Modeling of Physico-Chemical and Biological Parameters of Pao Cachinche Water Reservoir, Venezuela, using the Surface Reflectance from Landsat Satellite Images

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Abstract

In this paper, it is proposed multivariable linear models to estimate the physico-chemical and biological parameters of pao cachinche water reservoir using the surface reflectance from landsat satellite images. Eight parameters are included: 1) Total Phosphorus, 2) Total Nitrogen, 3) Plankton, 4) BOD, 5) COD, 6) Total Coliforms, 7) Electrical Conductivity and 8) pH. The results indicate that the adjustment between the water quality characteristics and the surface reflectance extracted from Landsat satellite images are successful due to the R-Squared statistic indicates that the models as fitted explain between 70.18 and 75.18% of the variability in the physico-chemical and biological parameters. It has been found by each model that only one spectral band might be removed because of the coefficient associated to the recorded reflectances in this band has a low significant influence on the result of the physico-chemical and biological parameters modeling

Keywords: *Water Quality, Physico-Chemical Parameters, Linear Modeling*

INTRODUCTION

The modeling of the physico-chemical and biological parameters of pao cachinche water reservoir using the surface reflectance from landsat satellite images is an attempt by minimizing the investment of economical resources for making the field and laboratory work correspoding to collect the water samples, to make monthly monitoring of these control variables, and to spend in laboratory materials such as chemical reagents likewise working hours of technical personnel for obtaining results that allow take operational decisions to improve the water quality provided by the water sources to human consumption, agricultural activities and flood control as it is represented by the water reservoirs. The Pao Cachinche water reservoir is one of the most important hydraulic work in Venezuela since this water reservoir provides the water for human consumption of a population near four million of inhabitants located in three states of the country. Bonasea et al., (2015) uses Landsat images to predict the water quality variables suchs as Chlorophyll-a concentration and Secchivdisk transparency in the Tercero river reservoir located in Argentina applying a structure of linear mixed model, finding that it is posible to obtain accuracy results to estimate these variables from the surface reflectances and temperatures. The main purpose of this paper is to model the physico-chemical and biological parameters of pao cachinche water reservoir using the surface reflectance from landsat satellite images.

STUDY SITE

The study site is the Pao Cachinche water reservoir located in the Carabobo State at the north region of Venezuela in the following geographic coordinates (Figure 1): N09°52'30", N09°56'30", W68°09'30" and W68°05'30". The Pao Cachinche water reservoir is the source of water supply for human consumption of three

states identified as Carabobo, Aragua and Cojedes with a population according to the National Institute of Statistical (2011) of 2,245,744 inhabitants, 1,630,308 inhabitants and 321,165 inhabitants, respectively. The water reservoir has operated from 1973 to the present. The total volume is 179 million of cubic meter. The flooded area is 16.18 km^2. The water reservoir is fed by five rivers (Figure 1): 1) Paito river, 2) Chirgua river, 3) Pira Pira river, 4) Paya river and 5) San Pedro River. Four monitoring stations of physico-chemical and biological parameters are identified in Figure 1 as A (W68°08'42.97", N09°55'4.37"), B (W68°08'0.072", N09°58'58.49"), C (W68°06'54.18", N09°53'15.48"), and D (W68°07'46.15", N09°52'32.18"), whose samples are processed in laboratory for determining the following eight control varibales: 1) Total Phophorus, 2) Total Nitrogen, 3) Plankton, 4) Biodegradable Oxygen Demand (BOD), 5) Chemical Oxygen Demand (COD), 6) Total Coliforms, 7) Electrical Conductivity and 8) pH. The monitoring and determining activities of physico-chemical and biological parameters are developed by the Hydrological Company identified as "Hidrologica del Centro C.A.". The

database covers the following two periods: 1996-2016, for this period, the Total Nitrogen and Total Phosphorus were measured. The second period covers from 2007 to 2016, for this period, the eigth parameters mentioned before were measured. Marquez et al., (2018) find that the water quality changes in the Pao Cachinhe water reservoir in terms of the presence of only sediments, a mixture of sediments and algae; coverage from water to vegetation can be estimated from the reflectance in the near infrared region; reporting that the surface reflectance associated to the concentration of sediments vary between 1 and 3%; 50 to 100 mg / l; 0.5 and 1%; 50 to 250 mg / l; an increase from 1% to 40%, respectively.

MATERIALS AND METHODS

The characteristics of Landsat satellite images are shown in Table 1. The remote sensing data are images of calibrated digital numbers (Chander et al., 2009) and surface reflectance corresponding to the Landsat Collection 1 Level-1 and Landsat Collection Level-2 (USGS, 2018a; USGS, 2018b), respectively, were downloaded from the following web site: https://earthexplorer.usgs.gov/.
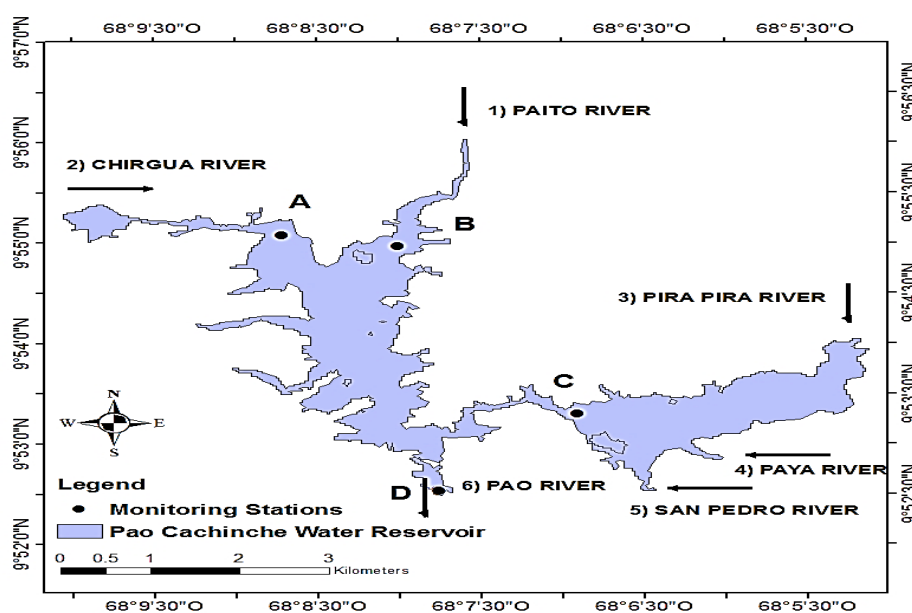

Fig: 1. *Location of the Pao Cachinche water reservoir, Venezuela*

Table: 1. Characteristics of Landsat satellite images

N°	1	2	3	4	5	6	7
1	LT50050531996299XXX02	1996-10-25	14:12:26.12Z	18.00	9	124.94450537	51.52871601
2	LT50050531997125AAA02	1997-05-05	14:20:38.53Z	50.00	9	75.28557916	57.71333274
3	LT50050531998032CPE00	1998-02-01	14:28:28.61Z	33.00	9	127.94531961	46.11991603
4	LT50050531999019CPE00	1999-01-19	14:31:37.37Z	23.00	9	132.94664692	45.23014868
5	LT50050532000182XXX02	2000-06-30	14:45:26.01Z	7.00	9	137.52485114	47.22916723
6	LT50050532001008AAA02	2001-01-08	14:32:22.57Z	10.00	9	135.84219087	44.77755780
7	LE70050532002051AGS00	2002-02-20	14:41:26.14Z	22.00	9	122.73905080	52.13911206
8	LE70050532003022PFS00	2003-01-22	14:41:05.97Z	10.00	9	134.07217263	47.15930857
9	LE70050532004073ASN01	2004-03-13	14:41:51.49Z	26.00	9	111.11140194	57.01474688
10	LE70050532005075ASN02	2005-03-16	14:42:18.932Z	9.00	9	109.44234858	57.70389275
11	LE70050532006350EDC00	2006-12-16	14:42:47.378Z	22.00	9	142.06462940	47.39871653
12	LE70050532007033EDC00	2007-02-02	14:42:57.770Z	3.00	3	130.64547180	48.91437918
13	LE70050532008020EDC00	2008-01-20	14:42:57.702Z	20.00	9	135.08382735	47.19709575
14	LE70050532009102ASN00	2009-04-12	14:42:56.648Z	45.00	9	90.15646316	62.27902760
15	LE70050532010073EDC00	2010-03-14	14:44:44.519Z	15.00	9	111.34110186	57.80472117
16	LT50050532011100CHM00	2011-04-10	14:42:23.804Z	52.00	9	92.02577526	61.92475822
17	LE70050532012047EDC00	2012-02-16	14:46:44.903Z	8.00	9	125.97656640	52.29227579
18	LE70050532013033EDC00	2013-02-02	14:48:49.631Z	11.00	9	131.92278103	50.15978418
19	LC80050532014076LGN01	2014-03-17	14:53:05.124Z	16.84	9	111.02915450	60.45368381
20	LO80050532015063LGN00	2015-03-04	14:52:20.814Z	13.13	9	119.09567247	57.19634293
21	LC80050532016018LGN00	2016-01-18	14:52:41.936Z	6.09	9	138.18721946	48.77317194

1) the scene identification code, 2) the acquisition date, 3) the scene center time, 4) the cloud coverage, 5) the image quality, 6) the angle of solar azimuth and 7) the angle of solar zenith.

The selected satellites are the group of Landsat satellites; using images from three of these: 1) Landsat 5 (L5), 2) Landsat 7 (L7) and 3) Landsat 8 (L8) (Figure 2); whose sensors are: L5: Thematic Mapper (TM), L7: Enhanced Thematic Mapper (ETM) and L8: Operational Land Imager (OLI); respectively. Twenty one Landsat images have been acquired corresponding to a single scene; where the Pao Cachinche watrer reservoir is contained. The scene is identified under the world reference system according to the following raw and path: 005, 053, respectively. The temporal series of images from the three Landsat satellites grouped according to the type of Landsat Satellite are: 1) L5TM (1996, 1997, 1998, 1999, 2000, 2001, 2011), 2) L7ETM (2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2012, 2013) and 4) L8OLI (2014, 2015 and 2016). In most of the images, the variable is surface reflectance excepting in the images corresponding to L7ETM, only available to download from Landsat Collection 1 Level-1. On these images were applied corrections of type: radiometric, atmospheric and topographic. The criteria for selecting of the TS of Landsat images are: 1) the same season of each year, and 2) the lowest coverage of: clouds, aerosols and haze.

The image characteristics acquired according to each satellite are identified as follows (Table 1): a) the scene identification code, b) the acquisition date, c) the scene center time, d) the cloud coverage, e) the image quality, f) the angle of solar azimuth and g) the angle of solar zenith. In the Table 1, it is observed the following characteristics of each image: LT50050531996299XXX02; 1996-10-25; 14:12:26.1290060Z; 18.00%; 9; 124.94450537°; and 51.52871601°. The parameters of map projection according to the United State Geological Survey (USGS) are: a) Projection: Universal Transverse Mercator (UTM), b) Datum: World Geodetic System 1984 (WGS84), c) UTM Zone: 19 N and e) Resample Method: Cubic Convolution.

In case of the images obtained from the Landsat Collection 1 Level-1, which are the based on the calibrated digital number (Q_{cal}), this variable is transformed to radiance (L_λ) and then converted to top of atmosphere reflectance (ρ_λ). The equation applied is the following (Chander et al., 2010):

$$\rho_\lambda = \frac{\pi.L_\lambda.d^2}{ESUN_\lambda.cos\theta_s} \quad (1)$$

Where ρ_λ= Planetary TOA reflectance [unitless], π= Mathematical constant equal to ~3.14159 [unitless], L_λ= Spectral radiance at the sensor's aperture [W/(m^2 sr μm)], d= Earth–Sun distance [astronomical units], ESUNλ= Mean exoatmospheric solar irradiance [W/(m^2 μm)] and θ_s= Solar zenith angle [degrees].

The modeling of the physico-chemical paramters as a function of the reflectances in each spectral band is achieved by applying the multiple regression procedure designed to construct a statistical model describing the impact of a two or more quantitative factors X on a dependent variable Y (Box, 1994). The general form of the model is

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \ldots + \beta_kX_k \quad (2)$$

where k is the number of independent variables. In this case, Y is the physico-chemical parameters and X is represented by the recorded reflectance in each spectral band of Landsat Satellite in the solar reflective region, as a sample, the spectral bands included in Landsat 5 TM vary in the solar and thermal reflective regions as follows: spectral band 1 (b1): 0.452-0.518 μm, spectral band 2 (b2): 0.528-0.609 μm, spectral band 3 (b3): 0.626-0.693 μm, spectral band 4 (b4): 0.776-0.904 μm, spectral band 5 (b5): 1.567-1.784 μm, spectral band 6 (b6): 10.45-12.42 μm, spectral band 7 (b7): 2.097-2.349 μm. The statistics for the fitted model, include the following five: 1) R-squared , 2) Adjusted R-Squared, 3) Standard Error of Estimated, 4) Mean absolute error and 5) Durbin-Watson Statistic.1) *R-squared:* represents the percentage of the variability in Y which has been explained by the fitted regression model, ranging from 0% to 100%. For the sample data, the regression has accounted for about 72.7% of the variability in the miles per gallon. The remaining 27.3% is attributable to deviations from the model, which may be due to other factors, to measurement error, or to a failure of the current model to fit the data adequately. 2) Adjusted R-Squared − the R-squared statistic, adjusted for the number of coefficients in the model. This value is often used to compare models with different numbers of coefficients. 3) Standard Error of Estimated − the estimated standard deviation of the residuals (the deviations around the model). This value is used to create prediction limits for new observations. 4) Mean Absolute Error − the average absolute value of the residuals, and 5) Durbin-Watson Statistic − a measure of serial correlation in the residuals. If the residuals vary randomly, this value should be close to 2. A small P-value indicates a non-random pattern in the residuals. For data recorded over time, a small P-value could indicate that some trend over time has not been accounted for. In the current example, the P-value is greater than 0.05, so there is not a significant correlation at the 5% significance level.
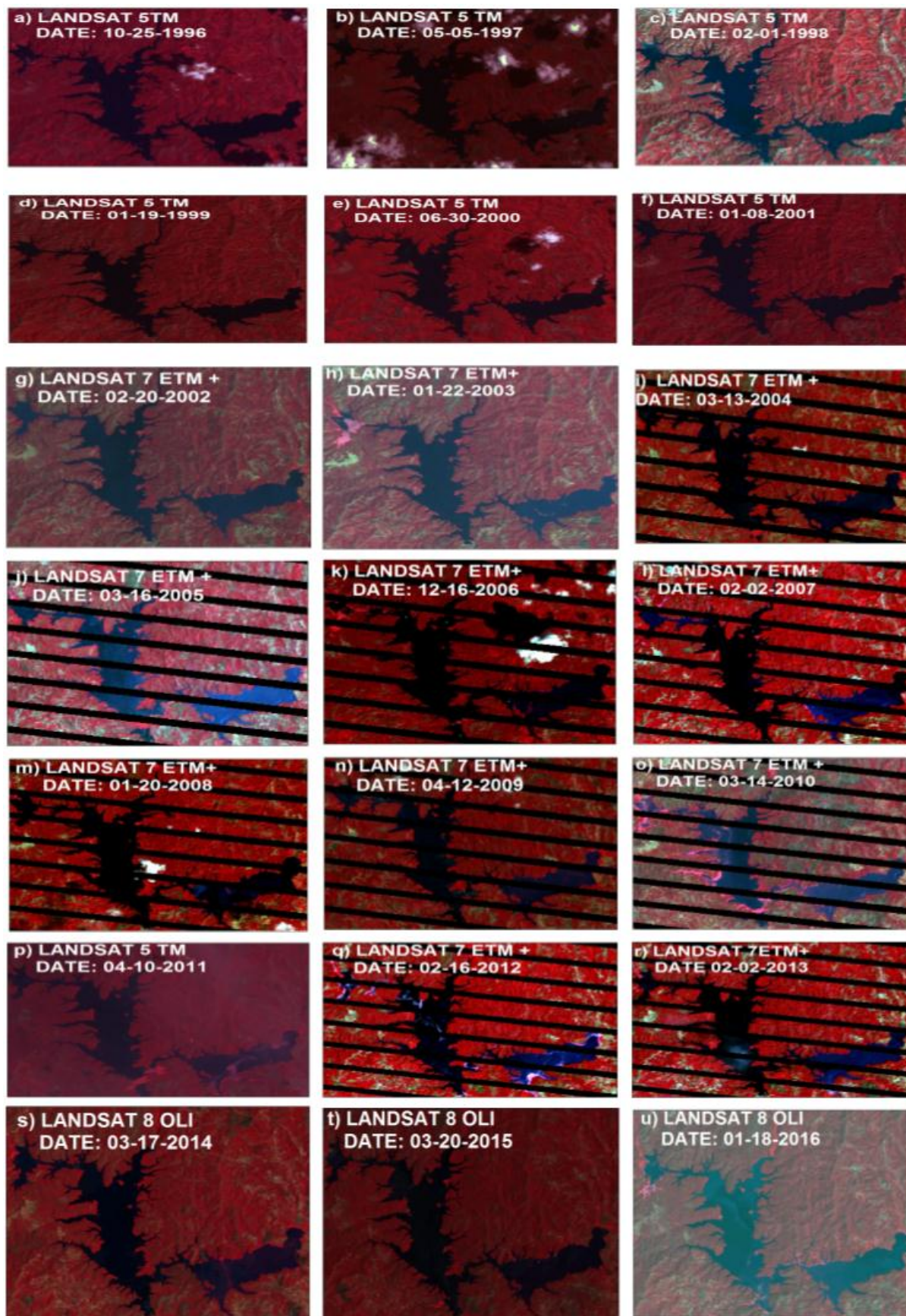
Fig: 2. *Landsat images used to extract the reflectance variable from the Pao Cachinche water reservoir, Venezuela*

RESULTS

The results of physico-chemical and biological parameters measured in the Pao Cachinche water reservoir are shown in Figure 3, where it is observed for the eigth physico-chemical parameters the following statisticals for each year:

Total Phosphorus (**Figure 3a**): **1996:** Mean: 0.22 mg/l, Standard deviation: 0.25, Variation coefficient: 111.93%, Minimum: 0.02 mg/l, Maximum: 0.56 mg/l. **1997:** Mean: 0.32 mg/l, Standard deviation: 0.46, Variation coefficient: 142%, Minimum: 0.01, Maximum: 1.01. **1998**: Mean: 0.32, Standard deviation: 0.46, Variation coefficient: 142%, Minimum: 0.01 mg/l, Maximum: 1.0 mg/l. **1999:** Mean: 0.13, Standard deviation: 0.69, Variation coefficient: 53%, Minimum: 0.07, Maximum: 0.23. **2000:** Mean: 0.11 mg/l, Standard deviation: 0.06, Variation coefficient: 63%, Minimum: 0.04, Maximum: 0.17. **2001:** Mean: 0.09 mg/l, Standard deviation: 0.06, Variation coefficient: 28%, Minimum: 0.05, Maximum: 0.1. **2002:** Mean: 0.065 mg/l, Standard deviation: 0.029, Variation coefficient: 44%, Minimum: 0.03, Maximum: 0.1. **2003:** Mean: 0.075 mg/l, Standard deviation: 0.038, Variation coefficient: 51%, Minimum: 0.04, Maximum: 0.13. **2004:** Mean: 0.075 mg/l, Standard deviation: 0.067, Variation coefficient: 62%, Minimum: 0.04, Maximum: 0.17. **2005:** Mean: 0.23 mg/l, Standard deviation: 0.21, Variation coefficient: 90%, Minimum: 0.01, Maximum: 0.5. **2006:** Mean: 0.23 mg/l, Standard deviation: 0.21, Variation coefficient: 93%, Minimum: 0.01, Maximum: 0.5. **2007:** Mean: 0.77 mg/l, Standard deviation: 0.27, Variation coefficient: 35%, Minimum: 0.44, Maximum: 1.11. **2008:** Mean: 0.74 mg/l, Standard deviation: 0.042, Variation coefficient: 5.6%, Minimum: 0.7, Maximum: 0.8. **2009:** Mean: 1.11 mg/l, Standard deviation: 0.26, Variation coefficient: 23.21%, Minimum: 0.87, Maximum: 1.45. **2010:** Mean: 0.74 mg/l, Standard deviation: 0.26, Variation coefficient: 35.76%, Minimum: 0.43, Maximum: 1.08. **2011:** Mean: 0.43 mg/l, Standard deviation: 0.05, Variation coefficient: 13.42%, Minimum: 0.36, Maximum: 0.5. **2012:** Mean: 0.57 mg/l, Standard deviation: 0.10, Variation coefficient: 17.65%, Minimum: 0.46, Maximum: 0.67. **2013:** Mean: 0.46 mg/l, Standard deviation: 0.08, Variation coefficient: 18.71%, Minimum: 0.36, Maximum: 0.56. **2014:** Mean: 0.84 mg/l, Standard deviation: 0.08, Variation coefficient: 9.54%, Minimum: 0.73, Maximum: 0.91. **2015:** Mean: 0.91 mg/l, Standard deviation: 0.15, Variation coefficient: 16.84%, Minimum: 0.71, Maximum: 1.07. **2016:** Mean: 0.84 mg/l, Standard deviation: 0.05, Variation coefficient: 6.59%, Minimum: 0.79, Maximum: 0.92. In general, based on 84 samples, the averaged annual results are the following: Mean: 0.44 mg/l, Standard deviation: 0.37, Variation coefficient: 83.32%, Minimum: 0.01, Maximum: 1.45.

Total Nitrogen (**Figure 3b**): **1996** Mean: 1.34 mg/l, Standard deviation: 0.93, Variation coefficient: 69.42%, Minimum: 0.28 mg/l, Maximum: 2.52 mg/l. **1997:** Mean: 1.51 mg/l, Standard deviation: 0.86, Variation coefficient: 56.89%, Minimum: 0.27, Maximum: 2.24. **1998**: Mean: 1.09, Standard deviation: 0.95, Variation coefficient: 87.05%, Minimum: 0.34 mg/l, Maximum: 2.48 mg/l. **1999:** Mean: 1.24, Standard deviation: 0.70, Variation coefficient: 56.24%, Minimum: 0.64, Maximum: 2.24. **2000:** Mean: 0.56 mg/l, Standard deviation: 0.15, Variation coefficient: 28%, Minimum: 0.42, Maximum: 0.78. **2001:** Mean: 0.48 mg/l, Standard deviation: 0.14, Variation

coefficient: 30%, Minimum: 0.32, Maximum: 0.66. **2002:** Mean: 1.06 mg/l, Standard deviation: 0.41, Variation coefficient: 38%, Minimum: 0.63, Maximum: 1.54. **2003:** Mean: 0.85 mg/l, Standard deviation: 0.24, Variation coefficient: 28.36%, Minimum: 0.56, Maximum: 1.12. **2004:** Mean: 0.56 mg/l, Standard deviation: 0.15, Variation coefficient: 28%, Minimum: 0.42, Maximum: 0.78. **2005:** Mean: 2.45 mg/l, Standard deviation: 1.45, Variation coefficient: 59%, Minimum: 0.56, Maximum: 4.06. **2006:** Mean: 2.45 mg/l, Standard deviation: 1.44, Variation coefficient: 59%, Minimum: 0.56, Maximum: 4.06. **2007:** Mean: 1.88 mg/l, Standard deviation: 1.10, Variation coefficient: 58.37%, Minimum: 0.67, Maximum: 2.85. **2008:** Mean: 1.76 mg/l, Standard deviation: 1.39, Variation coefficient: 79.39%, Minimum: 0.19, Maximum: 3.28. **2009:** Mean: 2.04 mg/l, Standard deviation: 2.11, Variation coefficient: 104%, Minimum: 0.16, Maximum: 4.04. **2010:** Mean: 3.35 mg/l, Standard deviation: 0.49, Variation coefficient: 15%, Minimum: 2.76, Maximum: 3.95. **2011:** Mean: 3.15 mg/l, Standard deviation: 0.57, Variation coefficient: 18.29%, Minimum: 2.56, Maximum: 3.92. **2012:** Mean: 4.2 mg/l, Standard deviation: 0.86, Variation coefficient: 19.65%, Minimum: 2.99, Maximum: 4.85. **2013:** Mean: 3.5 mg/l, Standard deviation: 0.78, Variation coefficient: 22.3%, Minimum: 2.56, Maximum: 4.33. **2014:** Mean: 4.32 mg/l, Standard deviation: 1.10, Variation coefficient: 25.56%, Minimum: 2.99, Maximum: 5.69. **2015:** Mean: 4.62 mg/l, Standard deviation: 0.67, Variation coefficient: 14.51%, Minimum: 3.75, Maximum: 5.24. **2016:** Mean: 6.12 mg/l, Standard deviation: 0.94, Variation coefficient: 15.38%, Minimum: 5.36,

Maximum: 7.45. In general, based on 84 samples, the averaged annual results are the following: Mean: 2.31 mg/l, Standard deviation: 1.74, Variation coefficient: 75.52%, Minimum: 0.16, Maximum: 7.45.

Plankton (Figure 3c): based on 40 samples, the averaged annual results are the following: Mean: 29629.2 org/ml, Standard deviation: 13195.7, Variation coefficient: 44.536%, Minimum: 13473.3, Maximum: 72609.5.

Biodegradable Oxygen Demand (Figure 3d): based on 40 samples, the averaged annual results are the following: Mean: 9.24 mg/l, Standard deviation: 10.46, Variation coefficient: 113.16%, Minimum: 2.2, Maximum: 72.04.

Chemical Oxyygen Demand (Figure 3e): based on 40 samples, the averaged annual results are the following: Mean: 40.22 mg/l, Standard deviation: 14.01, Variation coefficient: 32.85%, Minimum: 10.0, Maximum: 70.94.

Total Coliforms (Figure 3f): based on 40 samples, the averaged annual results are the following: Mean: 6373.75 MPN/ml, Standard deviation: 7180, Variation coefficient: 112.65%, Minimum: 170 MPN/ml, Maximum: 16000 MPN/ml.

Electrical Conductivity (Figure 3g): based on 40 samples, the averaged annual results are the following: Mean: 430.52 uS/cm, Standard deviation: 64.5, Variation coefficient: 14.98%, Minimum: 359.7 mg/l, Maximum: 598 mg/l.

The results of the cofficients of models of physico-chemical and biological parameters measured in the Pao Cachinche water reservoir are shown in Table 2.
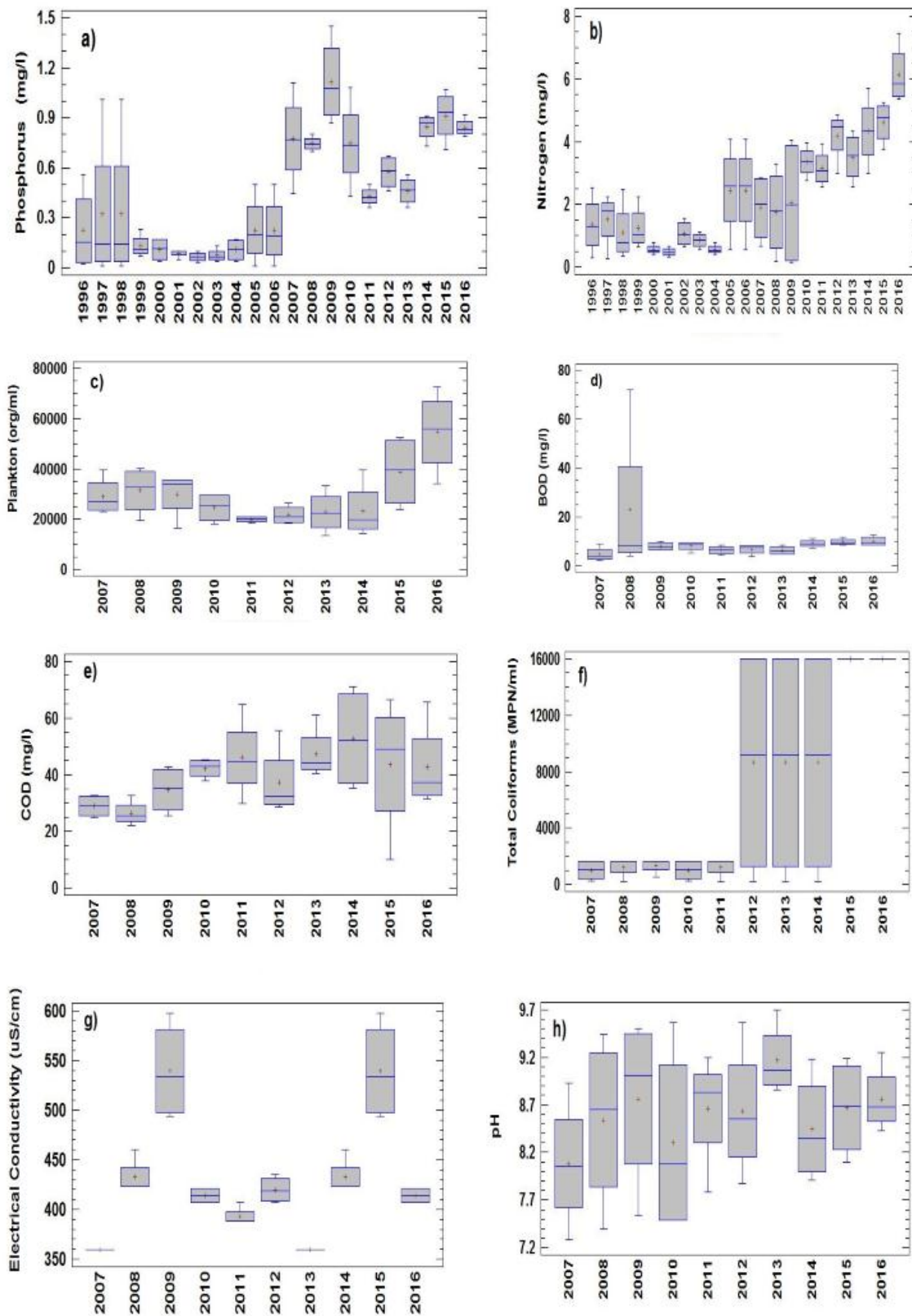
Fig: 3. *Physico-chemical and biological parameters measured in the Pao Cachinche water reservoir, Venezuela*

The coefficients of models are associated to the reflectance variable measured by the Landsat satellite in seven spectral bands in the visible and infrared regions. The averaged coefficients obtained according to the physico-chemical and biological parameters are described as follows:

Total Phosphorus **(Table 2):** constant: 0.13, coefficient of reflectance in spectral band 1 ($\rho 1$): -0.08, coefficient of reflectance in spectral band 2 ($\rho 2$): -0.07, coefficient of reflectance in spectral band 3 ($\rho 3$): 0.18, coefficient of reflectance in spectral band 4 ($\rho 4$): 0.02, coefficient of reflectance in spectral band 5 ($\rho 5$): -0.03, coefficient of reflectance in spectral band 7 ($\rho 7$): 0.01. The equation based on the averaged coefficients is expressed as follows:

Total Phosphorus = 0.126205 - 0.0840584*$\rho 1$ - 0.0656771*$\rho 2$ + 0.178178*$\rho 3$ + 0.0212348*$\rho 4$ - 0.0319347*$\rho 5$ + 0.0139069*$\rho 7$ (3)

Total Nitrogen (Table 2): constant: 1.01, coefficient of reflectance in spectral band 1 ($\rho 1$): 0.14, coefficient of reflectance in spectral band 2 ($\rho 2$): -0.44, coefficient of reflectance in spectral band 3 ($\rho 3$): 0.83, coefficient of reflectance in spectral band 4 ($\rho 4$): -0.19, coefficient of reflectance in spectral band 5 ($\rho 5$): 0.051, coefficient of reflectance in spectral band 7 ($\rho 7$): 0.01. The equation based on the averaged coefficients is expressed as follows:

Total Nitrogen = 1.0127 + 0.138257*$\rho 1$ - 0.438569*$\rho 2$ + 0.829679*$\rho 3$ - 0.194923*$\rho 4$ + 0.0506535*$\rho 5$ + 0.01*$\rho 7$ (4).

Planckton (Table 2): constant: 34425.4, coefficient of reflectance in spectral band 1 ($\rho 1$): - 2712.72, coefficient of reflectance in spectral band 2 ($\rho 2$): - 304.766, coefficient of reflectance in spectral band 3 ($\rho 3$): 4365.72, coefficient of reflectance in spectral band 4 ($\rho 4$): 1201.86, coefficient of reflectance in spectral band 5 ($\rho 5$): - 4232.85, coefficient of reflectance in spectral band 7 ($\rho 7$): - 1886.89. The equation based on the averaged coefficients is indicated as follows:

Plankton = 34425.4 - 2712.72*$\rho 1$ - 304.766*$\rho 2$ + 4365.72*$\rho 3$ + 1201.86*$\rho 4$ - 4232.85*$\rho 5$ - 1886.89*$\rho 7$ (5).

BOD (Table 2): constant: 5.55657, coefficient of reflectance in spectral band 1 ($\rho 1$): - 0.976342, coefficient of reflectance in spectral band 2 ($\rho 2$): 0.520194, coefficient of reflectance in spectral band 3 ($\rho 3$): 0.831089, coefficient of reflectance in spectral band 4 ($\rho 4$): - 0.951038, coefficient of reflectance in spectral band 5 ($\rho 5$): 0.850037, coefficient of reflectance in spectral band 7 ($\rho 7$): 0.341962. The equation based on the averaged coefficients is indicated as follows:

BOD = 5.55657 - 0.976342*$\rho 1$ + 0.520194*$\rho 2$ + 0.831089*$\rho 3$ - 0.951038*$\rho 4$ + 0.850037*$\rho 5$ + 0.341962*$\rho 7$ (6).

COD (Table 2): constant: 37.2517, coefficient of reflectance in spectral band 1 ($\rho 1$): 3.19917, coefficient of reflectance in spectral band 2 ($\rho 2$): 3.265, coefficient of reflectance in spectral band 3 ($\rho 3$): - 4.79375, coefficient of reflectance in spectral band 4 ($\rho 4$): 2.47527, coefficient of reflectance in spectral band 5 ($\rho 5$): 2.68216, coefficient of reflectance in spectral band 7 ($\rho 7$): - 11.214. The equation based on the averaged coefficients is indicated as follows:

COD = 37.2517 + 3.19917*$\rho 1$ + 3.265*$\rho 2$ - 4.79375*$\rho 3$ + 2.47527*$\rho 4$ + 2.68216*$\rho 5$ - 11.214*$\rho 7$ (7).

Table: 2. *Coefficients of models of physico-chemical and biological parameters measured in the Pao Cachinche water reservoir*

N°	Dependent Variable		Constant			ρ1			ρ2		
			Est.	LL	UL	Est.	LL	UL	Est.	LL	UL
1	Total Phosphorus	mg/l	0.13	0.04	0.21	-0.08	-0.14	-0.03	-0.07	-0.10	-0.03
2	Total Nitrogen	mg/l	1.01	0.58	1.44	0.14	-0.08	0.36	-0.44	-0.61	-0.27
3	Plankton	org/ml	34425.40	29260.20	39590.50	-2712.72	-4666.99	-758.46	-304.77	-1937.55	1328.02
4	BOD	mg/l	5.56	4.56	6.55	-0.98	-1.59	-0.36	0.52	0.06	0.98
5	COD	mg/l	37.25	32.88	41.62	3.20	1.44	4.96	3.27	1.49	5.04
6	Total Coliforms	MPN	5281.29	2540.95	8021.62	-1015.24	-2161.56	131.08	-1964.24	-2908.25	-1020.22
7	Electrical Conductivity	uS/cm	422.02	402.73	441.30	-5.96	-12.46	0.54	-10.49	-16.98	-4.00
8	pH		8.73	8.47	8.98	-0.29	-0.40	-0.17	0.25	0.17	0.34

ρ: Reflectance, Est: Estimate, LL: Lower Limit, UL: Upper Limit

Continuation Table 2

Coefficients of models of physico-chemical and biological parameters measured in the Pao Cachinche water reservoir

N°	Dependent Variable		ρ3			ρ4		
			Est.	LL	UL	Est.	LL	UL
1	Total Phosphorus	mg/l	0.18	0.14	0.21	0.02	-0.01	0.05
2	Total Nitrogen	mg/l	0.83	0.64	1.02	-0.19	-0.34	-0.05
3	Plankton	org/ml	4365.72	1770.35	6961.09	1201.86	-856.46	3260.18
4	BOD	mg/l	0.83	0.48	1.18	-0.95	-1.32	-0.58
5	COD	mg/l	-4.79	-7.60	-1.99	2.48	0.70	4.25
6	Total Coliforms	MPN	3402.62	2170.40	4634.84	-34.88	-1168.87	1099.11
7	Electrical Conductivity	uS/cm	15.25	7.90	22.61	-5.58	-11.51	0.36
8	pH		-0.22	-0.32	-0.12	0.15	0.05	0.24

ρ: Reflectance, Est: Estimate, LL: Lower Limit, UL: Upper Limit

Continuation Table 2

Coefficients of models of physico-chemical and biological parameters measured in the Pao Cachinche water reservoir

N°	Dependent Variable		ρ5			ρ7		
			Est.	LL	UL	Est.	LL	UL
1	Total Phosphorus	mg/l	-0.03	-0.08	0.02	0.01	-0.05	0.08
2	Total Nitrogen	mg/l	0.05	-0.21	0.31	0.27	-0.07	0.61
3	Plankton	org/ml	-4232.85	-7027.55	-1438.16	-1886.89	-6912.75	3138.96
4	BOD	mg/l	0.85	0.33	1.37	0.34	-0.48	1.16
5	COD	mg/l	2.68	0.27	5.09	-11.21	-16.32	-6.11
6	Total Coliforms	MPN	-307.75	-1807.39	1191.89	-350.48	-2866.73	2165.77
7	Electrical Conductivity	uS/cm	-11.31	-19.41	-3.20	30.20	15.83	44.58
8	pH		0.31	0.18	0.45	-0.50	-0.70	-0.29

ρ: Reflectance, Est: Estimate, LL: Lower Limit, UL: Upper Limit

Total Coliforms (Table 2): constant: 5281.29, coefficient of reflectance in spectral band 1 (ρ1): - 1015.24, coefficient of reflectance in spectral band 2 (ρ2): - 1964.24, coefficient of reflectance in spectral band 3 (ρ3): 3402.62, coefficient of reflectance in spectral band 4 (ρ4): - 34.8813, coefficient of reflectance in spectral band 5 (ρ5): - 307.749, coefficient of reflectance in spectral band 7 (ρ7): - 350.481. The equation based on the averaged coefficients is indicated as follows:

Total Coliforms = 5281.29 - 1015.24*ρ1 - 1964.24*ρ2 + 3402.62*ρ3 - 34.8813*ρ4 - 307.749*ρ5 - 350.481*ρ7 (8).

Electrical Conductivity (Table 2): constant: 422.015, coefficient of reflectance in spectral band 1 (ρ1): - 5.96064, coefficient of reflectance in spectral band 2 (ρ2): - 10.4939, coefficient of reflectance in spectral band 3 (ρ3): 15.251, coefficient of reflectance in spectral band 4 (ρ4): - 5.57722, coefficient of reflectance in spectral band 5 (ρ5): - 11.3074, coefficient of reflectance in

spectral band 7 ($\rho7$): 30.2032. The equation based on the averaged coefficients is indicated as follows:

CE = 422.015 - 5.96064*$\rho1$ - 10.4939*$\rho2$ + 15.251*$\rho3$ - 5.57722*$\rho4$ - 11.3074*$\rho5$ + 30.2032*$\rho7$ (9).

pH (Table 2): constant: 8.72503, coefficient of reflectance in spectral band 1 ($\rho1$): **- 0.286363**, coefficient of reflectance in spectral band 2 ($\rho2$): **0.251979**, coefficient of reflectance in spectral band 3 ($\rho3$): **- 0.219012**, coefficient of reflectance in spectral band 4 ($\rho4$): **0.146623**, coefficient of reflectance in spectral band 5 ($\rho5$): **0.31438**, coefficient of reflectance in spectral band 7 ($\rho7$): **- 0.496899**. The equation based on the averaged coefficients is indicated as follows:

pH = 8.72503 - 0.286363*$\rho1$ + 0.251979*$\rho2$ - 0.219012*$\rho3$ + 0.146623*$\rho4$ + 0.31438*$\rho5$ - 0.496899*$\rho7$ (10).

The adjustment statistical parameters of models of physico-chemical and biological parameters measured in the Pao Cachinche water reservoir ae shown in Table 3 finding the following results according with each variable:

***Total Phosphorus* (Table 3):** the adjustment statistical parameters for modeling the Total Phosphorus are: R^2: Determination coefficient: 72.21%, R^2adjusted: Adjusted determination coefficient: 68.81%, SEE: Standard Error of Estimate: 0.167, MAE: Mean Absolute Error: 0.13, DW: Durbin Watson coefficient: 1.44 (P=0.0059) and F-ratio: 21.22 (P=0.0000).

Total Nitrogen (Table 3): the adjustment statistical parameters for modeling the Total Nitrogen are: R^2: 71.42%, R^2adjusted: 68.19%, SEE: 0.87, MAE: 0.72, DW: 1.66 (P=0.0453) and F-ratio: 22.08 (P=0.0000).

Planckton (Table 3): the adjustment statistical parameters for modeling the Planckton are: R^2: 72.43%, R^2adjusted: 64.91%, SEE: 6450.64, MAE: 4662.93, DW: 1.84 (P=0.1882) and F-ratio: 9.63 (P=0.0000).

BOD (Table 3): the adjustment statistical parameters for modeling the BOD are: R^2: 74.49%, R^2adjusted: 67.21%, SEE: 1.08, MAE: 0.77, DW: 2.08 (P=0.4434) and F-ratio: 10.22 (P=0.0000).

COD (Table 3): the adjustment statistical parameters for modeling the COD are: R^2: 72.05%, R^2adjusted: 63.67%, SEE: 5.38, MAE: 3.57, DW: 2.01 (P=0.3552) and F-ratio: 8.59 (P=0.0001).

Total Coliforms (Table 3): the adjustment statistical parameters for modeling the Total Coliforms are: R^2: 71.83%, R^2adjusted: 66.00%, SEE: 4145.03, MAE: 2680.85, DW: 1.50 (P=0.0235) and F-ratio: 12.33 (P=0.0000).

Electrical Conductivity (Table 3): the adjustment statistical parameters for modeling the Electrical Conductuivity are: R^2: 70.18%, R^2adjusted: 59.00%, SEE: 19.69, MAE: 14.71, DW: 2.43 (P=0.7070) and F-ratio: 6.28 (P=0.0000).

pH (Table 3): the adjustment statistical parameters for modeling the Total Coliforms are: R^2: 75.18%, R^2adjusted: 59.23%, SEE: 0.32, MAE: 0.23, DW: 2.14 (P=0.4888) and F-ratio: 12.63 (P=0.0000).

Table: 3. Adjustment statistical parameters of models of physico-chemical and biological parameters measured in the Pao Cachinche water reservoir

Dependent Variable	R^2	R^2adjusted	SEE	MAE	DW	F-ratio
Total Phosphorus	72.2078	68.8047	0.163699	0.126818	1.44595	21.22
Total Nitrogen	71.4252	68.1903	0.876892	0.724632	1.66596	22.08
Plankton	72.4282	64.9086	6450.64	4662.93	1.83899	9.63
BOD	74.4974	67.211	1.08466	0.776614	2.0832	10.22
COD	72.0531	63.669	5.38527	3.57188	2.0152	8.59
Total Coliforms	71.831	66.003	4145.03	2680.85	1.49723	12.33
Electrical Conductivity	70.187	59.0071	19.6989	14.7123	2.43366	6.28
pH	75.1871	69.232	0.318188	0.227637	2.14086	12.63

R^2: Determination coefficient, R^2adjusted: Adjusted determination coefficient, SEE: Standard Error of Estimate, MAE: Mean Absolute Error, DW: Durbin Watson coefficient
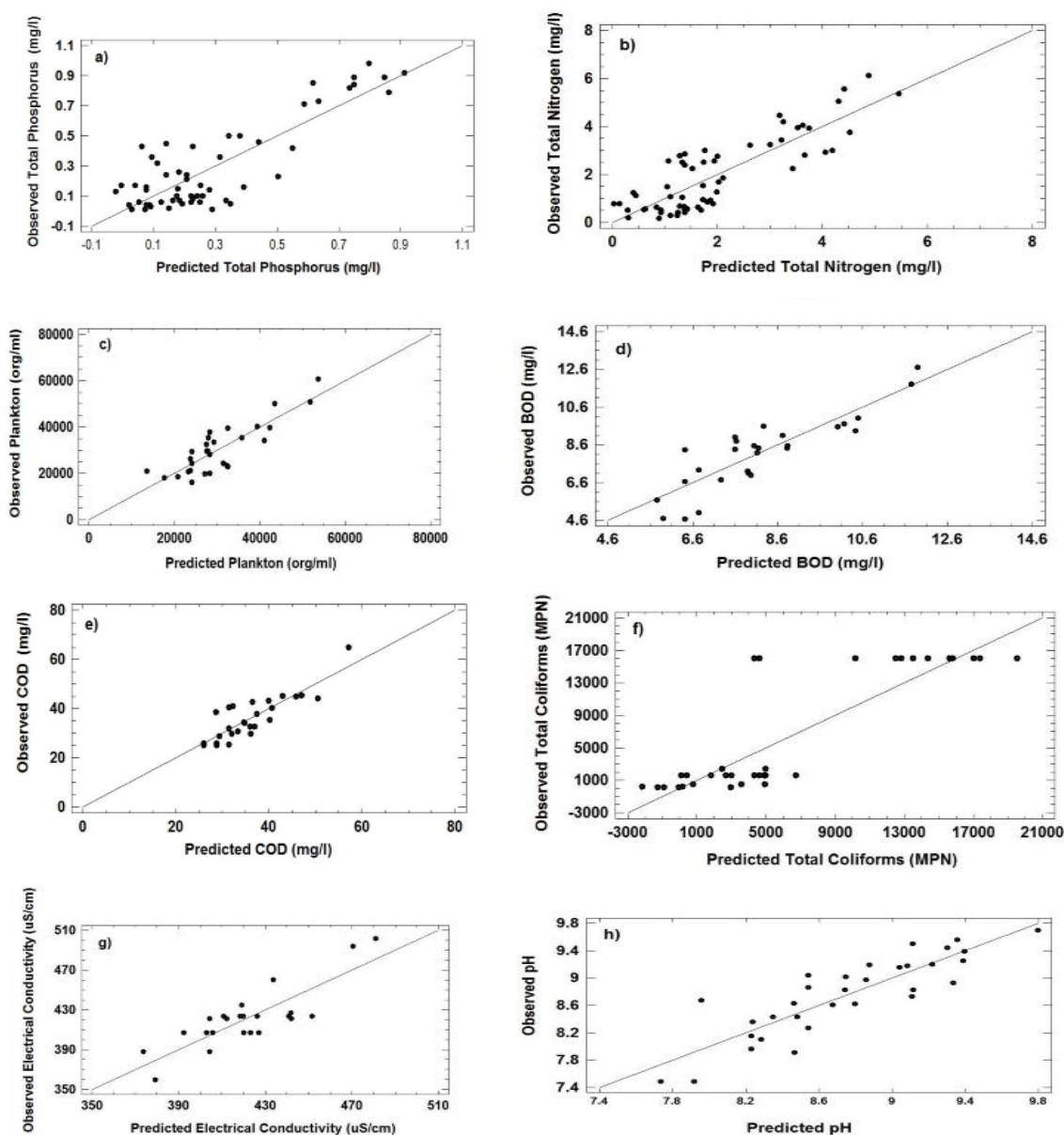

Fig: 4. Graphic of adjusted model represented by the predicted versus observed physico-chemical and biological parameters measured in the Pao Cachinche water reservoir, Venezuela

DISCUSSION OF RESULTS

The physico-chemical and biological parameters measured in the Pao Cachinche water reservoir such as Total Phosphorus (Figure 3a), Total Nitrogen (Figure 3b), Planckton (Figure 3c) and Total Coliforms (Figure 3f) show a trend to increase the values in a statistically significant magnitude in the two periods analyzed, which can be observed because the box diagrams do not match in some periods. The increase rate is estimated as follows for this parameters: 1) Total Phosphorus: 0.06 mg/l.year. The change occurs in 2009, 2) Total Nitrogen: 0.11 mg/l.year. The change occurs in 2006. 3) Plankton: 2084 org/ml.year. The change occurs in 2014. 4) The total coliforms: 2951 MPN/ml. The chage occurs in 2011. The rest of the variables such as: BOD, COD, Electrical Conductivity and pH do not vary significantly. In general, with respect to the modeling of physico-chemical and biologocal parameters, the R-Squared statistic indicates that the models as fitted explain between 70.18 and 75.18% of the variability in the physico-chemical and biological parameters. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, varies between 59 and 69.23%. The correlation between the prediected and observed physico-chemical parameters is shown in Figure 4, where it is observed that the dots are close to the linear function with slope 1:1; which is an indicator of a successful adjustment. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in the time series. Since the P-value associated to the Durbin-Watson coefficient is less than 0.05 for the variables such as: Total Phosphorus, Total Nitrogen and Total Coliforms, there is an indication of possible serial correlation at the 95.0% confidence level. The P-value for the variance analysis is less than 0.05, there is a statistically significant relationship between the variables at the 95.0% confidence level. In determining whether the model for estimating the Total Phosphorus can be simplified, it is observed that the highest P-value on the independent variables is 0.6583, belonging to $\rho7$. Since the P-value is greater or equal to 0.05, that term is not statistically significant at the 95.0% or higher confidence level. Consequently, $\rho7$ might be removed from the model. A similar results occur for Total Nitrogen ($\rho5$), Plankton ($\rho2$), BOD ($\rho7$), COD ($\rho5$), Total Coliforms ($\rho4$), Electrical Conductivity and pH ($\rho4$).

CONCLUSIONS

The modeling of physico-chemical parameters of Pao Cachinche water reservoir using as independent variables to the recorded reflectances in the spectral bands of Landsat Satellites coooresponding to the visible and infrared regions has been achieved successfully. The R-Squared statistic indicates that the models as fitted explain between 70.18 and 75.18% of the variability in the physico-chemical and biological parameters. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, varies between 59 and 69.23%. It has been found by each model that only one spectral band might be removed due to the coefficient associated to the recorded reflectances in this band has a low significant influence on the result of the physico-chemical and biological parameters modeling.

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