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Manatees Mortality Analysis at Los Bitzales, Tabasco, by Remote Sensing

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Abstract: The importance of the study of the environment lies in the consequences to health that can be generated from a problem, in an era full of industrial and technological development. Most of these investigations are carried out in field, however, nowadays measurements made from space contribute to its development. The present work shows the application of remote sensing satellites in a particular case in the state of Tabasco, Mexico, where there was an unusual increase in the mortality rate of manatees (*Trichechus manatus*) in the protected natural area known as the Pantanos de Centla Biosphere Reserve (PCBR).
Keywords: Bitzales, cyanobacteria, Ciudad Pemex, manatee, Nabor Cornelio, remote sensing, satellite

I. Introduction

Between May 18 and October 26, 2018, the Secretaría de Medio Ambiente y Recursos Naturales (Ministery of Environment and Natural Resources) (SEMARNAT), together with the Comisión Nacional del Agua (National Water Commission) (CONAGUA) and the Procuraduría Federal de Defensa al Ambiente(Federal Office of Defense to the environment) (PROFEPA), found a total of 48 carcasses of manatees (*Trichechus manatus*) in an advanced state of decomposition in water bodies in Tabasco, Mexico [1]. The majority of cases (33 of 48) were reported in the area known as Los Bitzales, within the Pantanos de Centla Biosphere Reserve (PCBR), with the highest incidence between the months of July and August. Regarding the possible cause of this environmental contingency, the results of studies carried out in the area suggest that it was a multifactorial process influenced by the prolonged drought season in the state, the high temperatures recorded, the presence of a high content of fecal coliforms, the toxicity of chemical substances derived from agrochemicals and hydrocarbons, as well as the presence of pathogens and harmful algal bloom (HAB) [2]. These studies are based on methodologies of field data acquisition, whose obtaining of results takes a certain time and must be done with prior knowledge of the area and the study case [4]. In order to present the use of satellite images of remote sensing as a tool for monitoring environmental contingencies, as well as to qualitatively corroborate the results of the case study, an evaluation was made by analyzing satellite image sequences of the Landsat 8 platform [3] with the use of the QGIS software (version 2.18.23 "Las Palmas"), by obtaining various vegetation and water parameters that allow discrimination and enhancement of responsible agents for the study case.

II. Study Area

The PCBR is located northeast of Tabasco, in the municipalities of Centla, Jonuta and Macuspana, and in a section of the municipality of Palizada, Campeche. It is located between the geographic coordinates 17°57’53’’ – 18°39’03’’ N and 92°06’39’’ – 92°47’58’’ W, covering an area of 302,706 ha, corresponding to 12.27% of the total surface of Tabasco (Fig. 1) [5]. The northwest and northeast limits of the PCBR are, respectively, the city of Frontera, Centla and the Gulf of Mexico at the mouth of the San Pedro/San Pablo river, while the southern limit is the area of the Bitzales, where the river of the same name goes through. PCBR is located in the “Southern Gulf Coastal Plain” physiographic province and in the “Plains and Swamps of Tabasco” subprovince. The altitude in the terrain varies from -1 to 7 m above mean sea level, which allows a complex hydrological system of rivers, lagoons, swamps and marshes [6]. Climate is subhumid with summer rains, annual average temperature of 25 ºC, and annual rainfall of 1,600 mm.

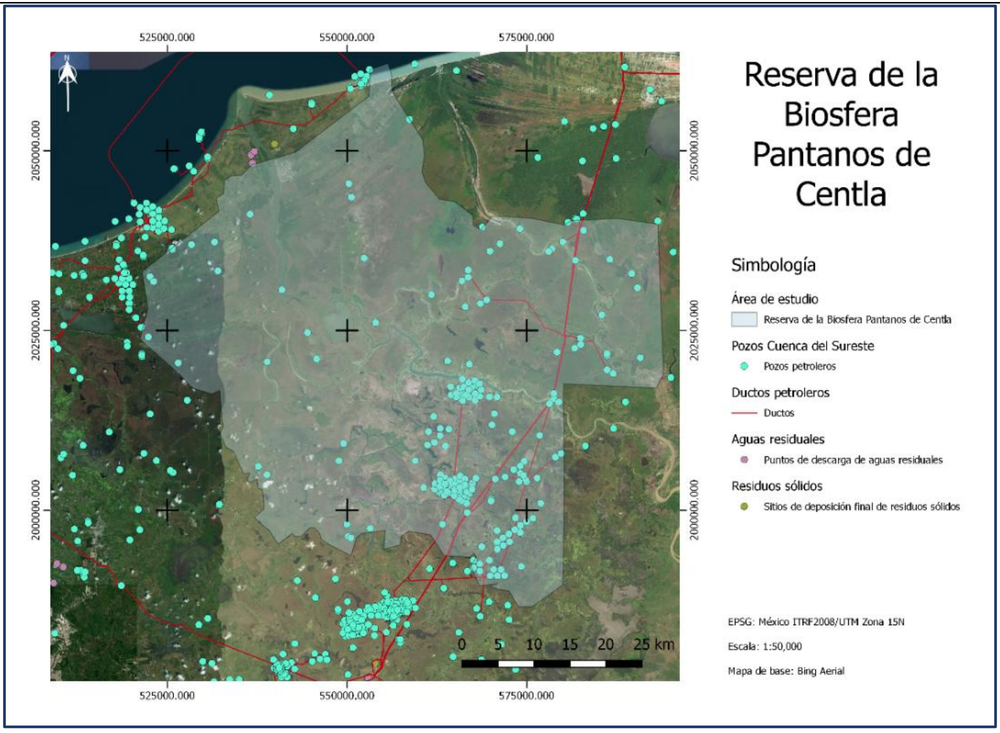

Figure 1: Location of the study area and anthropogenic activities that may contribute to pollution in the area [7, 8].

The nearestcities to the PCBR are Ciudad Pemex, Frontera, Jonuta, Macuspana and Villahermosa. These last two cities are located in the municipalities with the largest amounts of untreated wastewater discharge points and urban solid waste collected (Macuspana and Centro, respectively) [7]. The economic activities with greater presence in the study area are those related to the primary sector and the oil industry. On the first one, the studies carried out during the environmental contingency indicate that there has been a considerable variation in the soil use in the Bitzales area, which has caused an increase in soil and water pollution by the increase of wastewater spill from domestic, agricultural and livestock activities that occur near the area [2]. The presence of the oil industry in the area dates from the second half of the 20th century. Although it was decreed in 1992 as a natural reserve, there are a large number of oil and gas wells and pipelines, some of which are active to date [8]. This presents the potential risk of leaks and spills that could affect the flora and fauna around them.

III. Methodology

Satellite images of the Landsat 8 platform [3] were used for the present work, in order to obtain a good spatial and temporal resolution. The study consisted of the analysis of satellite images available in the January - October 2018 temporal interval, whose selection was based on the percentage of clouds present, to visualize the historical behavior before and after the contingency was reported (Fig. 2). To carry out the sequences of pre-process and process, by estimating various variables of vegetation and water analysis, free software QGIS (version 2.18.23 "Las Palmas") was chosen given its ease for data management in raster format [4, 9]. The selection of anomalies of interest was carried out by comparing the images obtained from the area, the databases corresponding to the anthropogenic activity, as well as the reports of findings of manatee carcasses in the area [1]. From this selection, an unsupervised classification was elaborated by means of the Semi-Automatic Classification Plugin (SCP), in order to obtain the spectral signatures that they present on each date [10].

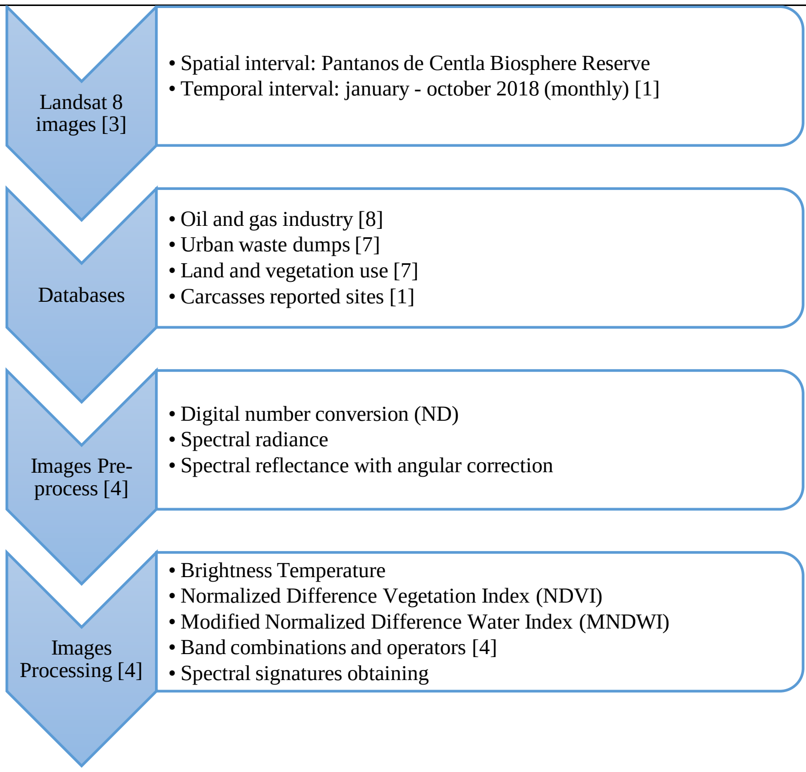

Figure 2: Methodology for the preparation of the study.

Table 1: Equations and parameters for the analysis of satellite images

Equation	Parameters
$L\lambda = M_L * Q_{cal} + A_L$ 1) Spectral radiance	M_L = RADIANCE_MULT_BAND_X A_L = RADIANCE_ADD_BAND_X Q_{cal} = Previously translated to ND Band
$\rho_\lambda = \frac{M_p * Q_{cal} + A_p}{\sin \theta_{se}}$ 2) Spectral reflectance with angular correction	M_p = REFLECTANCE_MULT_BAND_X A_p = REFLECTANCE_ADD_BAND_X Q_{cal} = Previously translated to ND Band θ_{se} = SUN_ELEVATION
$T = \left[\frac{\left(\frac{k_2[TIRS\ 1]}{\ln\frac{k_1[TIRS\ 1]}{L_\lambda[TIRS\ 1]}+1}\right) + \left(\frac{k_2[TIRS\ 2]}{\ln\frac{k_1[TIRS\ 2]}{L_\lambda[TIRS\ 2]}+1}\right)}{2}\right] - 273.15$ 3) Brightness temperature	k_1 = K1_CONSTANT_BAND_X k_2 = K2_CONSTANT_BAND_X L_λ = Previously translated to Radiance Band
$NDVI = \frac{\left[\left(\frac{Near\ Infrared - Red}{Near\ Infrared + Red} + 1\right) * 10\right]}{2}$ 4) Normalized Difference Vegetation Index (standardized)	*Near Infrared* = Previously translated to Reflectance Band *Red* = Previously translated to Reflectance Band
$MNDWI = \frac{\left[\left(\frac{Green - Medium\ Infrared}{Green - Medium\ Infrared} + 1\right) * 10\right]}{2}$ 5) Modified Normalized Difference Water Index (standardized)	*Green* = Previously translated to Reflectance Band *Medium Infrared* = Previously translated to Reflectance Band
RGB [4,3,2] Natural color RGB [5,4,3] Infrared for vegetation 6) Band combinations	Based on Landsat 8 spectral bands
RGB [(4/3),(5/4),(7/6)] 7) Band operators (Highlight for hydrocarbons)	Based on Landsat 8 spectral bands

IV. RESULTS

Initially, a total of 17 satellite images were analyzed for the study, corresponding to the temporal interval January - September 2018. Of these, two images corresponding to the months of April (04/04/2018) and July (25/07/2018) were chosen due to the low percentage of present clouds over the area and its temporal proximity to the environmental contingency record [1]. Based on the information available on the findings of the manatee carcasses in the area, a grid south of the PCBR was selected as the main area, which covers the following sections of interest: 1) Ciudad Pemex, 2) Nabor Cornelio and 3) the Bitzales (figure 3). The presence of the oil fields Chilapilla and Hormiguero (Ciudad Pemex), Bitzal and Cobo (Nabor Cornelio), and José Colomo (the Bitzales) stand out due to current activity.

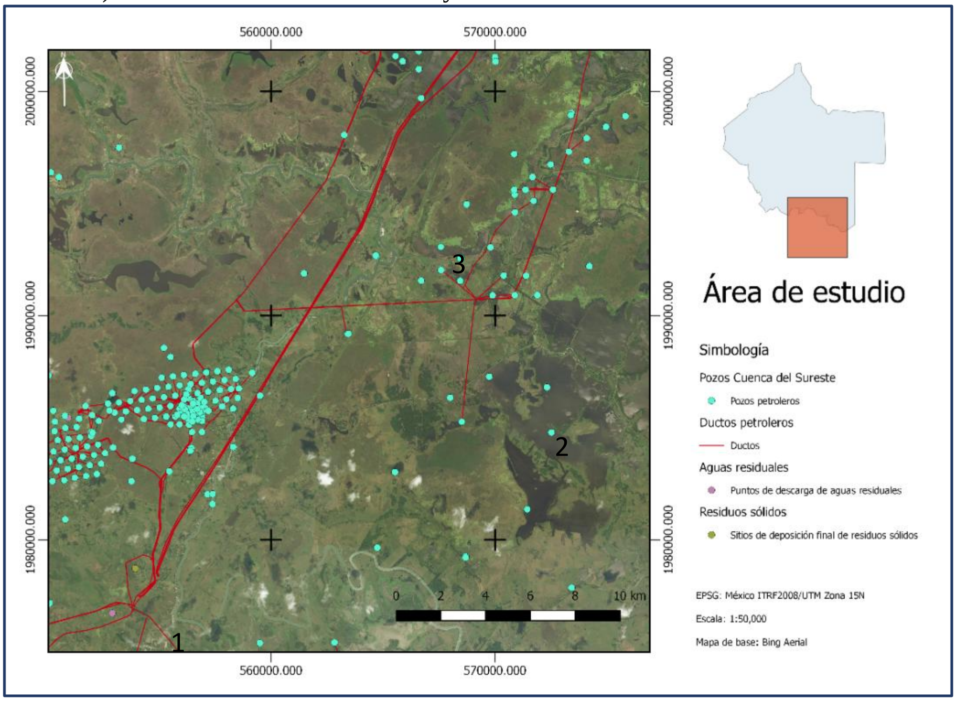

Figura 1: Main area for the satellite images analysis with the anthropogenic activities related to pollution. The study sections are indicated as 1) Ciudad Pemex, 2) Nabor Cornelio and 3) the Bitzales [7, 8].

4.1. Brightness temperature

In order to verify part of the meteorological information, the brightness temperature formula (3) was applied (Fig. 4), based on a logarithmic relationship that allows us to measure the heat emission of a body from the values of spectral radiance (1) [4].

The temperature range observed goes between 15 - 40 ° C, with the smallest variation in Ciudad Pemex, despite the fact that it has a focus of anomaly. Comparing it with figure 3, we can notice that the anomaly is located on a site of final deposition of solid waste, so we can assume that in this place garbage is burned constantly. If we observe the variations in Nabor Cornelio, we can assume initially that in those areas: a) there are places where garbage is burned, b) they are agricultural sections in sowing / harvesting season, c) they presented some forest fire or d) there are oil wells with flare stacks (applies only to specific sections). Based on the available information, this section may correspond to cases b) and c) [2, 11].

The temperature variations in the vegetation stand out more than those in the water. However, we must focus on the variation of the surface extension of the lagoon bodies in the area to give a good interpretation by comparing these results with the other parameters.

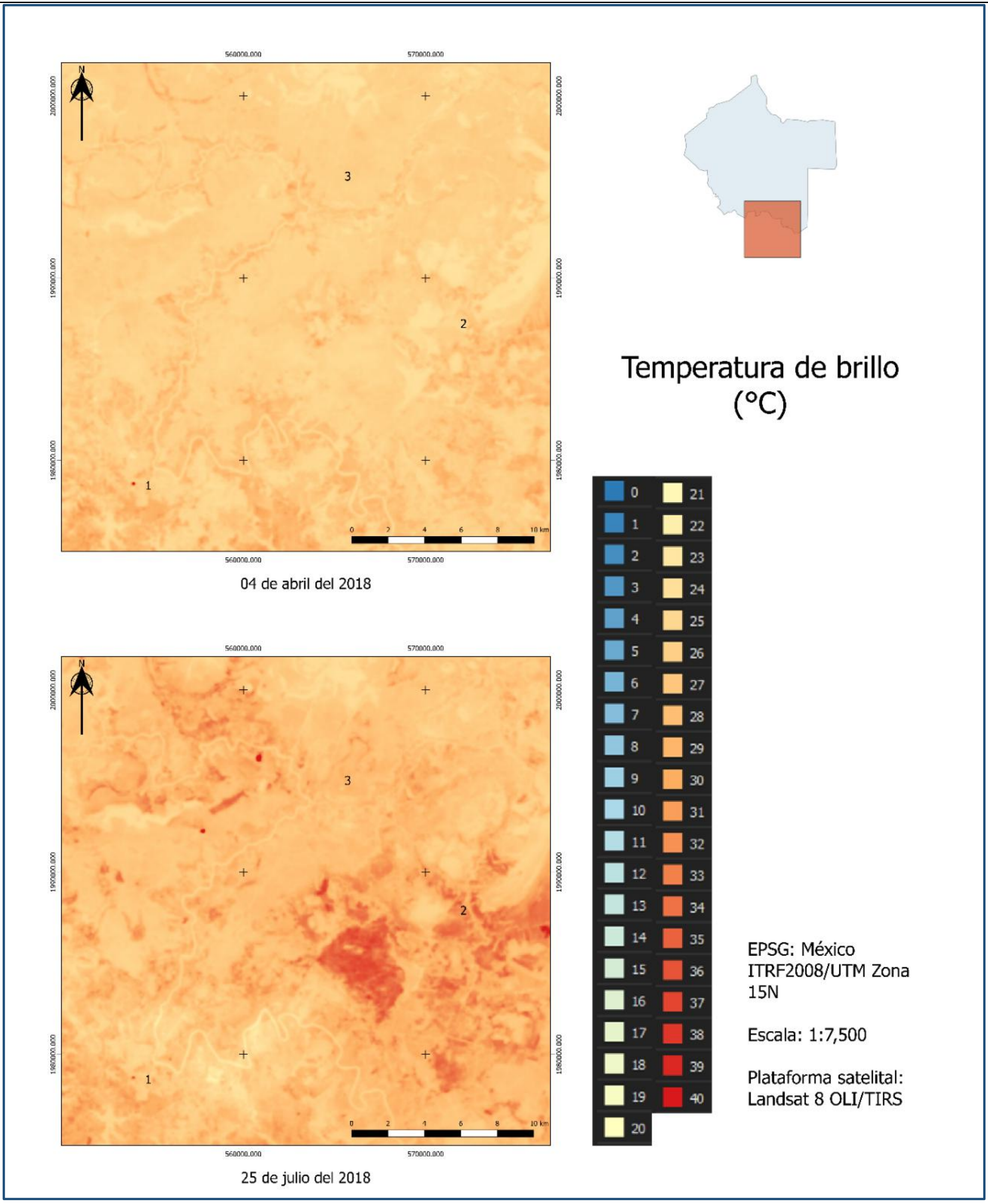

Figura 2: Comparison of the brightness temperature (3) between April 4 and July 25, 2018. The values on the scale are shown. Both satellite images correspond to the Landsat 8 platform [3].

4.2. Normalized Difference Vegetation Index (NDVI)

The reason for using this index is due to the strong contrast it has in the reflectance values of the red (*Red*) and near infrared (*Near Infrared*) bands, in order to analyze the behavior that vegetation has presented in the study area [12]. The magnitude of the NDVI is dimensionless and is in a range between -1 and 1, representing dense and healthy vegetation values close to 1, the values ≤ 0 correspond to the presence of little dense and sick vegetation, as well as water bodies and floating material (sediments, organic matter and substances of lower density such as hydrocarbons). The scale was standardized by equation (4) to facilitate the discrimination of anomalies (Fig. 5) [4].

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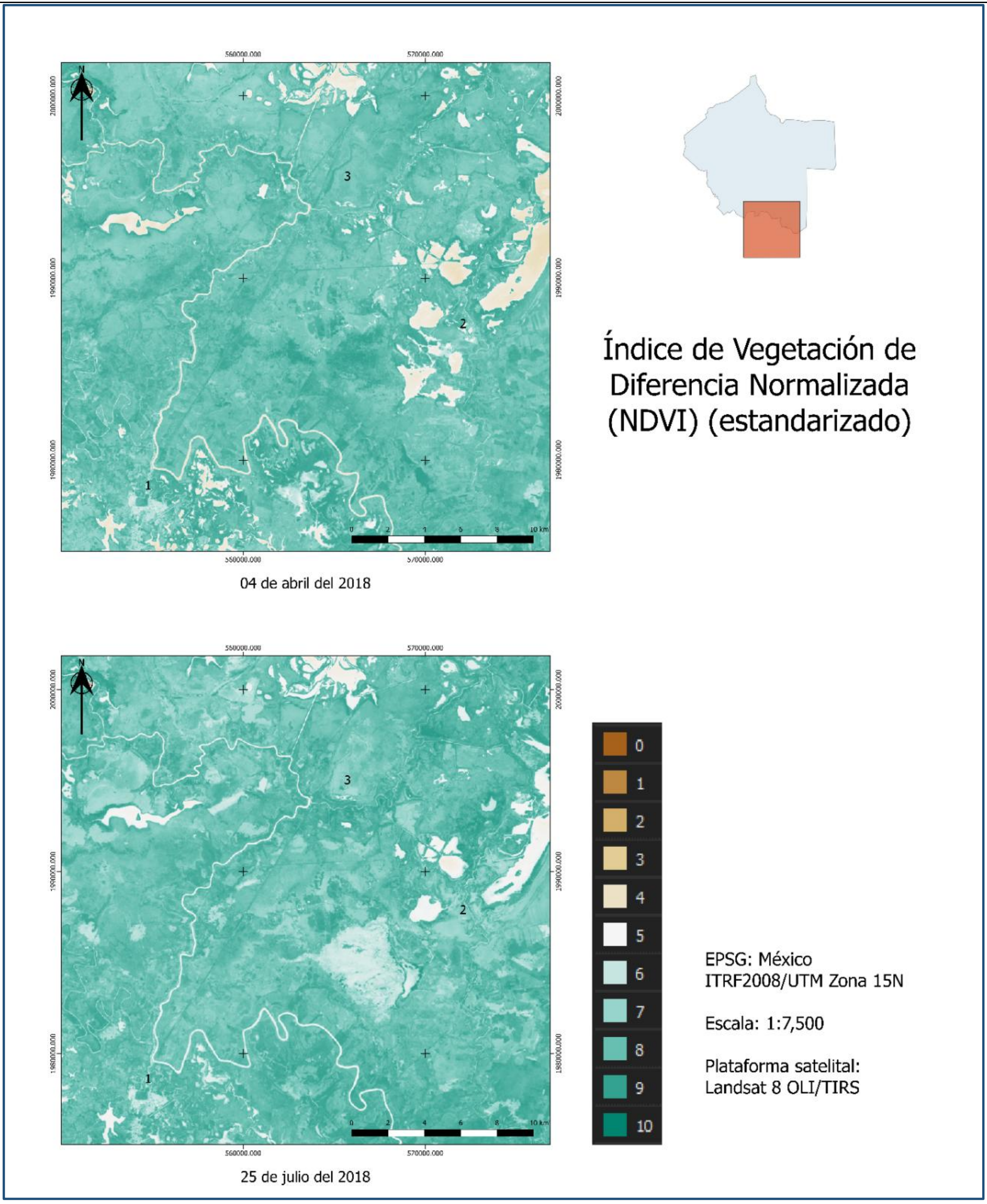

Figure 5: Comparison of the Normalized Difference Vegetation Index (NDVI) (standardized) (4) between April 4 and July 25, 2018. The values on the scale are shown. Both satellite images correspond to the Landsat 8 platform [3].

Analyzing the comparison between the images, the contrast in the vegetation is slight, except in Nabor Cornelio, where there is a decrease in the NDVI values. This indicates that the area underwent a combustion process (in the manner explained in the previous point), in such a way that the theory proposed by the comparison with brightness temperature (3) is partially corroborated. In the case of the Bitzales, there is a slight increase in the NDVI, which indicates that the vegetation improved in the areas near the Bitzal river.

For the water bodies in the area, an increase in the NDVI values was observed between the two satellite images, which is interesting for the study. The following causes can occur: e) variation in the presence of floating matter in water bodies and f) increase of surface vegetal activity through algal bloom. These can be discriminated based on the type of waterbody in which they are located, in such a way that there is a probability that the causes are partially or totally detected. For example, a greater influence of f) on lagoon bodies than on rivers is more logical, although the environmental conditions they present and the proximity of these to anthropogenic activities must be considered. For example, lagoon bodies in Ciudad Pemex are more prone to increase surface plant activity due to water stagnation and the contribution of wastewater from untreated discharges from urban areas and generated from agricultural and livestock activities in the area. area [7, 13]. It should also be noted the decrease in the areas of the lagoon bodies in the three sections, which may be related to the weather conditions in the months of study [2].

4.3. Modified Standardized Difference Water Index (MNDWI)

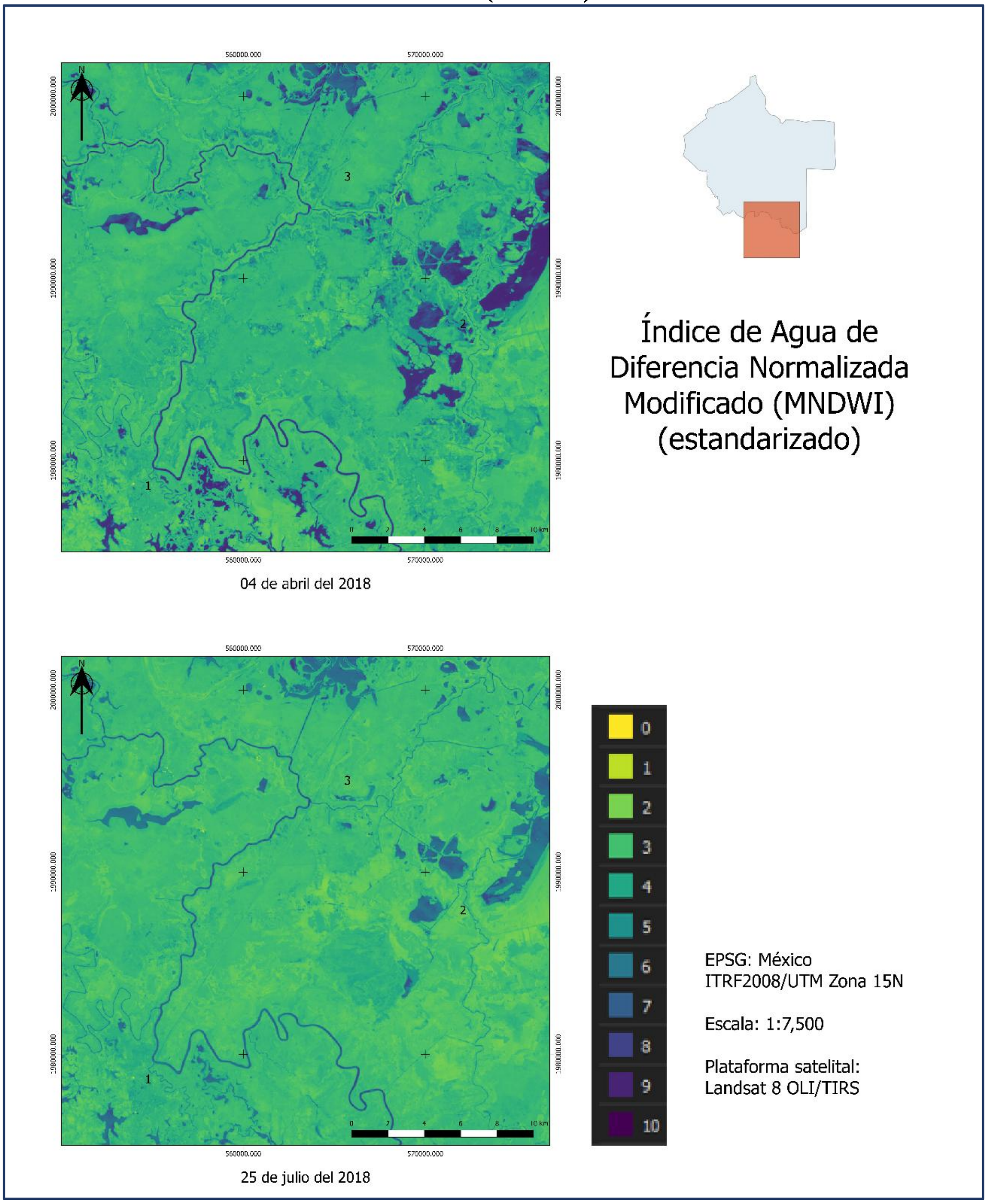

Figure 6: Comparison of the Modified Normalized Difference Water Index (MNDWI) (standardized) (5) between April 4 and July 25, 2018. The values on the scale are shown. Both satellite images correspond to the Landsat 8 platform [3].

Based on the application of the Green and Medium Infrared spectral bands, this index allows us to highlight water bodies due to the water absorption of radiometric waves with a wavelength in the range of second spectral band [14]. Its magnitude is also dimensionless and is in a range between -1 and 1, in which the positive values are related to water bodies (varying according to their quality and the presence of floating material and / or vegetation), while that those values ≤ 0 correspond to vegetation and urban areas. This index is suitable for fire detection because the affected areas register them with values close to -1. In the same way as with the NDVI, the scale was standardized by means of equation (5) to facilitate the discrimination of anomalies (Fig. 6) [4].

In the NDVI (4) it was observed that the health status of the vegetation varied slightly, however, in figure 6 it is shown that the loss of water in the vegetation is considerable in the three sections, based on the type of vegetation existing [2]. The vegetation anomaly in Nabor Cornelio has values between 2 and 4, so it can be concluded initially that in this section there was a fire prior to the day of the satellite image taken in July [3]. The areas with vegetation that presented the least variation correspond to those near the Tulijá and Bitzal rivers. To the east of the Bitzales a slight increase in the NDVI can be observed, which does not coincide with the other sections.

Regarding the water bodies, there is a considerable decrease in the values of MNDWI in the study area, which consists of a decrease from 7 – 9 to 5 – 8. In the first instance, this variation can be related to the meteorological conditions in the area, in such a way that it can also explain the reason for the decrease in the areas of the lagoon bodies, corroborating the results obtained when applying the NDVI (5). We should also consider that this variation could indicate a decrease in the levels of the water bodies, which would make sense when observing that the MNDWI values in the lagoon bodies are lower than those in the rivers. Another aspect that is still important is to consider the increase in surface plant activity, since the variation of MNDWI values makes sense in terms of vegetation indicators. The presence of floating material in the water is not yet ruled out, however, this can be better evaluated with the combinations of bands. We can say that there was a drastic change in weather conditions and water quality that led to the death of manatees in the study area, which has been observed drastically in the variations in the previous parameters between the months of April and July 2018.

4.4. Band combination: RGB natural color [4,3,2]

A combination of bands allows us to select three spectral bands and assign them a primary color in order to visually highlight certain characteristics that are recorded in them. In the case of the combination for natural color, the spectral bands of the visible spectrum are applied in order to obtain an image that is perceptible in the way the human eye does it. In the case of Landsat 8 satellite images, bands 4 (*Red*), 3 (*Green*) and 2 (*Blue*), respectively [4], are combined in RGB format (Fig. 7).

There is a high contrast in the color of the vegetation in the three sections, with a predominance of vegetation reduction in the area, except in the areas near the Tulijá and Bitzal rivers. With this combination of bands, it was possible to corroborate that the anomalies present in Nabor Cornelio observed in the previous parameters correspond to fires / crop burning in the area. In the Bitzales, this type of event is also detected, highlighting that they occurred on the same day of the photographic taking for the month of July due to the presence of smoke. The increase in greenness in the vegetation east of this section is also observed, which demonstrates the variation identified by the NDVI.

In the case of water bodies, a drastic change in water color is observed in all bodies present in the area, with greater variation in the lagoon area of Nabor Cornelio and in the Tulijá and Bitzal rivers. This can be an indicator of increased surface plant activity through algal blooms, based on a comparison with the results obtained with NDVI and MNDWI. In Ciudad Pemex, the lagoon to the west of the urban area stands out due to the dark tonality that already presents its correlation with the presence of a sewage discharge pipe, while in Nabor Cornelio most of the lagoons and streams present a moderate variation in color.

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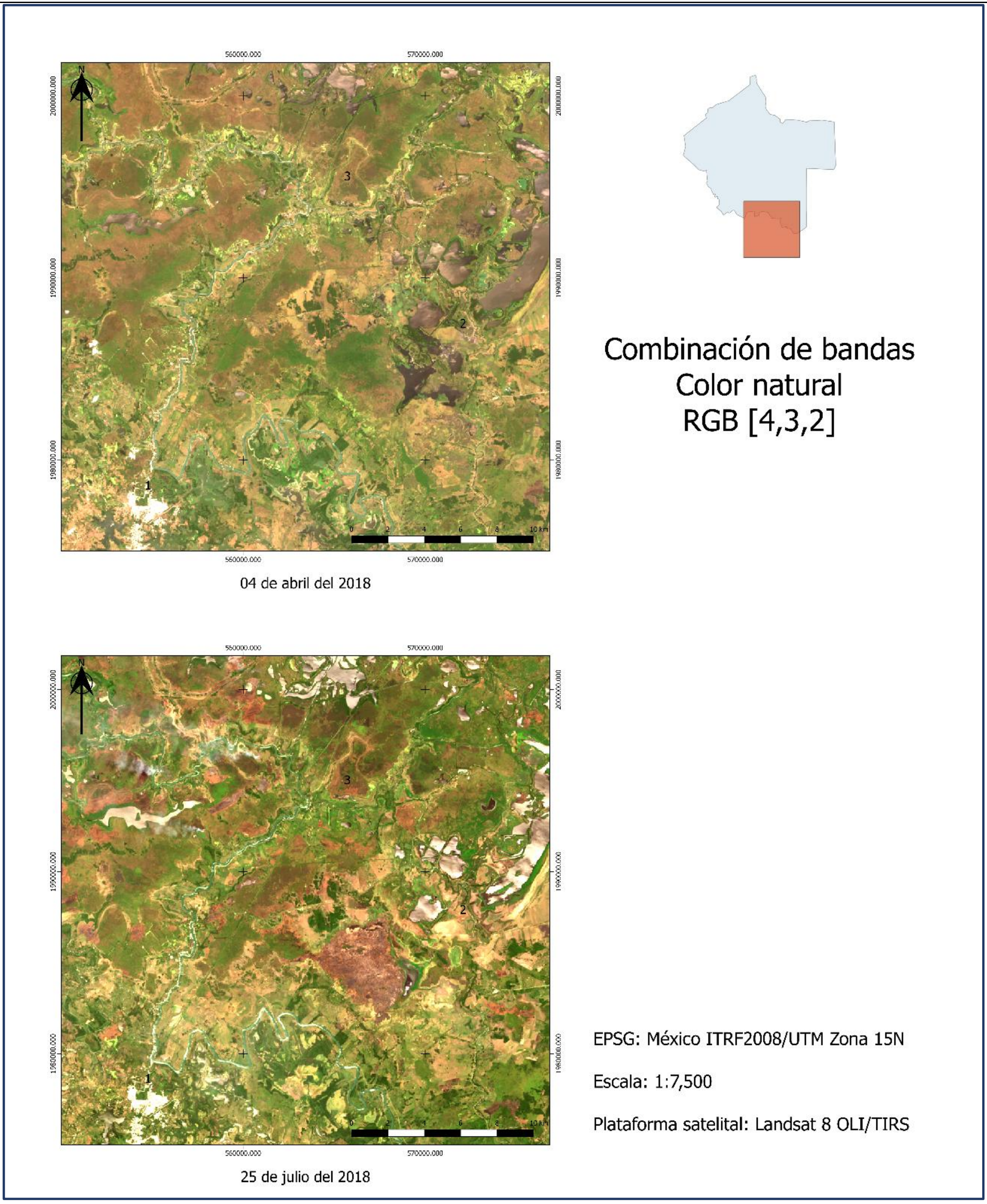

Figure 7: Comparison of the combination of RGB bands [4,3,2] (6) between April 4 and July 25, 2018. Both satellite images correspond to the Landsat 8 platform [3].

4.5. Combination of bands:RGB Infrared for vegetation [5,4,3]

The vegetation analysis is carried out by combining the visible spectrum with the infrared spectrum. For this, there is a combination of bands that, in the case of Landsat 8, consists in the use of bands 5 (*Near Infrared*), 4 (*Red*) and 3 (*Green*), respectively in the RGB format (Fig. 8) [4]. In this case, the vegetation is observed in a range between red-magenta and pink; Urban areas, clouds and areas of high reflectance such as bare soils and coasts, are presented in a range of white and pale colors, in water with a range of dark blue to black and areas affected by fire in a range of green and saturated colors of brightness.

Observing vegetation variations with this band combination, we can notice that the anomalies deduced from the previous parameters are corroborated again. What does stand out with this combination of bands is the proportion of areas burned in the area, which affects the vegetation is considerable.

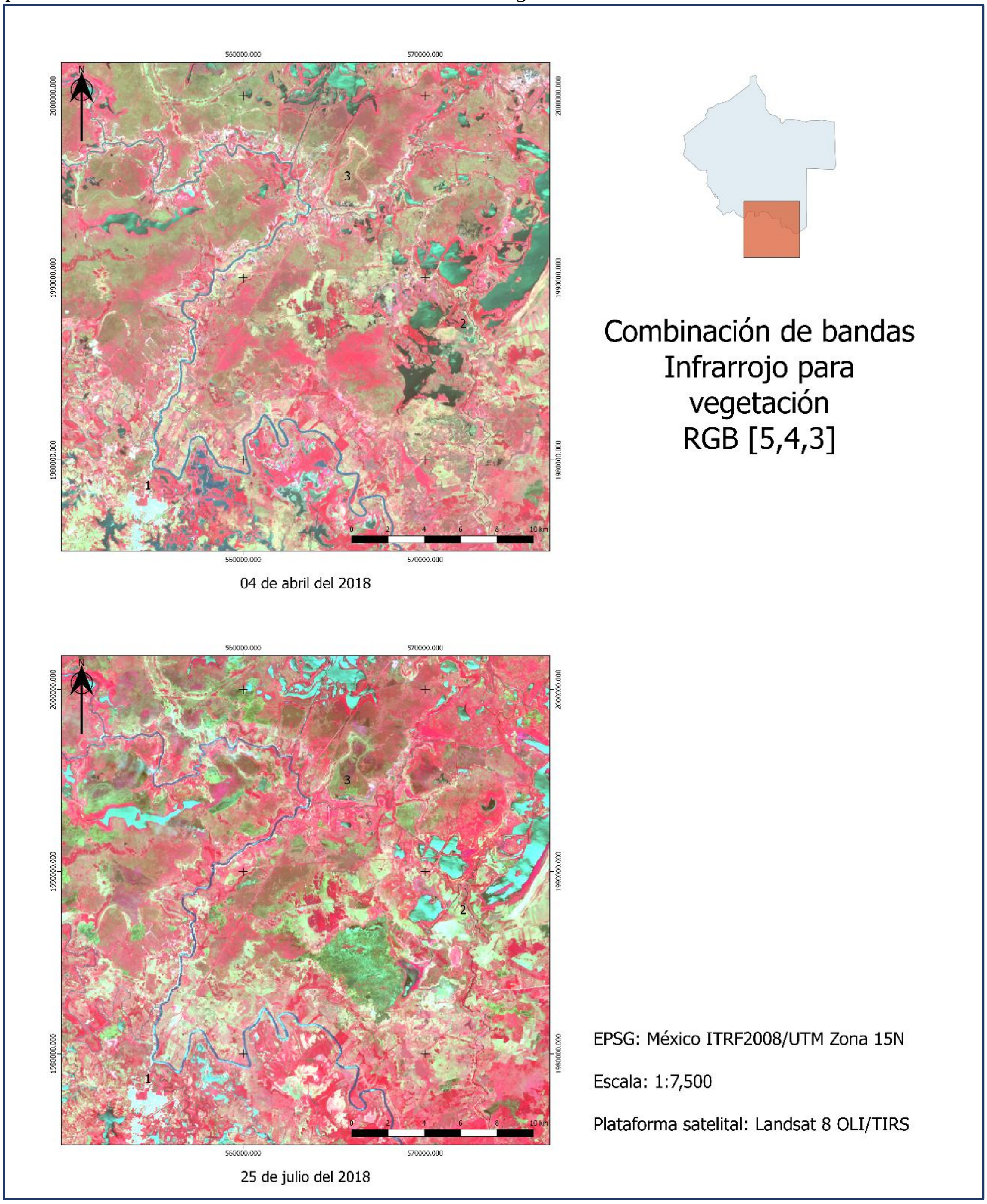

Figure 8: Comparison of the combination of RGB bands [5,4,3] (6) between April 4 and July 25, 2018. Both satellite images correspond to the Landsat 8 platform [3].

For the water analysis is where this combination of bands generates interest. It is observed that all water bodies have a range of hue between navy blue and green-blue. Regarding the lagoon bodies, this anomaly is more evident in Nabor Cornelio and the Bitzales, while in Ciudad Pemex a variation is detected in the lagoon located west of the urban area. In the case of the Tulijá and Bitzal rivers, it can be deduced that the anomalies are those surfaces with green-blue tonalities. Comparing with the results obtained in the previous parameters, the probabilities of the increase of the superficial vegetal activity in the study area are greater than the presence of another floating material. Regarding the type of surface vegetation in waterbodies, the presence of cyanobacteria in these is considered due to the variation of tonality that they present, above all, in the infrared spectrum [15]. This possibility is reported in the current reports on studies conducted in the area [1, 2].

4.6. Combination of bands: RGB hydrocarbon spills [(4/3), (5/4), (7/6)]

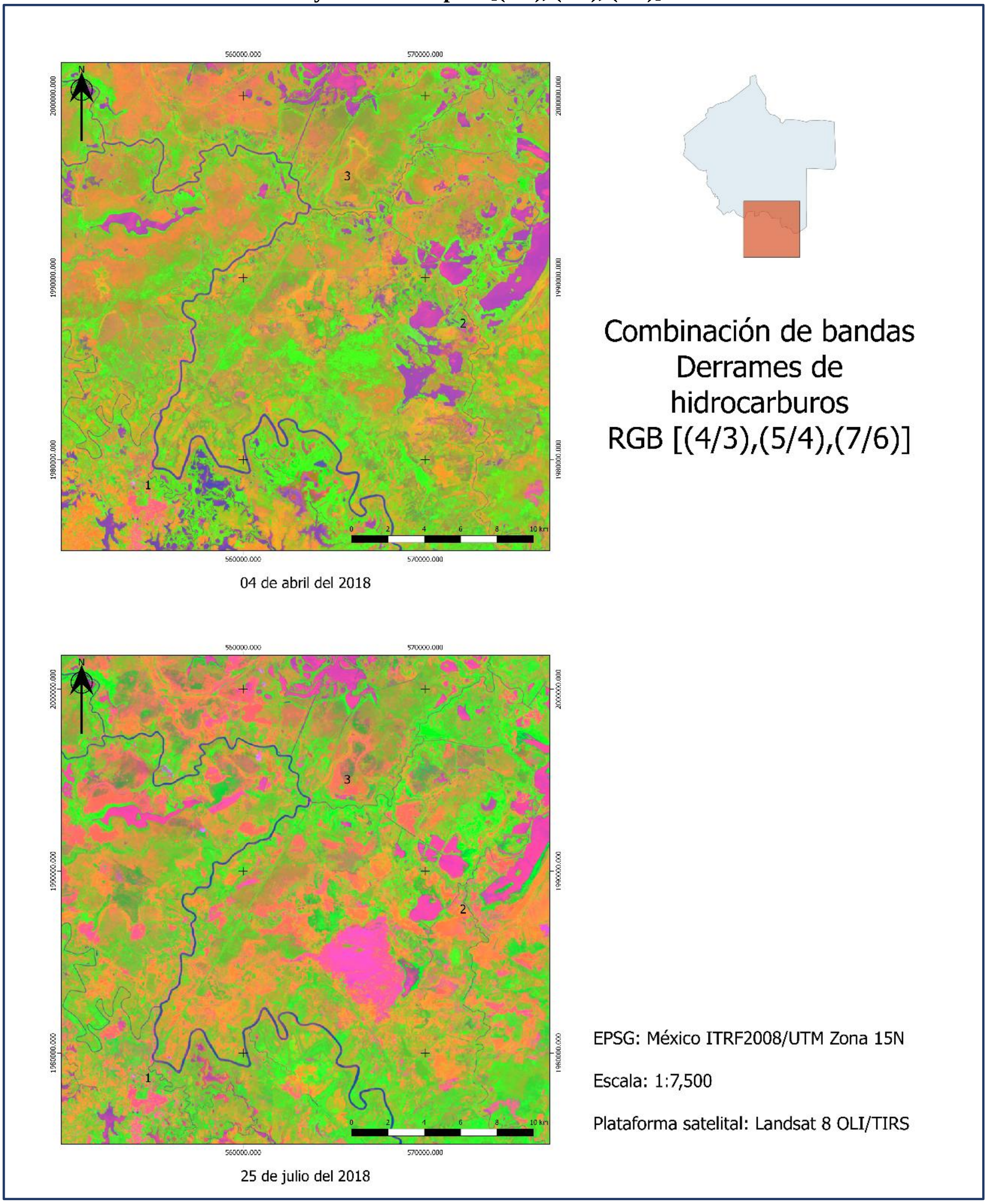

Figure 9: Comparison of the combination of RGB bands [(4/3), (5/4), (7/6)] (7) between April 4 and July 25, 2018. Both satellite images correspond to the Landsat 8 platform [3].

In order to discriminate the presence of spills of hydrocarbons in the area, it was proposed to use a band combination model based on band operators. The purpose of the operators is to highlight the reflective properties of the materials by modifying the spectral range by means of algebraic operations. Thus, the band composition [(4/3), (5/4), (7/6)] for the months of April and July 2018 was applied (7), based on the radiometric

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properties of this substance and in the boundary of the bands of the infrared spectrum, in such a way that it is highlighted in a range between 1.73 to 2.31 μm, represented in the processed satellite image with a tonality range between magenta to orange(Fig. 9) [16].

In the vegetation you can again see the evidence of fires in the month of July, which are being marked as anomalies by the composition of bands. However, the same happens with the urban area of Pemex city, which indicates that it also highlights those areas that have high reflectance values.

In the case of water bodies, the lagoon bodies have a shade between pink and purple. In the image corresponding to the month of April, tonalities close to the magenta are shown. However, if we correlate it with the results obtained through the NDVI and the MNDWI, we can assume the existence of sediments or floating material in the area. However, when comparing with the database of oil wells and pipelines [8], it is evident that these anomalies do not have a certain relationship with a hydrocarbon spill. The same happens with the lagoon bodies in the month of July, where it can be argued with the meteorological conditions presented in the area [2]. The Tulijá and Bitzal rivers have a tonality that does not represent the presence of oil on the surface, also concluding in the null relation between the mortality of manatees and the oil activity in the area.

V. Obtaining Spectral Signatures

Every object on the Earth's surface reflects electromagnetic radiation (EMR) according to a function that depends on the wavelength. Therefore, each one presents a spectral behavior called signature, which can be registered by remote sensors [10]. For the purpose of this study, an analysis of the spectral signatures of the anomalies in water bodies was carried out by means of the Semi-Automatic Classification Plugin of QGIS (SCP), by obtaining the reflectance values (2) of the bands 2 – 7 of the satellite images of Landsat 8 [3] and was compared with the vegetation signatures in order to corroborate the presence of algal blooms that show the results of the calculated parameters [4].To obtain the spectral signatures, spatial sample points were chosen based on the recorded values by the vegetation and water parameters for the satellite images for the month of July (Fig. 10). Regarding the water bodies, the lagoon near Ciudad Pemex, part of the Tulijá river arm (where two spatial samples are included), the Bitzal river diversion area and the Nabor Cornelio major lagoon were selected. Corresponding to vegetation, four variations were chosen: healthy vegetation, regular vegetation, scarce vegetation and burned area (Fig. 11 and 12) [10].

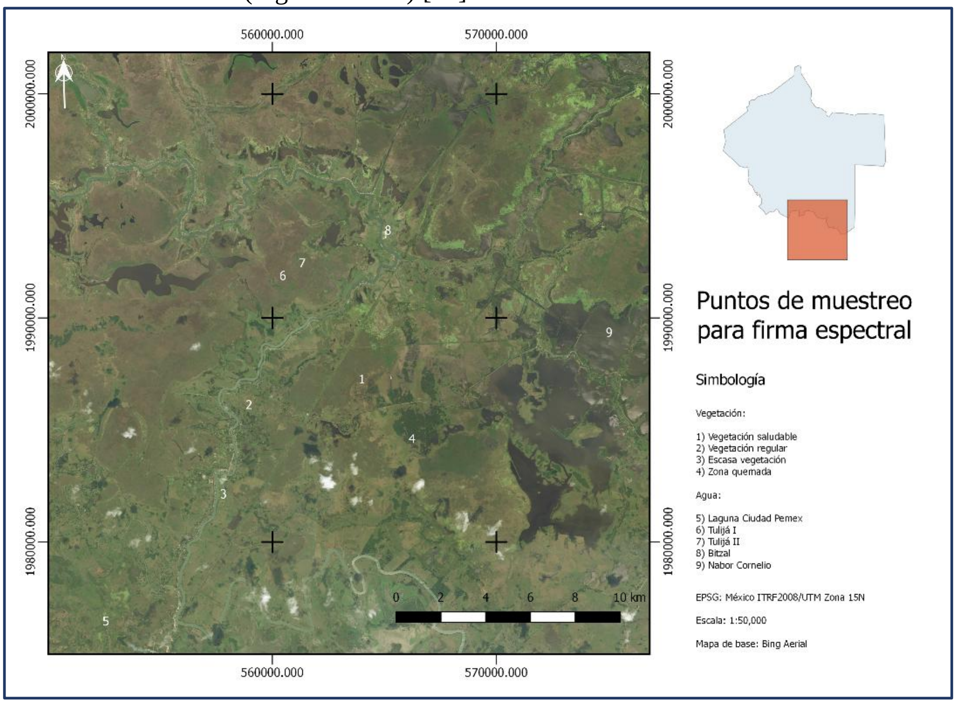

Figure 10: Spatial location of the sections chosen to obtain the spectral signatures, based on the results of vegetation and water parameters [4].

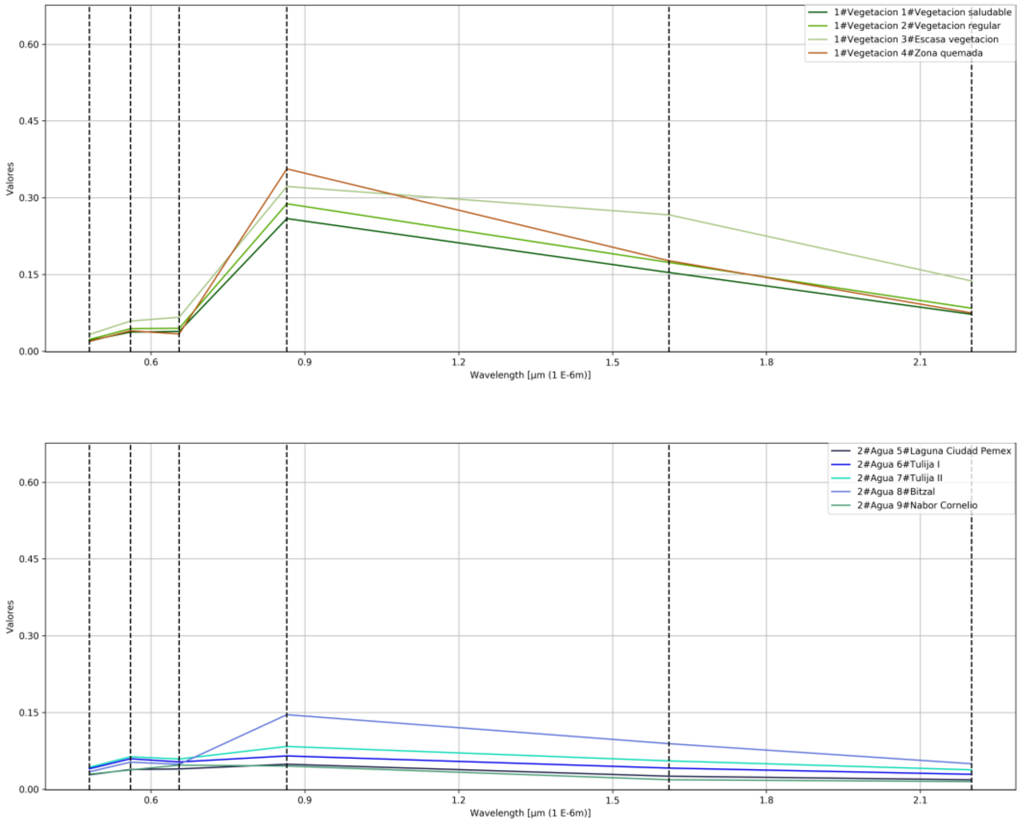

Figure 11: Record of spectral signatures of vegetation and water for the month of April (04/04/2018) [10].

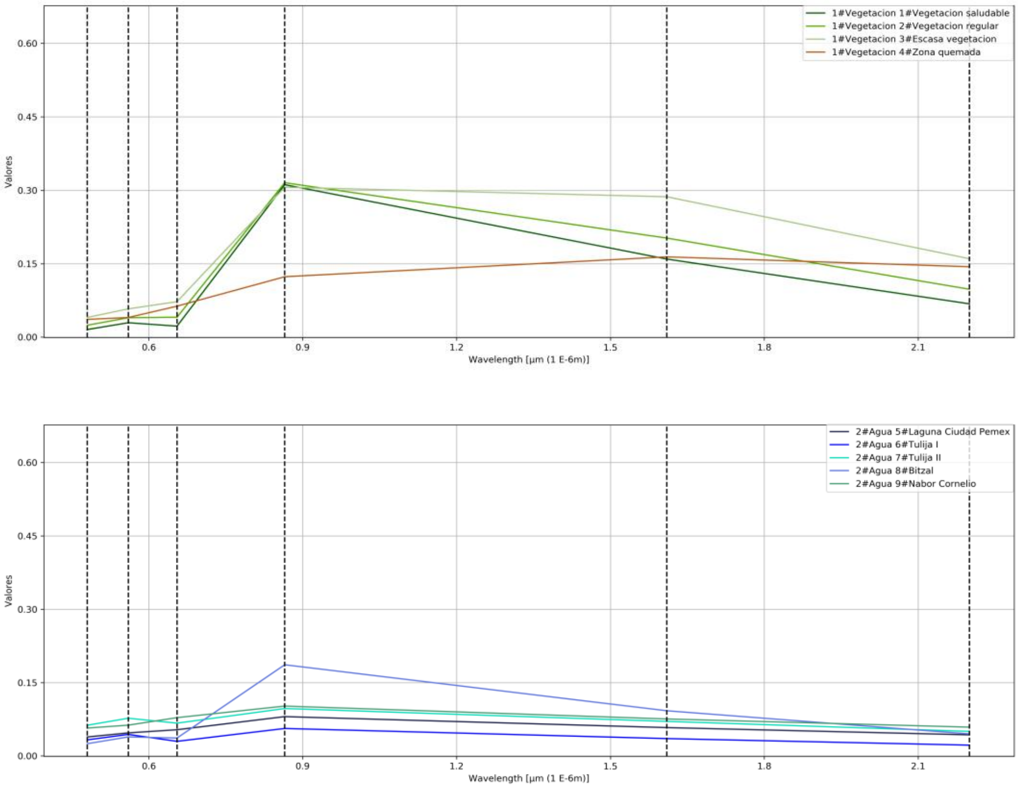

Figure 12: Record of spectral signatures of vegetation and water for the month of July (25/07/2018) [10].

In the case of vegetation, the primary factors that modify the spectral signature consist of the chlorophyll content and the percentage of humidity. For a vegetation in good condition low values are presented in the visible spectrum, while in the near infrared, the highest reflectance values are obtained and in the short-wave infrared, it decreases slightly. As the reflectance values decrease in the near infrared spectrum and increase in the shortwave visible and infrared spectra, the vegetation is said to be diseased and dry, depending on the topography and the type of vegetation. For this case, sections of pastures, popales and swamp trees are presented [2].

The reflective properties of water lie in the analysis of the visible spectrum, in such a way that in this range they have the highest values, although they are slightly lower than those found in healthy vegetation. As it moves in the infrared, the reflectance values decrease until reaching an approximate to zero. Therefore, it is easy to identify variations in water due to increases in reflectance values in any spectrum. For this study, it can be observed that the water presents a superficial agent in the five cases, in such a way that it presents a behavior similar to that of the sparse vegetation, both in the month of April and in the month of July. However, the great difference between the reflectance values for the Tulijá and Bitzal rivers, which presented considerable variations with the application of the above parameters, is noted. The comparisons between the parameters calculated for the satellite images and the analysis of the spectral signatures of the water bodies coincide in the increase of the vegetal activity in the surface, information which is also mentioned in the studies carried out in the field [1, 2]

VI. Conclusion

It is shown that the application of remote sensing tools is adequate for the monitoring of environmental contingencies, in particular the application of Landsat 8 satellite images [3]. By evaluating the parameters used in the study and the spectral signatures in QGIS, it was possible to determine qualitatively the presence of vegetation on the surface of the water bodies [4, 9, 10], in the same way, it was possible to verify that the Existing meteorological conditions during the study interval, coincide with the results reported to date [1, 2]. The continuous temporal update of Landsat 8 images allows monitoring to locate the possible causes of the event, and its correlation with field studies can speed up and improve the proposals of this study. However, the quality of the results should be sought based on the resolution and the percentage of clouds present in the satellite image because the information of the earth's surface can be affected by the radiometric properties of the clouds [17].

The results were verified with the information by the authorities of water and the environment, coinciding in that such deaths of manatees, are presumably due to the presence of cyanobacteria, given the way of feeding of the manatees, the historical route followed by the localizedcarcasses and the location of the wáter bodies that present the increase of algae.

Regarding the environmental contingency, it is suggested that the involved researchers take into account the advantages of this type of tool to improve the monitoring of water bodies in Tabasco, especially those in which wastewater of urban origin is discharged, and of irrigation that can carry fertilizers, pesticides and cattle excreta. Also monitor the water quality of those bodies that are used for human consumption, such as the Grijalva and Usumacinta rivers. Similarly, it is proposed to improve the monitoring of the dams that supply water to the state, such as the Netzahualcoyotl and Manuel Moreno Torres dams in Chiapas, since this type of reservoir is very susceptible to the flowering of algae and cyanobacteria [13, 15].

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