Hydrology and Pollution in Coastal Zone of Carmen City: Relationships with Effluents of Urban Areas

Alejandro Ruiz Marin[#1], Yunuen Canedo López[#2], Silvia del Carmen Campos García[#3]
José del Carmen Zavala Loria[#4], Nain Elvira Antonio[#5], Mirna Yolanda Sabido Perez[#6].

[#] Environmental Sciences Laboratory. Autonomous University of Carmen,
Faculty of Chemistry. Calle 56. No.4. Av. Concordia. Col. Benito Juárez., México
[1]aruiz@pampano.unacar.mx

Abstract- **City of Carmen is located within the natural reserve of Terminos Lagoon; Nevertheless, the high activity hydrocarbon exploration and exploitation and urban have increased in the last years and consequence a high generation of wastewater that flows into the beaches and the Terminos Lagoon. Therefore it is necessary studies of monitoring and hydrology for the ecosystem protection. This study evaluated and analyzed the variation hydrological present during the season characterized by strong winds, droughts and rains in beaches near the discharge of urban effluents. During north and rainy season the salinity decreased from 16-20 spu with better conditions for the survival of faecal coliforms (FC). A higher concentration of bacteria (790- 1700 MPN 100 ml^{-1}) for rainy season was observed that dry season (30 to 120 MPN 100 ml^{-1}). Similarly, higher levels of biochemical oxygen demand (BOD) was for north season (2.8 – 4.6 mg l^{-1}) that for dry season (0.1 – 1.7 mg l^{-1}). The high content of chlorophyll *a* and nitrogen during the dry season showed an important relationship; suggesting the contribution of nitrogen by the decomposition of organic matter from wastewater effluent of the channel Caleta, which received a high amount of wastewater. Despite that the BOD and bacteria concentrations exceed the acceptable levels during north season, suggesting a limited use of the beaches for recreational purpose; this is probably that the environmental conditions allow the dilution and dispersion of organic matter and bacteria, but the transportation of such pollutants can affect the adjacent beaches.**

Keywords- ***Wastewater; beach pollution; BOD and faecal coliforms; Terminos Lagoon***

I. INTRODUCTION

Wastewater is an important source of pollution in coastal zones. The discharge of urban wastewater with scarce or no treatment contain high levels of organic matter, nutrients and faecal coliforms that affect the quality of the water and the organisms that live there, affected also the tourism and aquaculture activity [1][2].

Most of the organic matter from wastewater discharge is decomposed by bacteria, protozoa and different superior organisms; such decomposition process is carried out through complex chemical and biological processes where the oxygen of the water is consumed to transform the organic matter; the process of mineralization of the organic load is called self-depuration. When the volume of organic wastes is increased, the capacity of depuration decreases until the oxygen is exhausted; forming anoxic zones that cause the death of organisms, the alteration of distribution patterns from species and the modification of the water use [3][4].

The Terminos Lagoon is one of the biggest lakes in México with 70 km long and 28 wide, an area equivalent to 1566.5 km^2 and a depth of 3.5 m. The lagoon is separated from the sea by Island of Carmen which is a barrier of 37.5 km. The terminos lagoon is connected to the sea by the channel of Puerto Real (Northeast) and channel of Carmen (Norwest) [5].

The municipality of Carmen City, Campeche is located in Island del Carmen, its primary activity is the hydrocarbons exploration and exploitation managed by PEMEX (Petroleum Mexicans) and other companies; as a consequence, according to the census of 2008, the population of Carmen City increased from 172 076 to 199 988 in the last eight years. This caused the demand of the basic services (water, electricity, etc.), generating a higher amount of solid wastes and urban effluents. The wastewater from Carmen City receive little or no treatment at all, it is discharged in three places: (1) Terminos Lagoon (located at the Southeast of the island), (2) Norte beach, an important recreational zone with 2 km of extension; (3) the channel Caleta with 7 km long and an average depth of 1.5 m. The channel is connected to the Terminos Lagoon and the México Gulf only in the Northwest area. Industrial complexes belonging to the oil activity, fishing cooperative and the city itself throw their wastewater causing a negative impact to the ecosystem.

Studies by Diaz-Ramírez [6] reported that the BOD in the coast of Carmen City during the north season showed maximum values of 1.60 mg l^{-1} and minimum values of de 0.3 mg l^{-1} at 250 m and 500 m of distance from the coast. The maximum concentration of faecal coliforms during the north season was 240 MPN 100 ml^{-1}; and minimal concentration of < 3 MPN 100 ml^{-1} at 250 m and 500 m from the coast. It is considered that the highest values of BOD are caused by illegal discharges into La Caleta and the municipal market [6]. In many of the reported cases, the discharge of wastewater has contributed to the increase of coliform bacteria in the surroundings of Carmen City [7]. Due to this situation, the Municipal authorities closed to the public some beaches during the summer (May-June).

There is little information about the seasonal variation of organic matter and faecal coliforms in important beaches of City of Carmen, as well as about the effect of urban effluents over the quality of the water during the typical seasons in the region: (1) dry season, from February to May; (2) rainy season, from June to September, and (3) north season, from

DOI 10.5963/IJEP0105005

October to February [8]. With this study, it is possible identify the seasons in which the coasts tend to be most vulnerable to the pollution by BOD and faecal coliforms, and to create programs to regulate the disposition of urban wastewater as well as the protection of the health of national and foreign tourists.

II. METHODOLOGY

A. Study Area

Island of Carmen, is a sandy barrier of medium extension, it is located at the South of the Gulf of Mexico between the meridians 91°15´and 92°00´ of West latitude and the parallels 91°15´and 92° 00´ of North longitude. Island of Carmen is 37.5 km long and 3 km wide, on its ends there are two entrances that separates the island from de continent, this entrances name's are mouth of Carmen (West), and mouth of Puerto Real (East) (Fig. 1). At the South of Island of Carmen is located Terminos Lagoon with an extension of 2500 km2 and 3.5 m of average depth [8].

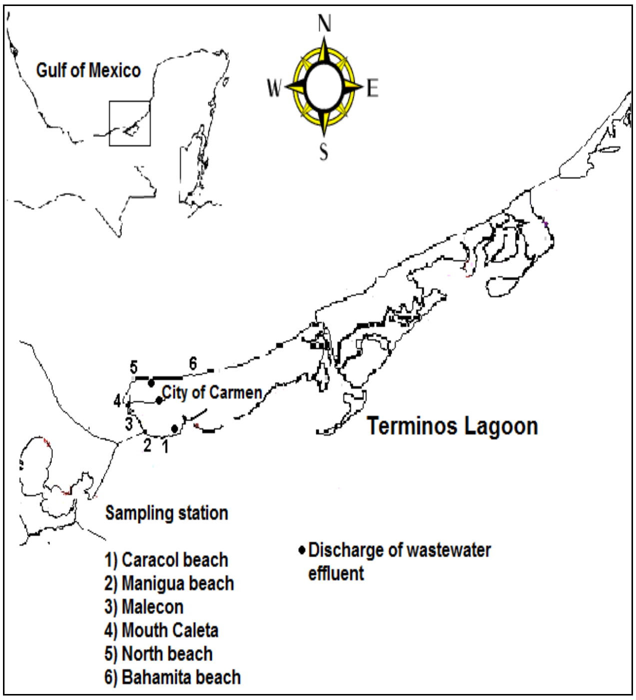

Fig. 1. Location of sampling stations and places of the urban effluent discharges.

Island of Carmen has several beaches that were taken into consideration for this study; some of these beaches border on Terminos Lagoon and other beaches are approach the Gulf of Mexico. The city discharges urban wastewater in three areas: Caracol beach (South), the channel Caleta (West), and North beach (North) (Fig. 1).

To evaluate the seasonal variation of salinity, dissolved oxygen (DO), biochemical oxygen demand (BDO), total nitrogen (TN), faecal coliforms (FC) and chlorophyll (Chl a), monthly samples were collected from six sampling stations around the West area of Island of Carmen (Fig. 1). For this study, were considered the beaches with the highest rates of visitors such as: Caracol beach, Manigua beach, Malecon, mouth Caleta, North beach and Bahamita beach.

B. Physical-Chemical Analysis and Nutrients

The samples were collected during January, February, March, May, June, July, October, November and December 2007; all the samples were collected from the water surface at 10 m from the coast. The temperature, salinity, pH and dissolved oxygen were measured in situ with a Sonda Hydrolab Data 4 placed on the surface of the water in every station; at the same time, other samples of water from the surface were collected with a Van-Dorn bottle.

The samples were preserved at 4 °C and the same day were sent to the Environmental Science laboratory at the Autonomous University of Carmen to determine the amount of total nitrogen (TN) through the NT Kjeldahl method, the BOD was determined through the five-days incubation method [9], and the chlorophyll a (Chl a) was determined according to the techniques described on the Standard method [9], the analysis were carried out in a 24 hours period.

C. Bacteriological Analysis

To determine the faecal coliforms (FC), the samples of water were transported in sterilized glass bottles and preserved at 4°C in order to be analyzed the same day. The quantification of FC was analyzed according to the Most Probable Number (MPN 100 ml-1) technique, with series of five tubes for analysis, by using both probabilistic and confirmative tests [9]. The results obtained from the analysis of FC were reported as average values per station during the same months of study for each corresponding season.

D. Statistical Analysis

The monthly content of BOD, TN, Chl a and FC were analyzed by one-way analysis of variance (ANOVA) at $P \le$ 0.05 using Statistica Software (StatSoft Inc., Tulsa, OK, USA). The Turkey test was used when there were significant differences in the results. In addition, analysis environmental variables of BOD and FC for the three seasons (north, dry and rainy) were realized used principal components analysis.

III. RESULTS AND CONCLUSIONS

A. Physicochemical Variables

The salinity during the months of study showed significant differences (ANOVA, $P < 0.05$) with maximum values of 36 spu during the dry season (March to May), and 16-20 spu during the north seasons and rainy (June to February). This pattern of seasonal variation suggests that the low levels of salinity registered during the seasons of north and rainy are caused by dilution processes due to pluvial runoff and a higher volume of water in the rivers that flow into the Terminos Lagoon, that affect beaches as Caracol, Manigua, mouth Caleta, Malecón, Norte beach and Bahamita beach; while that during the dry season the high levels of salinity are related to evaporation processes (Fig. 2).

Bahamita beach particularly showed a low monthly variation of salinity with minimum values of 32 spu and maximum values of 36 spu (Fig. 2); this sampling station presents more influence of sea water which causes a significant differences in the results of the salinity analysis (Tukey, $P < 0.05$).

DOI 10.5963/IJEP0105005

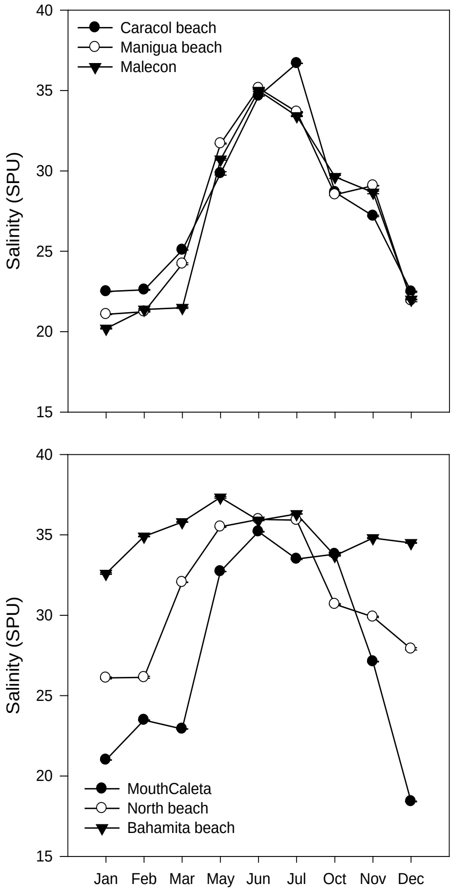

Fig. 2. Average monthly variation of salinity (ups) in the sampling stations.

The rainy season normally takes place from June to September; during this season the high levels of precipitation and pluvial runoff cause a major turbidity and the decrease of salinity in the water [10]. In addition to pluvial runoff during this season, a volume of fresh water is discharged into the coast of Island of Carmen as urban wastewater. All this water not only can cause the decrease of salinity but can cause a pollution problem due to the high load of nutrients, organic matter and other pollutants [11]. Probably one of the negative effects of pollution in the short term is the presence of faecal coliforms and the great amount of suspended solids that have a negative influence when they settle at the bottom of the bodies of water. This phenomenon can be observed in the mouth of channel Caleta and the areas surrounding of this station such as the seafront of the city, therefore, it can be the result of the transport of sediment.

The DO levels changed significantly during the months of study (ANOVA, P = 0.01). The DO levels show a decrease during the rainy season (July - September), and during the north season (august-February) showing a concentration of 6.7 – 7.0 mg l-1 , the highest concentration of oxygen was registered during the dry season (April - June) of 8.5-9.5 mg l-1 approximately (Fig. 3). Some studies confirmed that during the dry season the phytoplankton and the seagrass activity provide high levels of oxygen, as similar was reported by Morán-Silva et al. [4] (2005) and Ruiz-Marin et al. [12] for the Lagoonal systems of Alvarado and Lagoon Pom and Atasta-Mexico, respectively.

It is important to mention that the concentration of dissolved oxygen showed variations in the coast of Carmen City and could be related to factors such as photosynthetic activity, seasonability, the mixture of the water and the effect of tides [13]. In the present study, the low concentration of DO during the rainy and the north seasons is probably caused by an increased of the organic material and its decomposition by microorganisms that remove the oxygen from the water column [3][14].

The pH levels did not vary significant (ANOVA, P > 0.05) between the sampling stations and through the months, we found levels of 8.0 - 9.1. On the other hand, the temperature fluctuated between 27°C y 28°C and 32°C in July and August (data are not showed in this study).

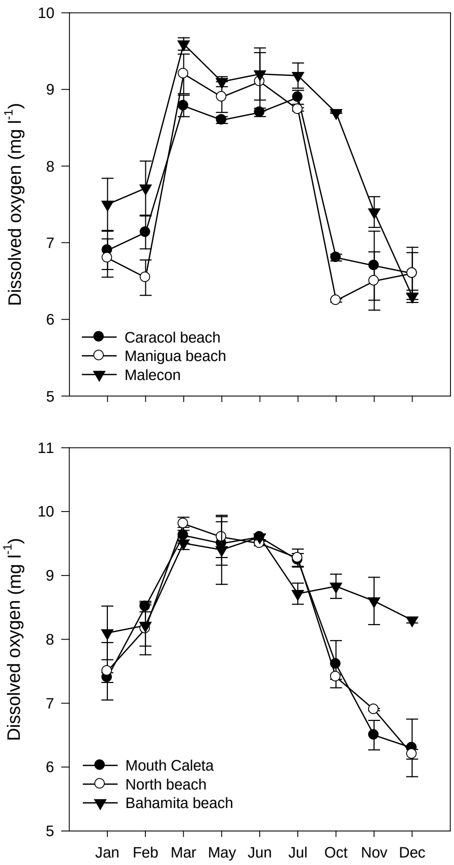

Fig. 3. Average monthly variation of dissolved oxygen (mg l-1) in the sampling stations.

B. *Chlorophyll a*

Chlorophyll a fluctuate during the year, it decreases during the rainy and north season with values of 2.0 -- 5.0 mg m-3 and increases gradually during the dry season from 10.0 to 40.0 mg m-3 (Fig. 4). The results show that the highest levels of chlorophyll correspond to higher levels of oxygen during the dry season and they decrease at the beginning of the rainy, this is an indication that a high photosynthetic activated provides considerable amount of oxygen at the beginning of the summer [15]. At the mouth of channel Caleta we found an important concentration of chlorophyll a in July (beginning of rainy season), this season is characterized by the presence of high levels of evaporation

DOI 10.5963/IJEP0105005

mainly during the periods when it is not raining and the temperature increases, based on this the presence of high contents of chlorophyll a equivalent to 100 mg m3 as have been reported [16]. However, the constant contribution of organic matter through pluvial and fluvial runoff tends to increase the turbidity, which may limit the photosynthetic activity; this phenomenon was present during the months that follow the rainy and north seasons (Fig. 4).

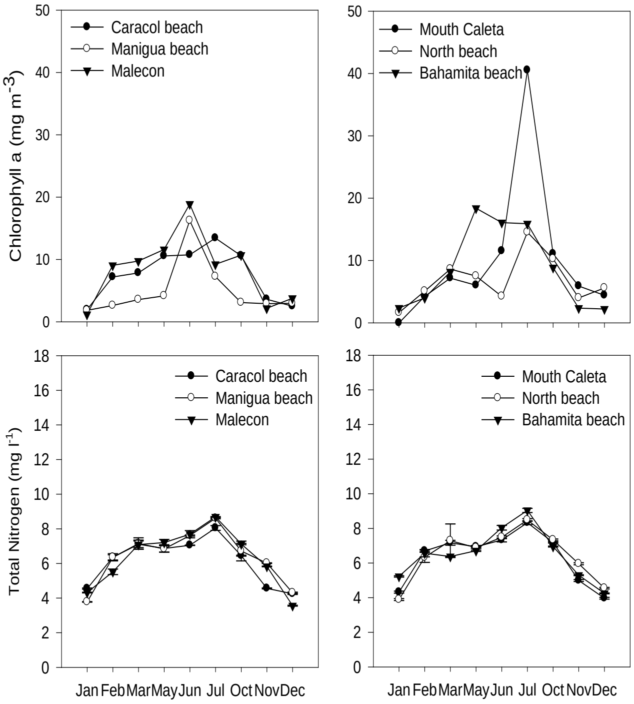

Fig. 4. Average monthly content of chlorophyll a and total nitrogen in the sampling station.

The increased of pigments is the result of a quick biological assimilation of nutrients by the phytoplankton [17]. It is a fact that the concentration of chlorophyll and nitrogen increased gradually during the spring and showing a maximum concentration at the beginning of the rainy (June); suggesting that during this period the ecosystem tends to become more productive.

A higher concentration of chlorophyll a regarding a high content of nitrogen can be interpreted as the result of the degradation of organic matter incorporated through pluvial runoffs. Similar results, equivalent to 7.1 mg m-3 of chlorophyll in April and 8.8 mg m-3 in June, were reported by De la Lanza and Lozano [5] at the station located on the West entrance of Terminos Lagoon; according to this we concluded that the spatial variation of chlorophyll at Terminos Lagoon is linked to the fluvial contribution of nutrients during the month of June. Similarly, Li et al. [18] reported results that confirm an association of phytoplankton with high concentrations of nutrients. In this study, the maximum levels of chlorophyll obtained during the first months of floods corresponded to a high concentration of nitrogen, however, we have also consider fluvial contribution of nutrients, pluvial runoffs and the dynamic of water interchange between the lagoon and the coast that contribute to the presence of nutrients.

The high volume of wastewater received by the Caleta channel (53 359 m3 per month), represents an elevated organic charge that after being decomposed by bacteria contributes with considerable amounts of nitrogen to the water column; that can be used by phytoplankton. This suggests that the channel Caleta system exports nitrogen to the West entrance of Terminos Lagoon which favors the production of phytoplankton (Fig. 4).

C. Total Ammonia Nitrogen (TAN)

Ammonium is the main subproduct of the proteins catabolism, it is considered an indicator of pollution when its concentration in bodies of water is higher to >0.1 mg l-1. In certain combinations of pH and temperature it can be toxic for aquatic species. In this study, the nitrogen concentration registered monthly variations according in different sampling stations (ANOVA, $P = 0.001$), the coast of Carmen City showed a high content of nitrogen from June to September (rainy season) equivalent to 9 mg l-1, and decreased during December (north season) with contents equivalent to 4 mg l-1. During the dry season, the content of nitrogen increased gradually and reaches a higher concentration during the first months of the rainy season (Fig. 4).

In the proportion of ammonium and ammonia according to the temperature and water pH, the minimum concentration equivalent to NH3-N (0.11 mg l-1) was obtained during the dry season and the maximum concentration equivalent to 0.22 mg l-1 was obtained during the rainy season. Therefore, the levels of ammonia nitrogen presented in this study do not represent any risk of toxicity for the fish of the region.

Regarding the places identified with wastewater discharges (North beach, Manigua and Caleta), we did not observe a nitrogen increase, however the increase of nitrogen during the rainy season cannot be only attributed to wastewater discharges due to the presence of other processes that determine the content of nitrogen in a lagoonal system located on the coast such as: the dynamic of nutrients dominated by feedback mechanisms between the lagoon and the sea [19] [20].

Studies carried out by De la Lanza and Lozano [5] showed that the concentrations of nitrogen (NH4) at the West entrance of Terminos Lagoon were equivalent to 0.8, 1.0 y 0.2 µg at l-1 during the months of April (dry season), June (rainy season) and November (north season), respectively. Compared with our study, it is probable that during the rainy season, the presence of more nitrogen at the entrance between the lagoon and the ocean suggests the nutrient exportation from the lagoon.

Studies suggests that for a lagoon or bay the flux of nutrients at the long term, always occur from the lagoon to the outside [21], this may be related to the high concentration of nitrogen at the West entrance of Terminos Lagoon, Due to the fact that the conservative mixture of nutrients vary with the flushing time, which controls the biological processes, allow to the microorganism modify the nutrients that they receive.

According to this, the decrease of nitrogen and chlorophyll during the north and rainy seasons, suggests a higher level of movement of nutrients from the lagoon to the

DOI 10.5963/IJEP0105005

ocean despite the fact that during this period, the flowering of plankton is limited because to the turbidity generated by the sediment and the organic material of pluvial runoffs.

D. Biochemical Oxygen Demand (BOD) and Faecal Coliforms (FC)

The values of BOD showed significances differences (ANOVA, P < 0.05) between sampling stations, though the analysis for seasons they did not appreciate significant differences (ANOVA, P > 0.05). With the Tukey test was possible observed that Manigua beach and mouth Caleta were statistically different to the other sampling stations. The results suggest that the maximum values of BOD (2.8 -- 4.6 mg l-1) are present during the north and rainy seasons, while than the minimum values are present during the dry season (0.1 -- 1.7 mg l-1) (Fig. 5).

Although the Mexican law recommends a maximum permissible of BOD of 75 mg l-1 monthly average and 125 mg l-1 daily average for recreational water are higher compared to the American law (California and Oregon) with a range of 30--45 mg l-1 [3] [22]; the BOD values found in beaches of City of Carmen are within of the permissible. The beach Manigua was identified as one of the beaches with great amounts of BOD (3 -- 4.8 mg l-1) compared to the other sampling stations during the north and rainy seasons, followed by North beach (1.5 -- 2.5 mg l-1). These values were higher to the reported by Diaz-Ramirez [6] of 0.4-1.6 mg BOD l-1 in beaches of Carmen City during the north season.

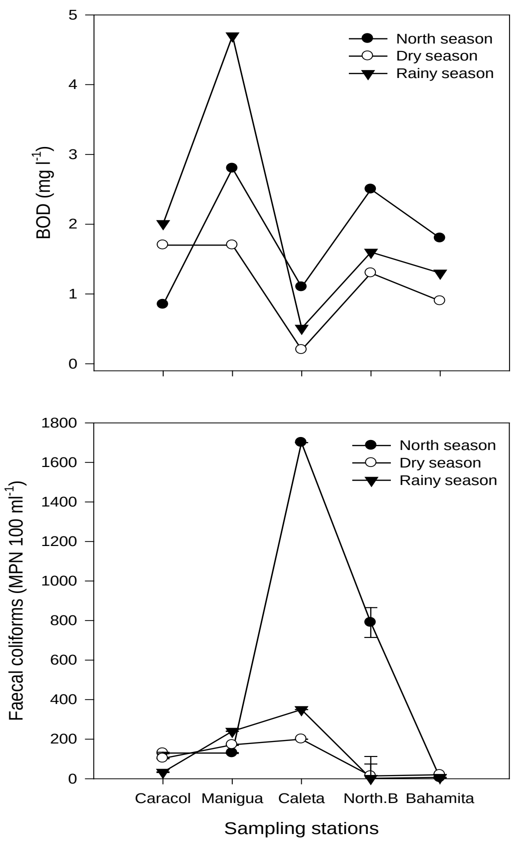

Fig. 5. Average content of BOD and faecal coliforms at the beaches of Ciudad of Carmen by seasonal

On the other hand, at the mouth of the channel Caleta in direction to the West, entrance of Terminos Lagoon low values of BOD were detected (Fig. 5); though does not possess sufficient information to determine the BOD degradation rate inside the channel La Caleta, the low values of BOD can be explained by the biological degradation that occurs along the 7 km where the wastewater circulates just before reaching the West entrance of Terminos Lagoon. The average contribution of BOD (75 mg l-1) found in the urban effluents, suggest a need to improve the efficiency of the water treatment plants, because even though there is a natural reduction of BOD in the ecosystem, the presence of bacteria as well as the accumulation of sediment could represent a higher risk at the short term in the coast.

The seasonal concentration of faecal coliforms showed significant differences (ANOVA, P = 0.001). The highest concentrations were recorded during the north and rainy seasons, mainly at mouth Caleta and North beach (Fig. 5). The results suggest that the presence of coliforms could not be seasonal and its permanence at the water surface is determined by the weather. Lizarraga –Partida et al. [23] reported that the highest concentration of heterotrophous microorganisms at Terminos lagoon occurs during September and October suggesting that the strong winds and the sediment resuspension increments significantly the concentration of faecal coliforms (10000 MPN 100 ml-1), regarding what was found during the dry season (5200 MPN 100 ml-1). This could explain the high content of bacteria found in sampling stations such as mouth of the channel Caleta and North beach during the north season (790-- 1700 MPN 100 ml-1), the other stations show a lower content during the dry season from 100 to 250 MPN 100 ml-1 (Fig. 5).

Other factors can affect the permanence of bacteria such as solar radiation, turbidity, temperature and salinity. The rain can cause the runoff of pollutants causing an increased of the turbidity and a decrease of salinity [24]; therefore, the low levels of salinity during the north and rainy create less rigorous conditions for the survival of this kind of bacteria. The low concentration of bacteria in sea water has been attributed to dilution processes in the ocean, osmotic shock and the antibacterial effect factors that occur simultaneously and include changes of temperature, deposition, depredation and the presence of specific antibiotics produced by algae [25].

It is evident that the increase of bacteria on the water surface is caused to the anthropogenic activity with its respective wastewater effluents. According to the sanitary quality of the water for recreational purposes based on faecal coliforms, it is recommended that the content of faecal coliforms should be 200 in 100 ml-1 and less than 1000 total coliforms in 100 ml-1 in sea water [26]; we can conclude that some beaches in Carmen City such as Manigua beach, Caracol beach, North beach and mouth of the channel Caleta could represent a risk for the bathers only in north season because these beaches exceed the maximum permissible of faecal coliforms.

All this can be confirmed with the dendogram of the analysis of the environmental variables of BOD and FC, showing that in North beach, Manigua beach, Caracol beach and mouth Caleta present similar characteristics (Fig. 6),

DOI 10.5963/IJEP0105005

suggesting that the beach near to the wastewater discharge tend to change the environmental original conditions.

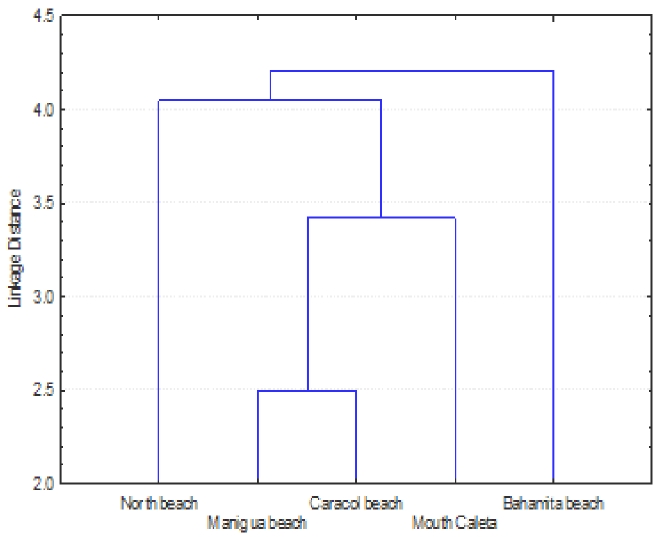

Fig. 6. Dendogram of environmental variables of BOD and FC during the three climatic seasons.

This association it is due to the fact that these variables have a similar behavior and a common origin because the BOD estimates the pollutants of the organic effluents acting as energetic substrate for the growth of bacteria [2]. Future works will have to be realized in the analysis of nutrients flow and metabolism principally in zones as the Caleta channel, which for his characteristics of receptor of wastewater could be an exporter or nutrients sink.

IV. CONCLUSIONS

According to the present study, the decrease of salinity during the winds north and rainy season contributes to the permanence and distribution of bacteria due to less rigorous conditions that increase the survival of these microorganisms. During these two seasons, the beaches with higher levels of faecal coliforms and BOD were: North Beach, Manigua beach, Caracol beach and channel Caleta. The Caleta is the station that needs to be more observed because is the one that receives the higher amount urban effluents. The contribution of BOD from urban effluents towards the channel Caleta present a significant reduction suggesting that the ecosystem presents heterotrophic characteristics and exports a considerable concentration of nitrogen which favors the flowering of phytoplankton at the West entrance of Términos Lagoon. The results suggest that the wastewater discharges contribute to the pollution of the water at the beaches; however the environmental conditions allow the dilution and dispersion of organic material and FC; therefore the transport of these pollutants put at risk the adjacent beaches that are still considered as suitable for bathers.

Although in this study we did not include economical or political recommendations, the generated information can be used to detect the periods in which there can be an increase on the levels of pollution at the beaches of Carmen City and as a consequence, take the necessary actions to control the discharges of urban effluents.

ACKNOWLEDGMENT

This project was carried out thanks to the internal support of Autonomous university of Carmen. We thank to the quality control laboratory of Faculty of Chemistry, especially to Lorena Guevara Cruz and Martina Cruz Lopez for their support during the execution of the chemical and microbiological analysis.

REFERENCES

[1] M.V. Orozco-Borbón, J.A. Segovia-Zavala, F. Delgadillo- Hinojosa, and A. Muñoz-Barbosa, “Bacteriological study of seawater for the culture of bivalve molluscs in Baja California,” Ciencias Marinas, 20(2), 183-198. 1994.

[2] J.A. Segovia-Zavala, F. Delgadillo- Hinojosa, M.V. Orozco-Borbón, A. Muñoz-Barbosa, and R.A. Canino-Herrera, “Distribution of BOD and bacteria along the coast of the US-Mexico border”, Ciencias Marinas, 21(4), 415-426, 1995.

[3] M.C. Ortiz-Hernández, and R. Sáenz-Morales, “Effects of organic material and distribution of fecal coliforms in Chetumal bay, Quintana Roo, Mexico”. Environmental Monitoring and Assessment, 55, 423-434. 1999.

[4] Morán-Silva, L.A. Martínez-Franco, R. Chávez-López, J. Franco-López, C.M. Bedia-Sánchez, F. Contreras-Espinosa, F. Gutiérrez-Mendieta, N.J. Brown-Peterson, and M.S. Peterson, “Seasonal and spatial patterns in salinity, nutrients, and chlorophyll a in the Alvarado lagoonal system, Veracruz, Mexico”. Golf and Caribbean Research, 17, 133-143, 2005.

[5] E.G. De la Lanza and M.H. Lozano, “Comparación fisicoquímica de las lagunas de Alvarado y Términos”. Hidrobiológica, 9(1), 15-30, 1999.

[6] J.A. Díaz-Ramírez, “Distribución espacial de materia orgánica biodegradable y bacterias coliformes totales en agua superficial de la costa oeste de Isla del Carmen, Campeche, México: Comportamiento en temporada de nortes”. Tesis de Licenciatura. Universidad Autónoma del Carmen, Facultad de Química, 2006.

[7] J. Romero-Jarero and M.J. Ferrara-Guerrero, L. Lizarraga-Partida, and H. Rodríguez-Santiago, “Variación estacional de las poblaciones de enterobacterias en la laguna de Términos, Campeche, México”, Anales del Instituto de Ciencias del Mar y Limnología, 13(3), 73-86, 1986.

[8] Yañez-Arancibia and J.W Day, “Ecological characterization of Terminos Lagoon, a tropical lagoon-estuarine system in the southern Gulf of Mexico”. In: A. Yañez-Arancibia, and J.W. Day. (Eds). Ecología de los ecosistemas costeros en el sur del Golfo de México: La región de la Laguna de Términos. Pp. 431-440. Instituto de Ciencias del Mar y Limnología., Universidad Autónoma de México, Coastal Ecology Institute, Louisiana State University, Editorial Universitaria, México, 1988.

[9] AWWA-APHA-WPCF, “Standard Methods for the Examination of Water and Wastewater. 19th Edn”, 1105, 1995.

[10] E.F. Contreras, “Lagunas Costeras Mexicanas”; Centro de Ecodesarrollo, Secretaria de Pesca, México D.F, 253p, 1985.

[11] G. Hotos and D.E. Avramidou, “A one year water monitoring study of Klisova Lagoon (Mesolonghi, W. Greece)”. Geojournal, 41(1), 15-23, 1997.

[12] Ruiz-Marín, S. Campos-García, J. Zavala-Loría and Y. Canedo-López, “Hydrological aspects of the lagoons of Atasta and Pom, México”. Tropical and Subtropical Agroecosystems, 10, 63-74, 2009.

[13] E.G. De la Lanza and R.M. Cantú, “Cuantificación de clorofilas y aplicación del índice de diversidad de pigmentos (D430/D665) para estimar el estado biótico de la laguna de Pueblo Viejo, Ver”. Universidad y Ciencia, 3(5), 31- 43, 1986.

[14] M.J. Kennish, “Ecology of Estuaries. Physical and Chemical Aspects”, CRC Press, Boca Raton, F.L, USA. 254p, 1986.

[15] M. Falcao, and C. Vale, “Nutrient dynamics in a coastal lagoon (Ria Formosa, Portugal): The importance of lagoon-sea water exchanges on the biological productivity”, Ciencias Marinas, 29 (3), 425-433, 2003.

[16] E.F. Contreras, A. García and O. Castañeda, “La clorofila como base para un índice trófico en lagunas costeras mexicanas”. Anales del Instituto de Ciencias del Mar y Limnología. Universidad Autónoma de México, 2(21), 1-15, 1994.

DOI 10.5963/IJEP0105005

[17] T.E. Jordan, D.L. Correll, J. Miklas and D.E. Weller, "Nutrients and chlorophyll at the interface of a watershed and an estuary", Limmol. Oceanogr, 36 (2), 251-267, 1991.

[18] M. Li, A. Gargett and K, Denman, "What determines seasonal and interannual variability of phytoplankton and zooplankton in strongly estuarine systems? Application to the semi-enclosed estuary of Strait of Georgia and Juan de Fuca Strait". Estuarine, Coastal and Shelf Science, 50, 467-488, 2000.

[19] S.W. Nixon, "Between coastal marshes and coastal water a review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry". In: Hamilton, P and K.B. MacDonald, (Eds), Estuarine and Wetland Processes. Plenum Publ. Corp., New York, 437-525, 1980.

[20] R. Dame, T. Chrzanowski, K. Bildstein, B. Kjerive, H. McKellar, D. Nelson, J. Spurrier, S. Stancyk, H. Steveson, J, Vernberg and R. Zingmark, "The outwelling hypothesis and north inlet, South Carolina". Mar. Ecol. Prog. Ser, 33, 217-229, 1986.

[21] S.W. Nixon, S.L. Granger, D.I. Taylor, P.W. Johnson and B.A. Buckley, "Subtidal volume fluxes, nutrient inputs and the Brown tide-an alternate hypothesis". Estuar. Coast. Shelf Sci, 39. 303-312, 1994.

[22] S. Sañudo and C. Suarez, "Carga orgánica de las aguas negras municipales de la ciudad de Tijuana, Baja California". Ciencias Marinas, 8(2), 155-166, 1982.

[23] M.I. Lizarraga-Partida, C.R. Carballo, F.B. Izquierdo-Vicuña and C.L. Wong, "Bacteriología de la Laguna de Términos, Campeche. Universidad Autónoma de México". Instituto de Ciencias del Mar y Limnología, 12-21, 1986.

[24] Kocasoy, "A method for prediction of extent of microbial pollution of seawater and carrying capacity". Environmental Management, 13, 469-475, 1989.

[25] G. Barrera-Escorcia and P.E. Namihira-Santillan, "Microbiological contamination in the Akumal coastal zone, Quintana Roo, México". Hidrobiológica, 14(1), 27-35, 2004.

[26] Secretaría de Desarrollo Urbano y Ecología (SEDUE), "Criterios ecológicos de calidad del agua CE-CCA-001/89". Gaceta Ecológica, 2(6), 26-36. 1989

DOI 10.5963/IJEP0105005