natural resources due to this concentration-dispersion relationship of human settlements have to do with both population distribution and the natural effect of taking advantage of the environment to support communities. On the one hand, there is the growing need to use the territory to form urban areas and, on the other, the use of resources to satisfy basic needs, expanding the agricultural or livestock frontier, illegal logging, excessive firewood collection, unsustainable forest management, as well as the lack of basic services with the effect of contaminating water bodies and soils due to inadequate wastewater and solid waste management [26].

The Oaxacan Mixteca region is one of the poorest regions in Mexico, with high levels of deforestation, the highest levels of soil deterioration and water scarcity. It has been estimated that close to 500,000 ha of this region have severe erosion problems. In the Mixteca Alta, the situation of environmental deterioration is a consequence of a historical process of changes in the social and productive structure, which dates back to pre-Hispanic times when its inhabitants made indiscriminate use and exploitation of their natural resources to achieve the necessary self-sufficiency [29].

4. Solid waste

Solid waste management is a worldwide problem for large cities. Factors such as population growth, concentration of population in urban areas, inefficient development of the industrial and/or business sector, changes in consumption patterns and improvements in living standards, among others, have increased the generation of solid waste in the towns and cities of the region [30,31]. In the last 30 years, the

generation of solid waste in the Latin American and Caribbean region has increased; In addition, the composition of this waste has changed, with less organic waste and more waste that lasts longer in the environment, as well as the generation of a significant amount of toxic waste. Most of these countries lack the infrastructure (particularly for solid waste disposal), the will or the management capacity to deal with this situation. In Caribbean countries, problems can be found at all stages of the waste stream (collection, disposal and treatment), and although many countries in the region have some type of legal framework with respect to solid waste management, in most countries, there is no formal responsible for solid waste management [32]. With the exception of some countries in the English-speaking Caribbean, MSW management is an eminently municipal responsibility in almost all of the region [33].

Waste generated by human groups has always existed, but its presence as an environmental problem is a recent phenomenon [34]. Urban Solid Waste (USW) is the waste generated in households, resulting from the disposal of the materials used in their domestic activities, the products they consume and their containers, packaging or wrappings; the waste from any other activity within establishments or on public roads that generates waste with household characteristics, and the waste resulting from the cleaning of roads and public places, provided that they are not considered by this law as waste of another nature [35]. The importance of the issue of waste generation and management does not only involve the environmental and public health effects derived from its generation and management, the integral management of waste, besides trying to reduce its generation and achieve its adequate final disposal, can also give as a collateral result the reduction of the extraction of resources, energy and water used to produce them, as well as the reduction of the emission of greenhouse gases, all of which is accompanied by important economic, social and environmental benefits; waste is contained in containers or deposits, and needs to be subject to treatment or final disposal based on the provisions of the General Law for the Prevention and Integral Management of Waste (Ley General para la Prevención y Gestión Integral de los Residuos) [36].

The management of municipal solid waste (MSW) in Mexico is complex and has evolved in parallel with urbanization, economic growth and industrialization. It is known that, in the 1950s, the national average daily generation of MSW was 8200 tons/day, which increased to more than 109,000 tons/day by 2010. This means that in six decades the generation of waste has increased almost 13 times, however, the problem is not only in the large amounts generated, but also in the change of the internal composition of waste, which is no longer mostly organic, and has been transformed into materials that require physical, chemical and biological processes to degrade [37,38].

Article 10 of the General Law for the Prevention and Integral Management of Waste (LGPGIR) establishes that municipalities are responsible for the integral management of urban solid waste, which consists of collection, transfer, treatment, and final disposal [39], Ochoa [40] (cited in Sáez et al. [41]), establishes that solid waste management is comprised of all functional or operational activities related to the handling of solid waste from the place where it is generated to its final disposal. The generation and management of solid waste requires the commitment of society, governments, academia, the media, the community, organizations and individuals, in

order to minimize the adverse effects on the environment and health, mainly, the proper management of recyclable materials is of vital importance to reduce the amount of waste that is taken to landfills occupying unnecessary space and reducing the useful life of the same [42], in 2013, 83% of household solid waste generated in Colombia went to landfills and only 17% was recovered by recyclers for reincorporation into the productive cycle [43]. In Mexico, the disposal of municipal solid waste (MSW) is subject to the official Mexican standard NOM-083-SEMARNAT-2003, which classifies final disposal sites (FDS) into: Landfills (RESA), controlled sites and uncontrolled sites or open dumps, according to the infrastructure and management and operating conditions of the site [44]. The management of solid waste in the Mixteca region should become a central point since the amount of tons registered in 2009 places the region in fourth place in waste production with 51 thousand tons, which represents 9% of the total statewide waste collected [26].

The final disposal sites for garbage are as follows: in 2010, with the information collected from 570 municipalities, there were 401 open dumps, 0 controlled sites and 7 sanitary landfills; for 2012, of the 570 municipalities, the following data are available: 3 sanitary landfills, 7 controlled sites and 214 open dumps [45], these figures reflect a decrease from one period to another in the number of sanitary landfills and open dumps, as well as an increase in the number of controlled sites. One difficulty associated with garbage collection capacity is the marked difference in the coverage of municipal public services, since on average 64% of garbage is collected in the capitals and 32% in the outlying areas. This leads to the prediction that uncollected garbage is burned or dumped clandestinely in places that are not suitable for this purpose. The State Institute of Ecology and Sustainable Development of Oaxaca (now the Secretariat of the Environment, Energy and Sustainable Development) managed the establishment of the State Program for the Prevention and Integral Management of Urban Solid Waste and Special Handling in the State of Oaxaca (PEPGIRSUME), which has as one of its specific objectives: To have an instrument that clearly indicates the programmatic goals in the area of solid waste; that marks and defines the direction to take, to modernize, professionalize and strengthen the management of solid waste in the State of Oaxaca; 16 studies were conducted on the generation of urban solid waste generated in residential homes and a statistical analysis was performed to establish the average per capita generation of solid waste, the physical composition and the volumetric weight in situ of the solid waste [35].

The diagnoses contained in the State and Municipal Programs for the Prevention and Integral Management of Waste (PEyMPGIR), allowed us to estimate a weighted average value of 0.85kg/inhab/day (gpc). To determine this value, 1144 data were available (46.56%) for the total number of municipalities in the country. The weighted average volumetric weight (ww) in 2012 is 153.12 kg/m³ (value adjusted to the number of inhabitants per municipality size). The available pv data are presented for 25.44% of the country's municipalities. Regarding composition, 99 data of composition in by-products were analyzed, based on the information presented in Module 6: Urban Solid Waste of the National Census of Government, Municipal Governments and Delegations 2011 conducted by INEGI, the results obtained are shown below in **Table 1** [46].

Table 1. MSW composition by by-product.

Category	By-product	Percentage
Susceptible to use 39.57%.	Cardboard	6.54
	Paper	6.20
	Ferrous material	2.09
	Non-ferrous material	0.60
	Rigid plastic and film	7.22
	Waxed cardboard packaging	1.50
	Synthetic fibers	0.90
	Expanded polystyrene	1.65
	Rubber	1.21
	Can	2.28
	Stained glass	2.55
	Transparent glass	4.03
	Polyurethane	2.80
	Construction material	1.46
Organic 37.97	Leather	0.51
	Vegetable hard fiber	0.67
	Food waste	25.57
	Bone	0.59
	Landscaping waste	9.38
	Wood	1.25
Others 22.46% Others 22.46% Others 22.46% Others 22.46% Others	Fine residue	3.76
	Disposable diaper	6.52
	Cotton	0.70
	Rag	3.57
	Earthenware and ceramics	0.55
	Various	5.90
Total		100%

Source: Own elaboration with data from INEGI, 2013 [18].

The management of solid waste in the Mixteca should become a central point, although the amount of tons registered in 2009 placed the region in fourth place in waste production with 51 thousand tons, by 2013 it was already in second place at the state level with 86,410. **Figure 3** shows the generation of solid urban waste from households in each of the regions of the State of Oaxaca. This analysis shows that the central valleys region is the one that generates the greatest amount of solid urban waste, but it is noteworthy that the Mixtec region follows in the generation of MSW, considerably increasing the generation of the same [35]. It is worth mentioning that the analysis of solid waste samples by municipality showed that in all cases the most important element is carbon, which is due to the high percentage of organic matter present in the samples.

Waste Generation Obtained from studies carried out in 2013 ton/day

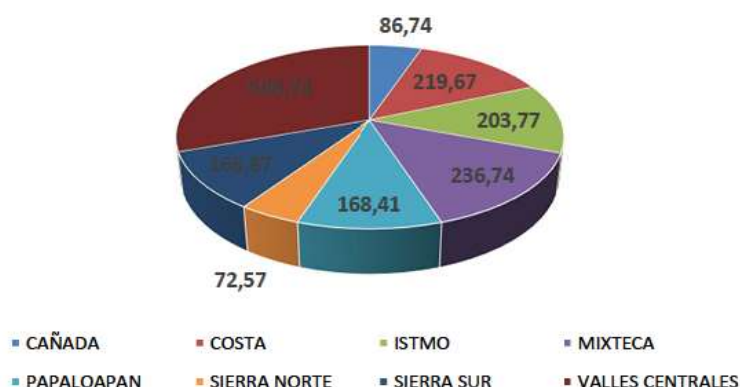


Figure 3. Waste generation obtained from studies conducted in 2013 ton/day.

In the planning of solid waste management services and, in particular, in the economic management of solid waste, it is important to know the incidence of waste generation by the population. This knowledge is also necessary to formulate action plans for minimization, recovery and recycling. Thus, the way to understand the problem and offer technically adequate, socially feasible and economically viable solutions is to measure and quantify the phenomenon of interest, in this case to determine the quantity and composition of solid waste [47]. In the case of Latin America and the Caribbean, waste management under the “collection and final disposal” scheme has prevailed, leaving behind waste recovery, recycling and treatment, as well as sanitary and environmentally adequate final disposal. In general, it should be noted that the greatest contamination problem is found in open dumps, which causes contamination through the air and through rain where water flows to the adjacent land [48,49].

The community of San Miguel el Grande, to cite one community in the region, through the Community Land Use Planning Study conducted by Grupo Mesófilo A.C., shows that the inhabitants pointed out that the air and water pollution and the visual impact of the garbage is unquestionable and added that the damage caused by the garbage to the road system is evident as it clogs the sewage and water evacuation systems; the causes of the problem seem complex, since looking for the root of the problem it cannot be omitted that the current consumption and production mode are the main responsible and precisely some inhabitants of San Miguel el Grande affirm that consumerism and “the big companies (referring to their production model)” are the causes of the problem [50].

5. Final considerations

Environmental pollution is a rapidly growing global problem and a threat to life on the planet due to adverse practices that negatively impact the environment. Urbanization, industrialization, the constant and excessive use of pesticides and fertilizers, energy production and the modern way of life have caused the production of goods and services that generate substances that contaminate water, soil, vegetation and the atmosphere; Mexico faces the challenge of addressing and solving

environmental problems that endanger future sustainability. The waste generated by human activities has always been present in our environment, but it has become a problem since the composition of waste has changed from organic to chemical compounds, as a result of changes in consumption patterns, standard of living and production.

The General Law for the Prevention and Integral Management of Waste (LGPGIR) establishes that urban solid waste is the waste resulting from household activities, establishments and public roads; it also places the municipalities in charge of the functions of integral management of urban solid waste; The integral management of these must be focused on reducing their generation, disposing of them in an adequate manner, encouraging their use, recycling and treatment, resulting in a reduction in the use of resources for their production, emission of greenhouse gases and reduction of the pressure on the environment and natural resources, which is a scheme that seems complex since in Mexico the scheme of collection and final disposal in open dumps prevails.

In Oaxaca, soil degradation has been linked to climate change and anthropogenic activities. In 2013, the Mixteca region of Oaxaca ranked second in the state in terms of solid waste generation as a result of inadequate waste management, generating adverse environmental and public health effects.

Conflict of interest: The author declares no conflict of interest.

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