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Mapping an urban ecosystem service: quantifying carbon storage in soils at an island-city on a wide scale

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Abstract

This study examined the temporal and spatial patterns of carbon storage in an island-city by evaluation of soils across the entire urban and mangrove forests areas during dry, rainy and norths seasons of 2013–2014. The ecosystem service (mitigation of climatic change) was quantified and mapped on a wide scale in Carmen Island, Campeche, Mexico by using geo-statistics methods. Carbon sequestration rate and several important physicochemical parameters on a wide scale in the city were determined at 30 cm depth, which is the most relevant depth affected by land management practices. An evident seasonal pattern was observed for organic carbon, exhibiting its highest levels at the beginning of the dry season. In addition, a geographical distribution analysis identified mangrove and flooded sites as those zones in which carbon storage was higher, concluding that hydrogeology and dominant vegetation were the factors with a greater influence on carbon storage rate. Carbon storage rate obtained in this work (1.07 Kg C m^{-2} yr^{-1}) was comparable with those obtained for isolated and forested wetlands in others regions of the world. This study is the first in the region that provides a high-resolution map of soil carbon stocks in a mixed and complex frame where an important urban zone and mangrove forest co-exist.
Keywords: mapping, Carmen Island, urban ecosystem, carbon storage, Mexico.

1 Introduction

There is an increasing demand of geo-information of soils with a quantitative focus; therefore, the development of modern tools constitutes a potential frame to give information about soils in a quick, objective and precise way. Spatial distribution studies allow to know the main spatial correlations between variables of natural resources and soils. In tropical and sub-tropical forests, it has been found that geo-statistic is the better technique to determine the parameters variability to assess nutrients cycles. Edaphologic information can be represented spatially by maps, showing those areas where agriculture can be developed as a function of some specific properties of soils, to propose different choices for management or treatment.

Thematic maps of soils show only one edaphologic characteristic or a mix of attributes inter-related. Usually, data reported correspond to surface level of the soil, and they are processed by geo-statistical techniques. These reported data are related to some specific problem of use or management of soil, usually with an environmental character. The variability in soil properties is mainly spatial, and it should be known in order to have an efficient use of this resource. Variability in soil characteristics is an inherent condition, since through its formation, several different processes are involved. These processes are controlled in turn by factors as climate, parental material, organisms, relief and time. When a value of a property in a given site depends on distance and direction in which it is located in relation to other neighbor site, this is a variable with a spatial dependence. These types of variables are named regionalized variables. These regionalized variables describe a natural phenomenon that is geographically distributed with some grade of correlation. To study these variables, a group of statistical tools known as geo-statistic is available.

There is an increasing need of producing estimates and detailed distribution maps of carbon stocks in soils across cities to limit deforestation and to facilitate the development of resource management policies [1]. One ecosystem service used to develop policies focused to mitigate climate change is carbon storage within biomass and soil. The forests do not only store huge amounts of carbon, but they actively capture additional CO_2 from the atmosphere and sequester it in their soils. Forest with the highest potential to store carbon are found in the equatorial tropics, while those found in temperate regions have lower quantities of stored carbon [2]. Wetlands play a key role as suppliers of environmental services, being the most important the carbon sequestration. The World Wildlife Foundation [3] reports a mangrove cover area of 655,667 ha for Mexico; Campeche State contributes with 30% of this total area. Unfortunately, mangrove forests have been disappearing faster than other forest types, and a third of the world´s mangroves have been lost over the last 50 years through conversion to urban, aquaculture or agriculture use.

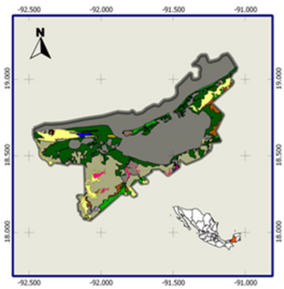
In addition, conserving carbon storage areas grants benefits to urban zones residents, such as climate regulation, reducing air pollution, decreasing surface water runoff and creating tourism and recreational opportunities. Therefore, estimations and detailed distribution maps of carbon stocks across cities are required to develop successful management policies focused to protect these carbon stocks in urban areas. Therefore, spatial analysis of ecosystem services is required to regulate land use and to make decisions focused on conservation.

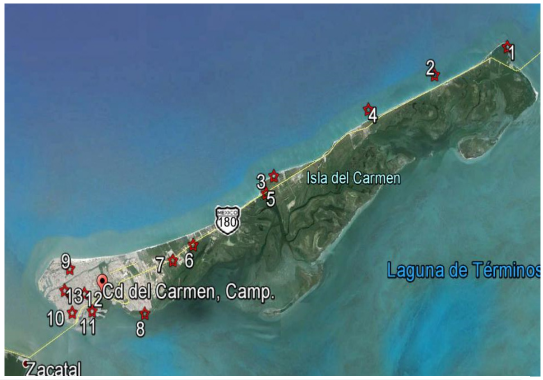
In this paper, spatial and temporal patterns of stored carbon in soils were examined to identify carbon storage hotspots in a mixed and complex frame, where mangrove forests and an urban zone with an economy based in gas and oil industry co-exist. It will provide a baseline that supports management strategies that could conserve and optimize environmental services from mangrove forests.

2 Study site

Carmen Island is located at Campeche State in Mexico and constitutes the greatest populated Island in the country. Carmen Island is part of the morphological lagoon-estuarine system of Terminos Lagoon. Ecosystem associated to this lagoon is a natural protected area and a Ramsar site. Carmen Island has an area of 153 km^2, it is about 36.5 km long, and 7.5 km wide. Moreover, one of the most extensive mangrove forests in the country surrounds the lagoon almost completely. Therefore, both, lagoon and the mangrove forest are home of a huge biodiversity. Carmen City is the principal human settlement on this island, being the head of the municipality of Carmen. This island-city has an urban area of 27.3 km^2 and a population just over 170,000 inhabitants. This region constitutes a hotspot in Mexico due to the following reasons: 1) the proximity to Natural protected area named “Terminos Lagoon” and 2) the proximity to the greatest area of oil and gas offshore production in the country.

Climate in this zone is characterized by three well defined climatic periods: rainy season (from June to September), norths season (from October to February), and dry season (from March to May). Winds flow from E–SE, the most of the year, except for winter storm season. Annual mean temperature is 27.5°C, and annual average rainfall is 1410.6 mm. The dominant vegetation in Carmen Island is induced grass in both, urban zone and in the east edge; and tular-popal vegetation in the middle part of the island. Mangrove forests are located in the surroundings of the island and the most of them remain undisturbed. The ancient urban zone is located at the west edge of the island, and the new population settlements have grown toward the middle part of the island, some of these housing units may have up to 1000 houses each. In addition, some conserved sites with sub-evergreen low forests are distributed along its territory. Tides are important in Terminos Lagoon circulation and are often involved in the occurrence of strong currents at the inlets, contributing to maintain some sites in the island completely flooded the most of the time [4]. The shelf circulation over the eastern Campeche Bank in the Gulf of Mexico is characterized by a southwesterly current that flows almost year-round parallel to the coast. During the winter season, the lagoon responds to the external circulation with increased water level and modification of the mean circulation. On the other hand, at the end of the rainy season, when river discharge increases, the lagoon circulation changes because of the freshwater input. Figure 1 shows the location of Carmen Island and Carmen City, and details about sampling points.





ID	LOCATION	ALTITUDE	GEOGRAPHYCAL COORDINATES		
			N	W	Land-use type
1	Puerto Real	3	18°46'40.23"	91°31'51.16"	Urban
2	Highway Carmen-Puerto Real. Km 30.8	-5	18°45'46.50"	91°34'50.20"	Mangrove
3	Water Pump System SMAPAC (Rebombeo). Km 1	3	18°42'32.90"	91°41'25.11"	Urban
4	Ensenada Restaurant	-1	18°44'40.32"	91°37'32.90"	Urban
5	Highway to Bahamitas. Km 18.8	4	18°41'59.47"	91°41'43.93"	Mangrove
6	Ecological Park El Fenix	5	18°40'20.83"	91°44'43.06"	Farming
7	Limnology Institute UNAM	3	18°39'50.92"	91°45'32.99"	Mangrove
8	Botanical Garden UNACAR	3	18°38'80.51"	91°48'42.07"	Mangrove
9	Playa Norte (Ballena Avenue)	3	18°39'35.35"	91°49'46.33"	Farming
10	La Puntilla (17 Street between 36 and 36B)	5	18°38'10.96"	91°49'40.18"	Industrial
11	Emiliano Zapata-Francisco Villa	4	18°38'13.82"	91°48'51.22"	Industrial
12	Principal Campus of UNACAR	4	18°38'47.53"	91°49'10.14"	Industrial
13	Santa Margarita (49 Street)	4	18°38'53.53"	91°49'58.75"	Urban

Figure 1: Locations of sampling sites.

3 Methods

3.1 Sampling

To assess temporal and spatial patterns of carbon storage, we survey soil across the entire area in the island, estimating carbon stocks at 30 cm depth, which is the most relevant depth affected by land management practices. Sampling campaigns were performed from September 24, 2013 to September 24, 2014; during the rainy, norths and dry seasons at 13 sampling sites distributed along Carmen Island. Based on visual inspections, transects were established in a representative area for each sampling point. Sampling sites were selected to assure representative regional samples, taking in account the type of vegetation, easy access and hydrology. In each transect, three sampling points were located, and samples were taken at 0.30 m depth, including duplicate, by using a 193.3 cm^3 soil sampler. Because of the soil samples showed high moisture content, the core sampler was adapted with a one way check valve to create a vacuum inside the corer line and keep the sample inside the tube [5]. A total of 156 samples were collected with their replicas in 13 sampling points during six sampling campaigns along one year. The description of these sites is shown in Figure 1.

3.2 Chemical analysis

When the soil cores were removed from the tight-fitting end caps, free water was drained away and all biomass and solid material (shells, roots, leaves, insects, and so on) were removed, then, samples were grinded, dried at ambient temperature, and sieved to pass through a 2 mm mesh. Soil moisture was measured by a gravimetric method [6]. Electric conductivity was determined according to Mylavarapus and Kennelly [7], by means of a conductivity meter (Conductronic CL 35) in an extract 1:2 soil/water solution. Texture determination was carried out by the Bouyoucos method employing 5% sodic hexametafosfate solution as dispersant [8]. To find out apparent density, the test tube technique was used [9]. Soil pH was measured by a pH meter Thermo Orion Model 290 A, into a 1:2 soil/water solution [10]. Organic matter was determined by warming soil samples at 550°C during 4 hrs [11]. Organic carbon was quantified by the ignition method [12]. Additionally, in order to estimate the carbon storage rate, the following equation was used [13]:

$$C=CO\% \times Da \times Pr;$$

where, C= carbon storage rate, CO%=organic carbon content, Da=apparent density, and Pr=soil depth.

3.3 Geo-statistical analysis

Geo-statistic is a tool to estimate the variability in some regionalized variables, producing an automatic cartography of all studied parameters, grounded in result analysis of sampling and distribution of the studied natural resource. Geo-statistic tools model spatial dependence of variograms, applying kriging technique, and extrapolating to other positions not sampled [14]. Kriging is a regression model used with spaced data in irregular form in two or three dimensions. Its application follows these steps: 1) Statistical analysis to explore data, 2) Estimation and modeling of the qualitative function of spatial correlation, 3) Use of spatial correlation to determine series of linear equations and to identify their relative contribution, and 4) generation of estimated values and their standard deviations. Results obtained are used as an input for a contour program to produce iso-lines for a given variable [15].

3.4 Statistical analysis

Descriptive, comparative and relational statistical analysis was performed for studied parameters, sampling sites, and sampling seasons. The following test was applied to data set: 1) Barlett's test to exam the hypothesis of equal variances of physicochemical parameters during the three different sampling seasons: rainy, norths and dry; 2) Kruskal–Wallis test to analysis the hypothesis of equal means of soil parameters in categories for land-use type; and 3) Principal Component Analysis (PCA) to determine the relationships among the measured variables. The software applied to make the statistical analysis was XLSTAT (Statistical Software for Microsoft Excell) [16].

4 Results and discussion

4.1 Soil attributes

The main soil textural class in Carmen Island was sandy; it is agree with its sedimentary origin and carbonated nature. Soil moisture increased progressively in the plenitude of the rainy and norths seasons, reaching the highest levels of humidity at the end of the wet season and at the beginning of the dry season as a result of a process of water accumulation. During rainy season, the humidity percentage was higher at mangrove forest and at the east edge of the Island, where soils remain flooded most of the year. As a result of abundant rains, severe storms and cold fronts during rainy and norths seasons, there was a process favoring anoxic conditions and high humidity levels in soils at the beginning of the dry season [17]. Moisture % had the highest levels and a spatial variation at sampling points labeled 2 and 5, corresponding to flooded zones and mangrove forest, respectively, where tide influence was evident.

Sampling points were grouped according their land use, identifying three prevailing land uses: industrial, mangrove forest and urban. Soil moisture was higher in the mangrove forest. pH ranged from 6.32 to 8.50 with an average value of 7.91, demonstrating that neutral to moderately alkaline soils are dominant in the island, in part due to its sedimentary origin. Soil pH had not a significant variation between seasons. pH values were slightly higher at the beginning of the rainy season, increasing progressively as rainy and norths seasons reach the plenitude as a result of a dilution effect. pH did not exhibit a significant variation between sampling sites, showing uniform values in both scales, spatial and temporal. Regarding to land use, it was observed that soil pH did not exhibit variations as a result of the soil buffer capacity, attributed mainly to its carbonated nature. The pH strongly influences on the net amount of dissolved organic matter and its decomposition process, consequently, dissolved organic matter becomes more soluble at higher pH values [5].

Electric conductivity (EC) ranged from 101.98 to 5540.77 μSm^{-1} with a mean value of 430.77 μSm^{-1}. These values indicate the existence of high salinity in the island. High salinity is probably influenced by marine aerosols since this city is located at sea level. The low permeability of soils in Carmen Island promotes the water accumulation, consequently increasing sodium concentrations. This parameter showed an evident seasonal pattern, EC was much higher during dry season than during rainy and norths seasons. Higher EC values during the dry season correspond to higher salinities due to higher evaporating rates that conduct to accumulation of salts. Regarding to spatial distribution, the highest values of EC were in the middle part and at the east edge of the island (sampling points labeled as 2, 3, 5 and 9), where mangrove forests and flooded zones are located. These zones in the island are under the influence of tides the most of the year, so favoring flooding and anoxic conditions in these zones. Sampling point 3 (water pump system) within the mangrove zone showed the highest values of EC (437 μS/m) whereas the lowest value (169.3 μS/m) was found in sampling point 13 (Santa Margarita, an urban site). Lower values were observed at the west edge of the island, which corresponds to a land use exclusively urban. As sites were more urban, EC drastically decreased, suggesting that the disturbed grade of these sites affects the salinity and nutrients content of the soils.

Apparent density (g cm^{-3}) ranged between 1.20 and 1.76, with a mean value of 1.46. Although values were slightly higher during the dry season, this difference was not significant. The highest value for spatial variability was attained in the sampling sites 1, 2, 4 and 7, which correspond to flooded zones under tide influence. Apparent density did not exhibit any significant variability with respect to land use.

Organic carbon (%) exhibited a range from 1.20 to 1.76 and an average value of 1.46. This attribute showed a seasonal variability, with higher values during the dry season than the wet season. It is important to point out an evident spatial pattern, with the highest values in the middle part and at the east edge of the island (sampling points 2, 3 and 6), where flooded zones and mangrove forest are predominant. Concerning the land use, the highest values were in mangrove and industrial zones, which are located on flooded soils the most of the time. As a result of the intense rains, during the rainy and norths seasons, there was an evident seasonal pattern attributed to a dilution effect. As rains progressed, organic carbon levels were decreasing; during rainy and norths seasons, long tide periods flooded the sampled soils, maintaining anoxic conditions under 10 cm depth, however, since decomposition rates are slow, the highest organic carbon levels appears at the beginning of the dry season. During the dry season, organic carbon concentrates as a result of an increase in evaporation process, whereas during the rainy and norths seasons, pore water is diluted with rain and run-off waters resulting in lower dissolved organic carbon concentration, salinities and densities [18].

Organic matter maintained a range between 0.44 and 4.31%, with a mean value of 1.58%, exhibiting a marked seasonal pattern. The higher values observed during rainy season suggest an evident dilution effect during rainy and norths seasons. The hydrologic characteristics of Carmen Island could explain this decrease since it receives high inputs of fresh water, improving the flooding conditions, diminishing its infiltration capacity and saturating the vadose zone [19]. At the dry season, evapo-transpiration rate increases concentrating salts and organic matter, being vertically transported with percolation water. This process of accumulation of organic matter is favored in sites with abundant rains under the influence of tides and an inefficient drainage. On the other hand, a spatial variability was observed for organic matter, showing a similar distribution to organic carbon. The highest levels were in sampling points 2, 3 and 6, which correspond to flooded zones (points 2 and 3) and mangrove forest (point 6); categorized with a land use of mangrove forest and industrial.

4.2 Statistical analysis

The Barlett's test statistics for the normally distributed physicochemical parameters showed that the hypothesis on equal variances had to be rejected at 95% level for moisture percentage, pH, Electric conductivity (EC), and Organic matter (OM). There were not significant differences among the sampling seasons for apparent density (AD), organic carbon (OC) and stored carbon (SC). Kruskal–Wallis test statistics indicated that the hypothesis on physicochemical soil parameters are independent of land-use type categories had to be rejected at significance level > 95% for SC (during rainy, norths and dry seasons), OM (during norths and dry seasons), moisture (during rainy, norths and dry periods), pH (during the three sampling seasons), EC (during all seasons), except for OM (during rainy season), OC (for the three sampling seasons), and AD (during rainy, norths and dry seasons). Thus in general, the difference in SC, OM, moisture, pH and EC in measured soils among the land-use types was statistically significant.

Principal Component Analysis (PCA) was applied in order to know the relationships among the measured variables for rainy, norths and dry seasons. For rainy season, two components were enough to explain 80.85% of the total variance of data set. Four relationships were identified: Moisture-CE, SC-OM, AD-OC and pH. pH correlated in a significant way with OM (-0.730) and SC (-0.613), this is in agreement with the fact that in organic soils, bacterial activity produce organic acids that low pH values. An important correlation was found between moisture and CE (0.833) and strong correlations for AD-OC (1.00) and SC-OM (0.831) were found. For norths season, two components were enough to explain 62.947% of the total variance of data set. Two groups were identified: SC-PH-EC and AD-OC. pH correlated in a moderate way with EC (0.504) and the following parameters were correlated in a negative way: AD-OM (-0.590), OM-OC (-0.590). A strong correlation for AD-OC (1.00) was found. For dry season, two components were enough to explain 69.11% of the total variance of data set. Three groups were identified: OM-SC, AD-OC and Moisture-EC. Strong correlations were found between Moisture-EC (0.830), BD-OC (1.000) and OM-SC (0.799), whereas, moderate correlations were found for Moisture-BD (-0.538), Moisture-OC (-0.538), EC-OC (-0.490) and EC-AD (-0.490).

4.3 Carbon storage rates

Carbon storage interval was from 0.15 to 1.07 Kg C m^{-2} yr^{-1}, with an average value of 0.57. Mean, minimum and maximum values for carbon storage rate for sampling season, for each sampling site and for land use in Carmen Island are shown in Figure 2.

An evident seasonal pattern was observed, with the highest values at the beginning of the dry season (Figure 2). Long flooding periods prevailed during rainy and norths seasons as a result of abundant rains and an inefficient drainage, maintaining anoxic conditions required for organic matter decomposition, reaching their maximum accumulation process at the beginning of the dry season. At the same time, during dry season, salts and organic carbon are concentrated because of increased evaporation. On the other hand, during the

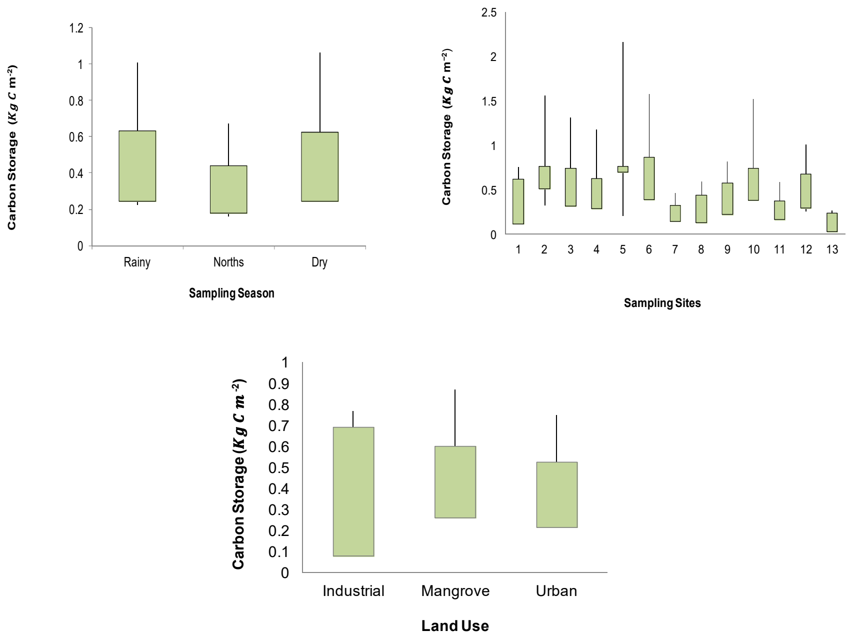
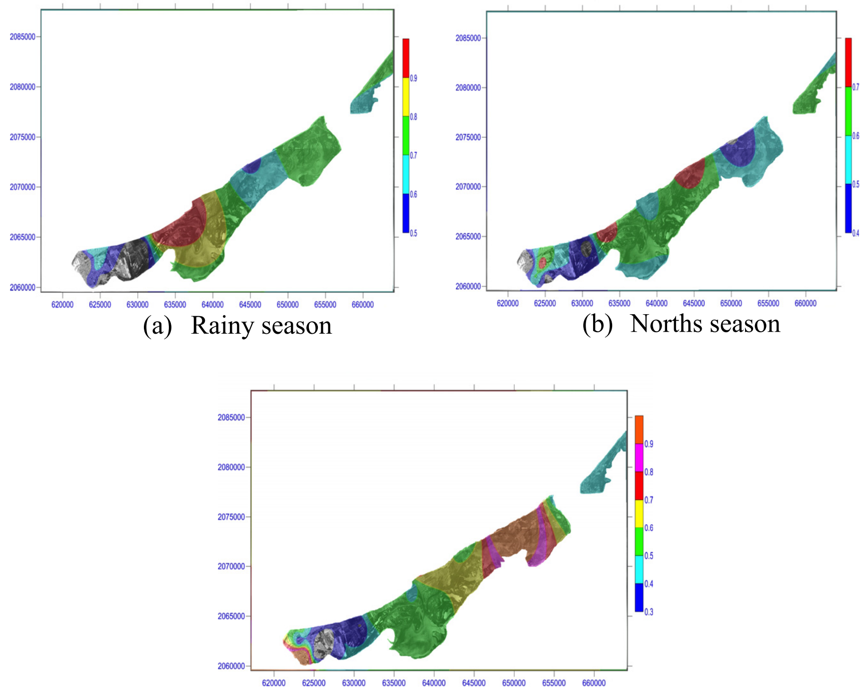


Figure 2: Mean, minimum and maximum values for carbon storage rate for sampling season, for each sampling site and for land use in Carmen Island.

plenitude of the wet season, concentration values present in pore water are diluted with rainwater and run-off waters, resulting in lower organic carbon levels, salinities and densities. This behavior could explain why carbon storage rate is lower during the wet season related with the dry season. Spatial distribution analysis makes palpable the highest values at sampling points 2, 3, 5, 6 and 10 (Figure 2). Since these sites are far of urban zone, could be considered as unperturbed sites and correspond to zones with mangrove forest. Concerning to the land use, carbon storage rates exhibited maximum values in mangrove forest and industrial sites (located at the east edge of the island, where flooding was present the most of the year) whereas the minimum values were found for the urban zone at the west edge of the island.

Comparing our results with carbon storage data obtained in other sites, we can suggests that sandy and alkaline soils, found in this study area, have a good potential of carbon sequestration, therefore, these hotspots of carbon storage must be maintained in undisturbed conditions. Carbon storage rate in island-city was comparable with the reported values by Bernal and Mitsch [5] in Costa Rica and by Cerón and collaborators [18] in Carmen Island. Values obtained in this study are not too high as those reported by Bernal and Mitsch [5] in Australia and Ohio, USA, even though it can be concluded that the sandy and slightly alkaline soils in Carmen Island has a good potential to storage carbon. Maps of



(a) Rainy season (b) Norths season

(c) Dry season

Figure 3: Spatial distribution of carbon storage rate for sampling season in Carmen Island: (a) rainy season, (b) norths season and (c) dry season.

spatial distribution of carbon storage rate on a wide scale in Carmen Island for the sampling season are shown in Figure 3.

Besides the evident seasonal pattern, there are other factors such as flooding conditions, infiltration capacity, vadose zone saturation, biomass composition at surface level, and tide influence controlling this parameter. During the wet season the accumulation of organic matter increases; however, decomposition process is slow, resulting with maximum values of carbon storage during the dry season.

5 Conclusions

During this research, a severe period of rains occurred, and a long dry season prevailed. Despite this, the physical and chemical parameters determined in soil samples showed the expected behavior according to that reported in a previous study. An evident seasonal and spatial pattern was identified for carbon storage rate. This pattern is typical of tropical forests, where organic matter and nutrients do not accumulate because they are quickly used by biotic systems. Hydrogeology and dominant vegetation were the factors with a greater influence on carbon storage rate. Despite the fact, this study reported the carbon storage rate at a wide-scale for an island-city, the carbon storage rate obtained was comparable with those obtained for isolated and forested wetlands in others regions of the world, therefore, we can conclude that studied soils are good carbon pools since the high productivity in this island provides a nutrient source that in synergy with hydro-geological conditions resulted in relatively high carbon storage rates. These results can help to guide decisions regarding priority areas for the conservation and rehabilitation of mangroves for climate change mitigation and the other environmental services associated to them. Therefore, it can be expected that local government stops deforestation in this island and promotes conservation and reforesting actions focused to conserve these hotspots of carbon pools.

References

[1] Davies, Z.G., Edmonson, J.L., Heinmeyer, A., Leake, J.R., & Gasto, K.J. Mapping an urban ecosystem service: Quantifying above-ground carbon storage at a city-wide scale. *Journal of Applied Ecology,* **48,** pp. 1125-1134, 2011.

[2] Hutchison, J., Manica, A., Swetnam, R., Balmford, A., & Spalding, M. Predicting global patterns in mangrove forests biomass. *Conservation Letters,* **7**, pp. 233-240, 2013.

[3] World Wildlife Foundation. Ecoregional Workshop. A conservation assessment of mangrove ecoregions of Latin America and the Caribbean. Washington, D.C. USA, 1994.

[4] Contreras, A., Douillet, P., & Zavala, J. Tidal dynamics of the Terminos Lagoon, Mexico: observations, and 3D numerical modeling. *Ocean Dynamics,* **64**, pp. 1349-1371, 2014.

[5] Bernal, B., & Mitsch, J.W. A comparison of soil carbon pools and profiles in wetlands in Costa Rica and Ohio. *Ecological Engineering,* **34**, pp. 311-323, 2008.

[6] Etchevers, J. D. Manual para la determinación de carbono en la parte aérea y subterránea de sistemas de producción de laderas. México. Colegio de Postgraduados, 2005.

[7] Mylavarapus, R. S., & Kennelly, D. E. Extension soil testing laboratory, Analytical procedures and training manual. Institute of Food and Agricultural Sciences. p. 28, 2002.

[8] Dietrich, H. Procedure for determining soil particle size using the hydrometer method. SOP Meth00400. Environmental Monitoring Branch. DPR, 2005.

[9] Ryan, J., Stefan, G., & Rashid, A. Soil and plant analysis. Laboratory Manual. International Center for Agricultural Research in the Dry Areas (ICARDA). Islamabad, Pakistan. 172 pp, 2001.

[10] Batjes, N. H. A homogenized soil data file for global environmental Research: A subset of FAO, ISRIC and NRCS profiles. Netherlands, International soil reference and information centre, 1995.

[11] Heiri, O., Lotter, A. F., & Lemcke, G. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of paleolimnology,* **25**, pp. 101-110, 2001.
[12] Craft, C.B., Seneca, E.D., & Broome, S.W. Loss on ignition and kjeldahl digestion for estimating organic carbon and soils: Calibration with dry combustion. *Estuaries,* **14**, pp. 175-179, 1991.
[13] Brahim, N.M., Bernoux, D., Blavet, B., & Gallah, T. Tunisian soil organic carbon stocks. *Int. J. Soil. Sci,* **5**, pp. 34-40, 2010.
[14] Myers, D.E. Interpolation and estimation with spatially located data. Elsevier Scientific Publishing, Co. New York. pp. 209-228, 1991.
[15] Cressie, N. Statistics for spatial data. New York, John Wiley & Sons, 1991.
[16] XLSTAT. Statistical Software for Microsoft Excel.
[17] Yañez, A., Twilley, R.L., & Lara, D. A. Mangrove ecosystems against climatic global change. *Madera y bosques,* **4**, pp. 3-19, 1998.
[18] Cerón, J., Cerón, R., Rangel, M., Muriel, M., Córdova, A., & Estrella, A. Determination of carbon sequestration rate in soil of a mangrove forest in Campeche, Mexico. *International journal of energy and environment,* **5**, pp. 328-335, 2011.
[19] Lal, R. World cropland soils as source or sink for atmospheric carbon. *Adv. Agron,* **71**, pp. 145-191, 2001.