

Discriminant analysis application in spatiotemporal evaluation of water quality in South Florida

Mohammad Haji Gholizadeh, Assefa M. Melesse and Lakshmi Reddi

ABSTRACT

The discriminant analysis (DA) method was used to differentiate and classify the water quality of three major rivers in South Florida. In this study, DA was used to assess the water quality and evaluate the spatial and temporal variations in surface water quality in South Florida. DA, as an important data reduction method, was used to assess the water pollution status and analysis of its spatiotemporal variation. It was found by the stepwise DA that five variables (chl-a, dissolved oxygen (DO), total Kjeldahl nitrogen (TKN), total phosphorus (TP) and water temperature) are the most important discriminating water quality parameters responsible for temporal variations. Spatial variation in water quality was also evaluated and identified five variables (TKN, TP, ammonia-N, magnesium, and sodium) and seven variables (chl-a, DO, TKN, TP, ammonia-N, magnesium, and chloride) as the most significant discriminating variables in the wet and dry season, respectively of three selected rivers in South Florida. It is believed that the results of apportionment could be very useful to the local authorities for the control and management of pollution and better protection of important riverine water quality.

Key words | discriminant analysis, river water, South Florida, spatiotemporal analysis, water quality

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INTRODUCTION

Surface water quality has become a serious concern for urban planners and managers. The surface water quality in a region is a function of natural factors (precipitation, weather, basin physiography, soil erosion, etc.) and anthropogenic factors (urbanization, industrial and agricultural activities, etc.) (Carpenter *et al.* 1998; Jarvie *et al.* 1998). As a result of their impacts, nutrients, toxic substances, and petroleum products enter the rivers, estuaries, lakes and other waterbodies, reducing the quality of water. Anthropogenic factors, such as residential and industrial wastewater, are a constant polluting source in urban areas, whereas natural factors like rainfall, surface runoff, and groundwater level are seasonal phenomenon that are mainly affected by climate (Singh *et al.* 2004). Seasonal variations in precipitation, surface runoff, ground water flow, and water interception and abstraction have significant effects on river discharge, and subsequently, on the concentration of

pollutants in river water (Vega 1998). Therefore, to better investigate and evaluate the water quality of watersheds, a study of temporal variations alongside the spatial variations of water quality seems to be inevitable.

To obtain reliable information about the inherent properties of water quality and to understand the spatial and temporal variations in the hydro-chemical and biological properties of water, continuous and regular monitoring programs are required (Singh *et al.* 2005). However, the generated databases are large and complex so that their analyses require robust analytical tools. Multivariate statistical techniques are widely used for the evaluation of both temporal and spatial variations and the interpretation of large and complex water quality data sets (Wunderlin *et al.* 2001; Simeonov *et al.* 2003; Singh *et al.* 2004, 2005; Kim *et al.* 2005; Kowalkowski *et al.* 2006; Shrestha & Kazama 2007; Schaefer & Einax 2010; Juahir *et al.* 2011; Mustapha & Aris 2012).

Discriminant analysis (DA) was conducted on the data set of water quality of three selected rivers in the study area to construct the discriminant functions (DFs) on two different standard and stepwise modes to identify the most significant variables that result in water quality spatial and temporal variation. In addition, this step was performed to optimize the monitoring program by decreasing the number of parameters monitored. Wunderlin *et al.* (2001) obtained a complex data matrix, which was treated using the pattern recognition techniques of cluster analysis (CA), factor analysis/principal component analysis, and DA. They found that the DA technique showed the best results for data reduction and pattern recognition during both temporal and spatial analysis. Singh *et al.* (2004, 2005) used multivariate statistical techniques to evaluate spatial and temporal variations in the water quality of the Gomti River (India). Zhou *et al.* (2007) used CA and DA to assess temporal and spatial variations in the water quality of the watercourses in the North Western New Territories of Hong Kong, over a period of five years (2000–2004), using 23 parameters at 23 different sites (31,740 observations). Their results showed that DA allowed a reduction in the dimensionality of the large data set and indicated a few significant parameters that were responsible for most of the variations in water quality. Shrestha *et al.* (2008) used different multivariate statistical techniques for the evaluation of temporal/spatial variations and the interpretation of a large complex water quality data set of the Mekong River. They also concluded that DA showed the best results for data reduction and pattern recognition during both spatial and temporal analysis. Li *et al.* (2009) also used DA to evaluate temporal and spatial variations and to interpret a large and complex water quality data set collected from the Songhua River basin in China. The results of DA showed a reduction in the dimensionality of the large data sets, by delineating a few indicator parameters of the water quality. Zhang *et al.* (2011) applied different multivariate statistical techniques for the interpretation of a complex data matrix obtained between 2000 and 2007 from the watercourses in the Southwest New Territories and Kowloon, Hong Kong. DA provided better results both temporally and spatially. Chen *et al.* (2015) used the fuzzy comprehensive assessment, CA and DA to assess the water pollution status

and analyze its spatiotemporal variation. Furthermore, long-term hydro-chemical data of shallow water bodies were evaluated using DA (Medina-Gomez & Herrera-Silveira 2003; Parinet *et al.* 2004; Solidoro *et al.* 2004).

Given the above considerations, a large data matrix obtained over a 15-year (2000–2014) monitoring period at 16 different sites for 12 water quality parameters, and in two wet and dry seasons (approximately 35,000 observations), was subjected to DA to identify the most significant water quality variables responsible for spatial and temporal variations in river water quality.

METHODS

Study area

Canals in South Florida form an extensive network to distribute water and to discharge seasonal excess flows into estuaries. They are biologically productive systems that support a variety of aquatic plants, animals, and microorganisms, many of which also thrive in ponds, sloughs, and marshes. In this study, three major rivers in South Florida, the Miami Canal, Kissimmee river and Caloosahatchee river, are investigated for their water quality by applying different multivariate analysis techniques. The average annual temperature range from 19.2 to 28.7 °C and the annual rainfall in the entire area of South Florida is generally approximately 1,400 mm. The major land uses in these watersheds include agricultural area, wetlands, cattle ranching and dairy farming, and urban areas. Figure 1 shows the location of the study area and the selected water quality monitoring sites on the three major rivers of South Florida.

Data set preparation

The hydrography network of the study area, generated using the 1:24,000 national hydrography data set obtained from the South Florida water management district's (SFWMD) geographic information systems (GIS) data catalog, was used to delineate the flow line of the three selected rivers. The most recent (2008–2009) land cover/land use (LCLU) map, provided by the SFWMD, was used in this study.

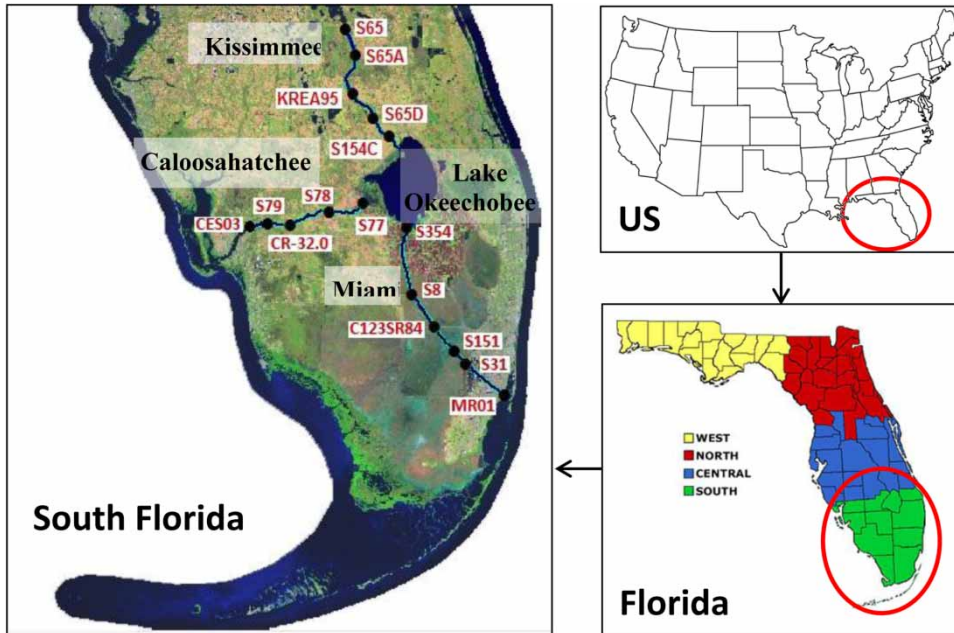


Figure 1 | The location of study area and water quality monitoring site.

These data were then clipped to fit our study area. The area of each type of land use within each watershed was calculated using an ESRI ArcGIS 10.0 platform. The monitoring stations, downloaded from the same source, were overlaid with the rivers' map in ArcGIS to design a network of sampling stations that include sufficient historical data to construct a robust statistical database of studied parameters, considering a suitable spatial distribution on the river. Then, the DBHYDRO (environmental database of SFWMD) was used to obtain continuous time series data for 12 selected water quality parameters from 2000 to 2014. This database was then divided into two dry and wet seasons (the wet season from May 15th to October 15th and the dry season from October 16th to May 14th). The selected water quality parameters for investigation in this study include chl-a, dissolved oxygen (DO), total Kjeldahl

nitrogen (TKN), total phosphorus (TP), total phosphate, ammonia-N, water temperature (WT), total suspended solids (TSS), turbidity, magnesium, chloride, and sodium.

Multivariate statistical methods

Multivariate statistical methods for classification, modeling and interpretation of large data sets allow for the reduction of the dimensionality of the data and the extraction of information (Massart & Kaufman 1983). DA, also called the supervised pattern recognition technique, is a multivariate statistical analysis method that uses linear combinations of several variables to construct statistical classification of samples into categorical-dependent values. DA is usually performed with prior knowledge of the membership of objects to a particular group. This technique builds up a

Table 1 | Wilks' lambda and chi-square test for the temporal DA of water quality variations across two wet and dry seasons

| Mode | DF | Canonical correlation (R) | Eigenvalue | Wilks' lambda | Chi-square | p-level (Sig.) |
|---------------|----|---------------------------|------------|---------------|------------|----------------|
| Standard mode | 1 | 0.882 | 3.515 | 0.222 | 277.271 | 0.000 |
| Stepwise mode | 1 | 0.870 | 3.102 | 0.244 | 267.490 | 0.000 |

DF for each group, which operates on raw data (Johnson & Wichern 1992; Wunderlin et al. 2001; Singh et al. 2004). Generally, two different modes are used, standard and stepwise, to construct the DFs. In this study, DA was applied on the

raw data matrix using both standard and stepwise modes in order to construct the DFs to differentiate and classify the water quality. The standard mode constructs discriminating functions containing all predictive variables, whereas in the stepwise mode, one variable that minimized the overall Wilks' lambda statistic was entered or removed at each step. Wilks' lambda is a statistical test used in multivariate analysis of variance to test the differences between the means of identified groups of subjects on a combination of dependent variables. It is a measure of how well each function separates cases into groups. Smaller values of Wilks' lambda indicate greater discriminatory ability of the function. The canonical DFs of the discriminating variables were used to discriminate among groups. The canonical DFs are defined as weighted linear combinations of the original variables, where each variable is weighted according to its ability to discriminate among groups. The first canonical DF defines the specific linear combination of variables that maximizes the ratio of among group to within group variance in any single dimension. It constructs a DF for each group as follows:

$$f(G_i) = K_i + \sum_{j=1}^n W_{ij} \times P_{ij} \tag{1}$$

where i is the number of groups (G), k_i is a constant inherent to each group, n is the number of parameters used to classify a set of data into a given group, and w_{ij} is the weight coefficient, assigned by DA to given parameters (P_{ij}). The weight coefficient maximizes the distance between the means of the dependent variable. In this study, 12 water quality parameters

Table 2 | Structure matrix for the temporal DA of water quality variations across two wet and dry seasons

| Standard mode | | Stepwise mode | |
|------------------|------------|------------------|------------|
| Parameters | Function 1 | Parameters | Function 1 |
| WT | 0.940 | WT | 1.000 |
| Dissolved oxygen | -0.321 | Dissolved oxygen | 0.613 |
| TKN | 0.195 | TKN | -0.300 |
| Chl-a | 0.164 | Chl-a | -0.337 |
| Ammonia-N | 0.091 | Ammonia-N | -0.234 |
| Total phosphate | 0.092 | TP | -0.179 |
| TP | 0.088 | Total phosphate | -0.157 |
| Magnesium | -0.047 | Magnesium | 0.094 |
| Sodium | -0.037 | Sodium | -0.016 |
| Chloride | -0.019 | Chloride | -0.017 |
| Turbidity | 0.014 | Turbidity | 0.016 |
| TSS | 0.012 | TSS | -0.046 |

Table 3 | CFs coefficients for the temporal DA of water quality variations in wet and dry seasons

| Parameter | Standard mode | | Stepwise mode | |
|------------------|------------------------|------------------------|------------------------|------------------------|
| | Dry coef. ^a | Wet coef. ^a | Dry coef. ^a | Wet coef. ^a |
| Chl-a | -0.586 | -0.532 | -0.116 | 0.046 |
| Dissolved oxygen | 9.121 | 8.514 | 3.338 | 1.985 |
| TKN | 27.702 | 25.936 | 24.694 | 27.791 |
| TP | 41.686 | 78.262 | 5.835 | 11.915 |
| Total phosphate | -126.870 | -168.289 | | |
| Ammonia-N | 43.744 | 45.375 | | |
| WT | 7.452 | 9.299 | 5.541 | 7.319 |
| TSS | -0.107 | -0.180 | | |
| Turbidity | 0.307 | 0.568 | | |
| Magnesium | -0.082 | -0.141 | | |
| Chloride | 0.017 | 0.020 | | |
| Sodium | 0.039 | 0.048 | | |
| (Constant) | -123.968 | -165.618 | -60.360 | -104.781 |

^aFisher's linear discriminant functions coefficients for wet and dry seasons correspond to w_{ij} as defined in Equation (1).

Table 4 | CMs for the temporal DA of water quality variations in wet and dry seasons

| Monitoring season | % correct | Season assigned by DA | |
|-------------------|-----------|-----------------------|------------|
| | | Dry season | Wet season |
| Standard mode | | | |
| Dry season | 89.6 | 88 | 8 |
| Wet season | 97.9 | 1 | 95 |
| Total | 95.3 | 89 | 103 |
| Stepwise mode | | | |
| Dry season | 87.5 | 84 | 12 |
| Wet season | 99.0 | 1 | 95 |
| Total | 93.2 | 85 | 107 |

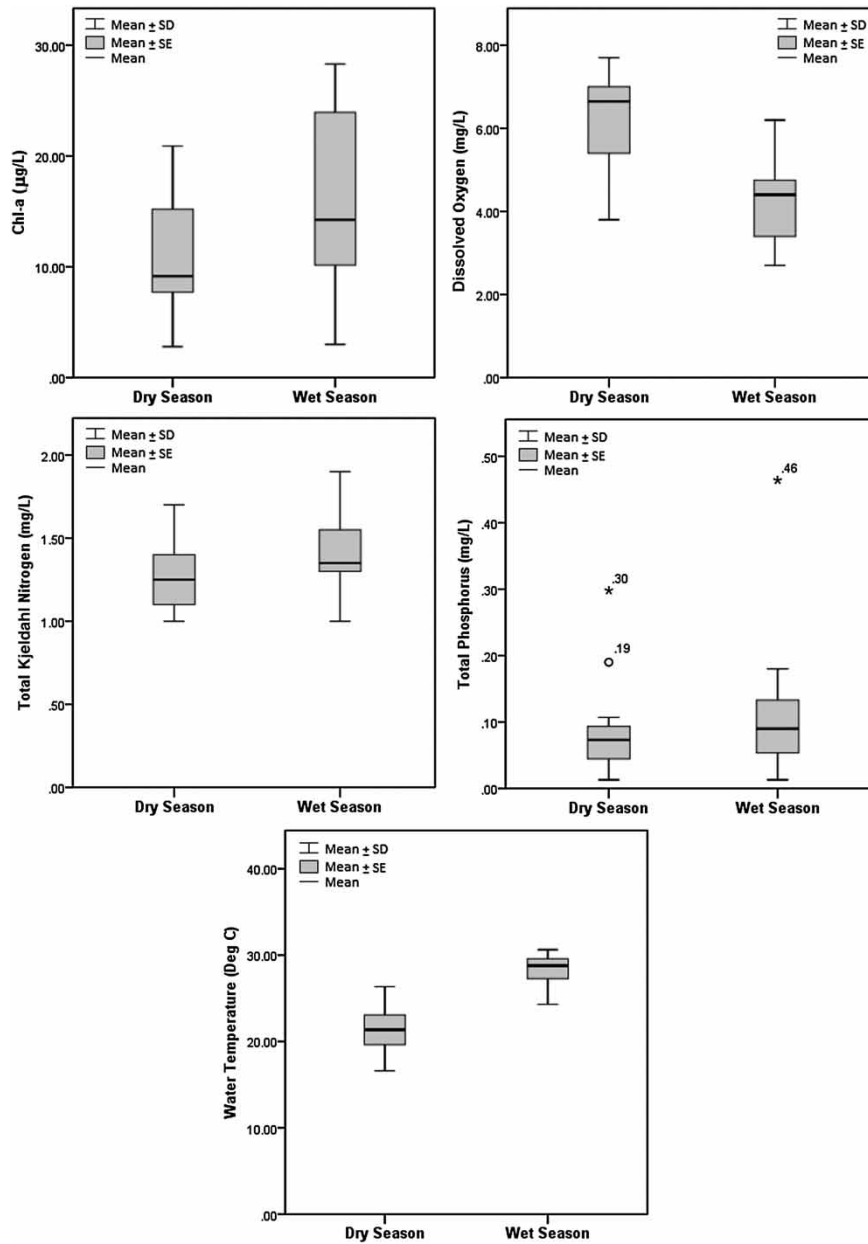


Figure 2 | Temporal variations in water quality of three major rivers of South Florida: chl-a; DO, TKN, TP, and WT.

Table 5 | Wilks' lambda and chi-square test for the spatial DA of water quality variations across three studied rivers in wet season

| Mode | DFs | Canonical correlation (R) | Eigenvalue | Wilks' lambda | Chi-square | p-level (Sig.) |
|---------------|-----|---------------------------|------------|---------------|------------|----------------|
| Standard mode | 1 | 0.821 | 2.065 | 0.217 | 133.646 | 0.000 |
| | 2 | 0.578 | 0.503 | 0.665 | 35.635 | 0.000 |
| Stepwise mode | 1 | 0.787 | 1.625 | 0.306 | 107.666 | 0.000 |
| | 2 | 0.443 | 0.243 | 0.804 | 19.830 | 0.000 |

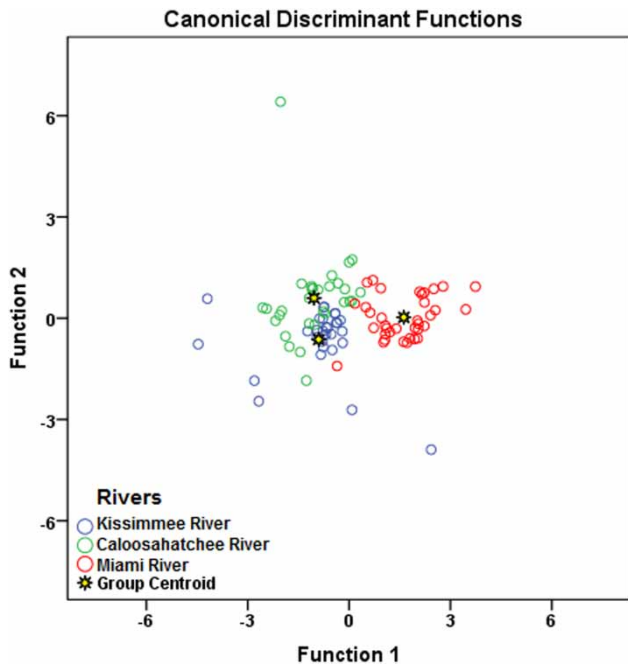


Figure 3 | Scatter plot for the spatial DA of water quality variations across three studied rivers in wet season (stepwise mode).

were considered for investigation including: chl-a, DO, TKN, TP, total phosphate, ammonia-N, WT, TSS, turbidity, magnesium, chloride, and sodium. Temporal DA was performed after dividing the whole data set into two groups of temporal (the wet season from May 15th to October 15th and the dry

season from October 16th to May 14th). Furthermore, spatial DA was performed for each season data matrix based on three selected rivers of Kissimmee River, Caloosahatchee River, and Miami Canal, as spatial regions. The selected rivers (spatial) and the season (temporal) were the grouping (dependent) variables, whereas all the observed parameters constituted the independent variables. The SPSS 16.0 software package was employed for data treatment.

RESULTS AND DISCUSSION

Spatio-temporal variations in river water quality using DA

Temporal variations in water quality

Temporal variation in water quality was evaluated through DA. Both standard and stepwise modes were applied on the raw data after dividing the whole data set into two seasonal groups (wet and dry seasons). Season was the dependent variable, while all observed water quality parameters were independent variables. The values of Wilks' lambda and the chi-square statistic for each DF were obtained from each standard mode and stepwise mode. As shown in Table 1, the values varied from 0.222 to 0.244 and from 277.3 to 267.5

Table 6 | Structure matrix for the spatial DA of water quality variations across three studied rivers in wet season

| Standard mode | | | Stepwise mode | | |
|------------------|------------|------------|------------------|------------|------------|
| Parameters | Function 1 | Function 2 | Parameters | Function 1 | Function 2 |
| Total phosphate | -0.404 | -0.070 | Total phosphate | -0.451 | -0.194 |
| TP | -0.405 | -0.038 | TP | -0.453 | -0.117 |
| Sodium | -0.095 | -0.206 | Sodium | -0.098 | -0.317 |
| Chloride | -0.136 | -0.125 | Chloride | -0.200 | -0.092 |
| Magnesium | -0.081 | 0.070 | Magnesium | -0.094 | 0.082 |
| Ammonia-N | 0.185 | -0.038 | Ammonia-N | 0.210 | -0.012 |
| Dissolved oxygen | -0.139 | 0.333 | Dissolved oxygen | -0.135 | -0.009 |
| Chl-a | -0.186 | 0.186 | Chl-a | 0.038 | 0.319 |
| TKN | 0.059 | 0.014 | TKN | 0.066 | 0.034 |
| Turbidity | -0.227 | -0.168 | Turbidity | -0.125 | 0.119 |
| TSS | -0.102 | -0.142 | TSS | 0.133 | 0.070 |
| WT | -0.094 | 0.256 | WT | -0.051 | 0.218 |

Table 7 | CFs coefficients for the spatial DA of water quality variations across three studied rivers in wet season

| Parameter | Standard mode | | | Stepwise mode | | |
|------------------|------------------------------|-----------------------------------|--------------------------|------------------------------|-----------------------------------|--------------------------|
| | Kissimmee coef. ^a | Caloosahatchee coef. ^a | Miami coef. ^a | Kissimmee coef. ^a | Caloosahatchee coef. ^a | Miami coef. ^a |
| Chl-a | -1.401 | -1.467 | -1.549 | | | |
| Dissolved oxygen | 9.940 | 10.897 | 11.142 | | | |
| TKN | 58.595 | 65.589 | 75.088 | 41.668 | 44.773 | 51.713 |
| TP | 5.466 | -21.418 | -26.290 | -18.42 | -8.456 | -72.102 |
| Total phosphate | -158.888 | -116.608 | -186.954 | | | |
| Ammonia-N | 81.958 | 88.992 | 114.317 | 32.908 | 36.687 | 52.102 |
| WT | 17.873 | 18.044 | 18.041 | | | |
| TSS | -0.773 | -0.792 | -1.006 | | | |
| Turbidity | 1.577 | 1.242 | 1.518 | | | |
| Magnesium | -0.059 | 0.061 | -0.049 | 0.182 | 0.26 | 0.197 |
| Chloride | 0.032 | 0.028 | 0.040 | | | |
| Sodium | -0.033 | -0.073 | -0.047 | -0.077 | -0.108 | -0.067 |
| (Constant) | -297.426 | -314.877 | -323.796 | -28.07 | -33.348 | -39.89 |

^aFisher's linear DFs coefficients for three groups of sites correspond to w_{ij} as defined in Equation (1).

for Wilks' lambda and the chi-square, respectively. Smaller values of Wilks' lambda indicate a greater discriminatory ability of the function. The associated chi-square statistic tests the hypothesis that the means of the functions listed are equal across groups. The small significance values (p -level < 0.01) indicate that the DF does better than chance at separating the groups. Thus, the temporal DA was credible and effective. The first function in standard DA explained almost all ($R = 88.2\%$) of the total variance in the dependent variables. The stepwise DA had similar results, which indicated that 87% of the total group differences in the data set were explained by its first DF. Therefore, the first DF alone was sufficient to explain the difference of water quality among the two wet and dry seasons.

The stepwise DA identified five variables (chl-a, DO, TKN, TP and WT) as the most important discriminating variables. Table 2 shows that the first function in the stepwise DA was perfectly correlated with temperature (coefficient = 1.000), and then mostly correlated with DO (coefficient = 0.613). Classification functions (CFs) and the classification matrices (CMs) obtained from standard and stepwise modes of DA are shown in Tables 3 and 4. In the standard mode, all 12 variables were included to construct CFs which correctly classified 95.3% of the original grouped

cases. In the stepwise mode, the DA correctly assigned 93.2% of the cases using only five discriminating variables. Therefore, the temporal DA results of the stepwise mode suggested that chl-a, DO, TKN, pH, and WT were the most significant parameters for discriminating differences between the wet season and dry season, and could be used

Table 8 | CMs for the spatial DA of water quality variations across three studied rivers in wet season

| Monitoring rivers | % correct | Rivers assigned by DA | | |
|-------------------|-----------|-----------------------|----------------|-------|
| | | Kissimmee | Caloosahatchee | Miami |
| Standard mode | | | | |
| Kissimmee | 80.0 | 24 | 5 | 1 |
| Caloosahatchee | 76.7 | 5 | 23 | 2 |
| Miami | 83.3 | 2 | 4 | 30 |
| Total | 80.2 | 31 | 32 | 33 |
| Stepwise mode | | | | |
| Kissimmee | 70.0 | 21 | 8 | 1 |
| Caloosahatchee | 70.0 | 7 | 21 | 2 |
| Miami | 94.4 | 1 | 1 | 34 |
| Total | 79.2 | 29 | 30 | 37 |

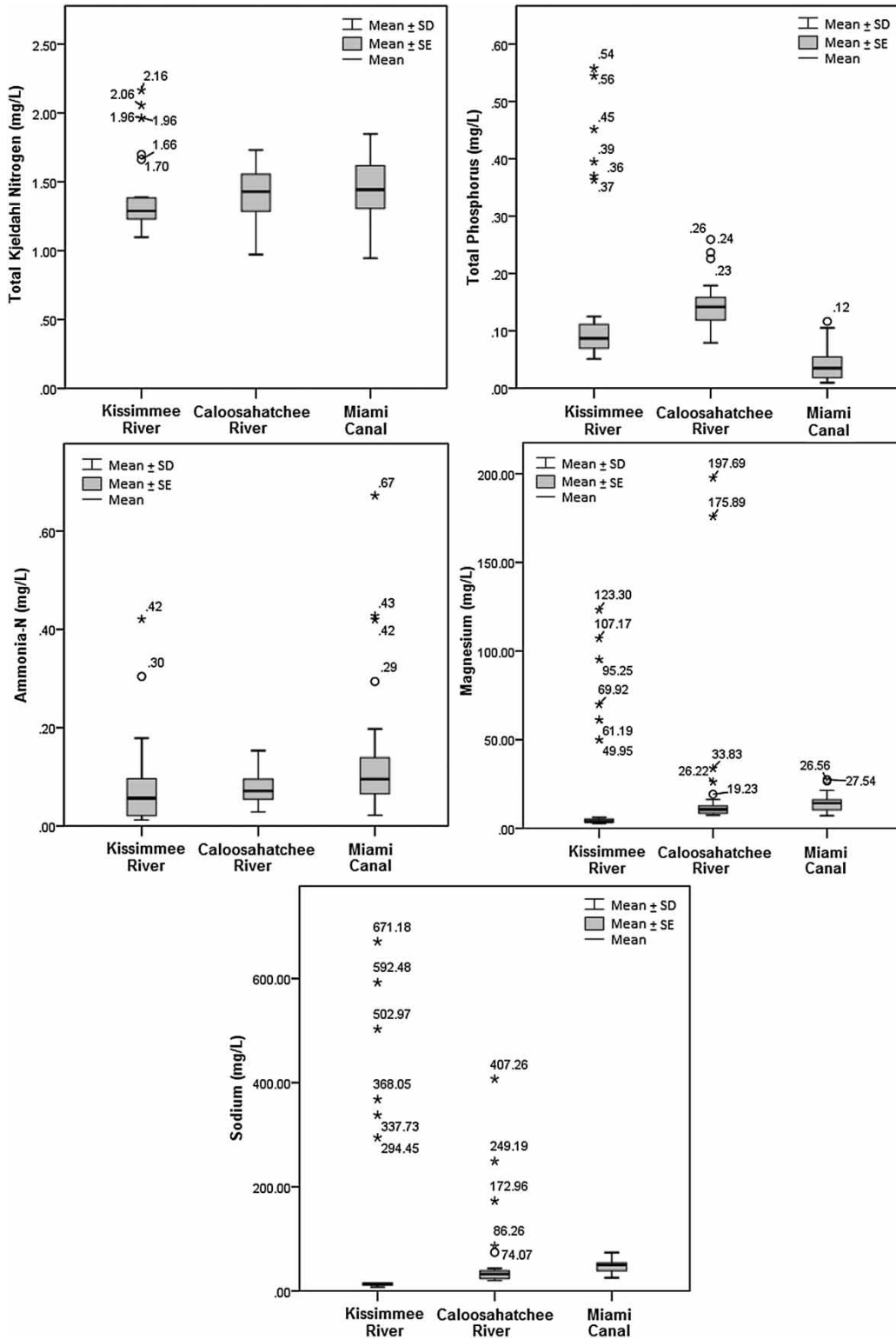


Figure 4 | Spatial variations in water quality of three studied rivers in wet season: TKN, TP, ammonia-N, magnesium, and sodium.

Table 9 Wilks' lambda and chi-square test for the spatial DA of water quality variations across three studied rivers in dry season

| Mode | DFs | Canonical correlation (R) | Eigenvalue | Wilks' lambda | Chi-square | p-level (Sig.) |
|---------------|-----|---------------------------|------------|---------------|------------|----------------|
| Standard mode | 1 | 0.837 | 2.348 | 0.168 | 156.314 | 0.000 |
| | 2 | 0.663 | 0.783 | 0.561 | 50.578 | 0.000 |
| Stepwise mode | 1 | 0.820 | 2.057 | 0.209 | 140.995 | 0.000 |
| | 2 | 0.601 | 0.567 | 0.638 | 40.419 | 0.000 |

to explain most of the expected temporal variations in water quality.

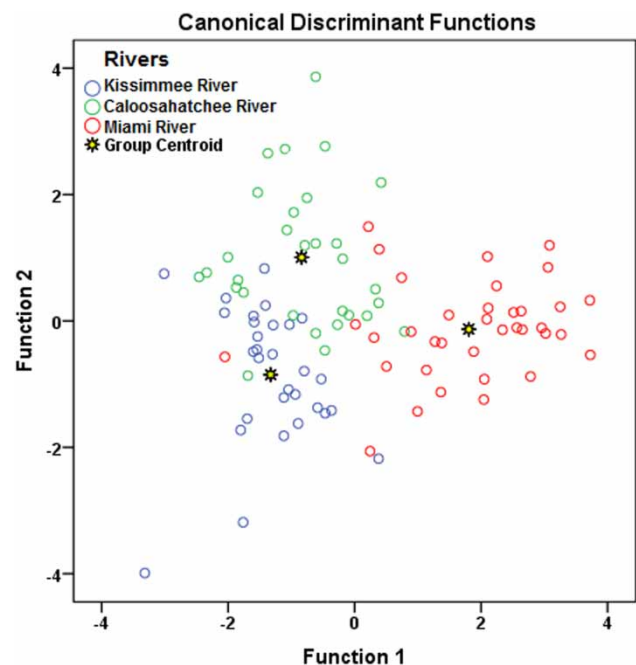
Box and whisker plots of discriminating parameters were constructed (stepwise mode) to evaluate different patterns associated with temporal variations in river water quality (Figure 2). The first pattern showed clear seasonal differences for chl-a, DO, and WT, in which chl-a and WT showed a clear inverse relationship with DO. This could be explained that as WT increases in the river, biological activity of aquatic organism strengthens, and therefore, the consumption of DO concentration increases. In addition, more oxygen dissolves in cooler water. The second pattern showed higher average concentrations of TKN and TP in the wet season. This could be due to the erosion of soil containing nutrients during the rain.

Spatial variations in water quality

Spatial variations in water quality between the studied rivers in wet season. Spatial variations in water quality between the studied rivers in wet and dry seasons were studied to evaluate the spatial patterns in the water quality of rivers. Three major rivers of South Florida were the grouping (dependent) variable, while the observed parameters in each season constituted the independent variables. Both standard and stepwise modes of DA were applied. First, the spatial variations in water quality between the studied rivers in the wet season were evaluated. As shown in Table 5, the values of Wilks' lambda and the chi-square for each DF varied from 0.217 to 0.804 and from 35.635 to 133.646. *P*-values were all less than 0.01, indicating that the spatial DA was credible and effective. In the stepwise DA, only five variables (TKN, TP, ammonia-N, magnesium, and sodium) were selected as the most important discriminating variables. The two DFs explained 78.7 and 44.3% of the group differences, respectively. The first DF separated Miami Canal from Kissimmee

River and Caloosahatchee River (Figure 3), and was significantly and negatively correlated with total phosphate and TP (Table 6). The second DF established some separation between Kissimmee River and Caloosahatchee River, and was significantly correlated with chl-a. The CFs and CMs obtained from the two modes are shown in Tables 7 and 8. In the standard mode, all 12 variables were included and the constructed CFs produced 80.2% accuracy in assigning cases. However, in the stepwise mode, DA produced 79.2% correct assignment using only five discriminating variables.

Box and whisker plots of discriminating parameters identified by spatial DA (stepwise mode) were constructed to evaluate different patterns associated with variations in river water quality between three studied rivers in the wet season (Figure 4). The points are outliers. These are defined

**Figure 5** Scatter plot for the spatial DA of water quality variations across three studied rivers in dry season (stepwise mode).

as values that do not fall in the inner fences. Outliers are extreme values. The asterisks or stars are extreme outliers. These represent cases that have values more than three times the height of the boxes.

The identified patterns of the most important discriminating variables show that, in general, the average concentrations of the water quality parameters in the Miami Canal are worse

than the other two rivers. The Kissimmee River demonstrated even lower average values. Nonetheless, the outliers in Figure 4 are related to the average concentration of the represented variables in two highly polluted sites of S154C and CES03 in the Kissimmee River and the Caloosahatchee River, respectively. However, TP showed that a different pattern and average concentrations of this variable were much higher in the

Table 10 | Structure matrix for the spatial DA of water quality variations across three studied rivers in dry season

| Standard mode | | | Stepwise mode | | |
|------------------|------------|------------|------------------|------------|------------|
| Parameters | Function 1 | Function 2 | Parameters | Function 1 | Function 2 |
| Total phosphate | -0.297 | -0.080 | Total phosphate | -0.278 | 0.006 |
| TP | -0.306 | -0.033 | TP | -0.327 | -0.074 |
| Sodium | -0.129 | -0.052 | Sodium | -0.211 | 0.004 |
| Chloride | -0.158 | -0.124 | Chloride | -0.176 | -0.129 |
| Magnesium | -0.126 | 0.197 | Magnesium | -0.135 | 0.226 |
| Ammonia-N | 0.210 | -0.132 | Ammonia-N | 0.228 | -0.157 |
| Dissolved oxygen | -0.262 | 0.084 | Dissolved oxygen | -0.285 | 0.107 |
| Chl-a | -0.083 | -0.250 | Chl-a | -0.095 | -0.274 |
| TKN | 0.450 | 0.000 | TKN | 0.493 | -0.023 |
| Turbidity | -0.147 | 0.008 | Turbidity | -0.025 | 0.054 |
| TSS | 0.016 | -0.003 | TSS | -0.211 | 0.058 |
| WT | 0.134 | 0.311 | WT | 0.238 | -0.001 |

Table 11 | CFS coefficients for the spatial DA of water quality variations across three studied rivers in dry season

| Parameter | Standard mode | | | Stepwise mode | | |
|------------------|------------------------------|-----------------------------------|--------------------------|------------------------------|-----------------------------------|--------------------------|
| | Kissimmee coef. ^a | Caloosahatchee coef. ^a | Miami coef. ^a | Kissimmee coef. ^a | Caloosahatchee coef. ^a | Miami coef. ^a |
| Chl-a | -0.722 | -1.022 | -0.738 | -0.148 | -0.368 | -0.17 |
| Dissolved oxygen | 16.053 | 17.204 | 15.654 | 7.805 | 8.413 | 7.292 |
| TKN | 47.975 | 52.815 | 69.377 | 59.089 | 63.939 | 77.278 |
| TP | -145.526 | -194.743 | -217.95 | -76.051 | -59.214 | -114.523 |
| Total phosphate | -45.610 | 28.722 | -10.294 | | | |
| Ammonia-N | 124.317 | 140.425 | 165.566 | 113.794 | 128.452 | 156.259 |
| WT | 6.786 | 7.158 | 6.704 | | | |
| TSS | 0.194 | 0.191 | 0.338 | | | |
| Turbidity | -0.298 | -0.335 | -0.620 | | | |
| Magnesium | 0.176 | 0.297 | 0.278 | 0.239 | 0.326 | 0.32 |
| Chloride | 0.033 | 0.018 | 0.021 | -0.008 | -0.023 | -0.019 |
| Sodium | 0.007 | -0.003 | 0.001 | | | |
| (Constant) | -146.359 | -166.618 | -168.765 | -61.155 | -70.314 | -80.84 |

^aFisher's linear DFS coefficients for three groups of sites correspond to w_j as defined in Equation (1).

Caloosahatchee River and the Kissimmee River, respectively, in comparison to the Miami Canal. Besides the two mentioned highly polluted sites, TP was found higher at the Caloosahatchee River and the Kissimmee River than the Miami Canal sites. The percentage of agricultural and urbanized areas in the Miami Canal watershed was measured from the LULC map in GIS and was seen to be even more than the other two rivers. Therefore, this could be related to the effectiveness of eco-restoration projects implemented in its watershed and adjacent linked watersheds (the water conservation area-3, WCA-3) in order to decrease the amounts of nutrients.

Spatial variations in water quality between the studied rivers in dry season. As shown in Table 9, the values of Wilks' lambda and the chi-square for each DF varied from 0.168 to 0.638 and from 40.419 to 156.314. All *p*-values were less than 0.01, indicating that the spatial DA was credible and effective. In the stepwise DA, seven variables (chl-a, DO, TKN, TP, ammonia-N, magnesium, and chloride) were selected as the most important discriminating variables. The two DFs explained 82 and 60.1% of the group differences, respectively. Likewise, in the wet season, the first DF separated the Miami Canal from the Kissimmee River and the Caloosahatchee River (Figure 5), and was significantly correlated with TP, DO, and TKN (Table 10). The second DF established some separation between the Kissimmee River and the Caloosahatchee River, and was correlated with chl-a and magnesium. The CFs and CMs

obtained from the two modes are shown in Tables 11 and 12. In the standard mode, all 12 variables were included and the constructed CFs produced 79.2% accuracy in assigning cases. However, in the stepwise mode, DA produced 81.3% correct assignment using only seven discriminating variables.

Box and whisker plots of discriminating parameters identified by spatial DA (stepwise mode) were constructed to evaluate different patterns associated with variations in river water quality between the three studied rivers in the dry season (Figure 6). The points are outliers. These are defined as values that do not fall within the inner fences. Outliers are extreme values. The asterisks or stars are extreme outliers. These represent cases that have values more than three times the height of the boxes.

The first pattern showed clear spatial differences for chl-a and DO as a measure of life's vitality and the activity level of the plants and animals living in rivers. The higher average values of these two variables were found in the Kissimmee River and the Caloosahatchee River, which indicates the dynamism and strength of aquatic lives in this river. Besides, the Miami Canal had lower average concentrations of chl-a and DO, which indicated that organic pollution may play a significant role in the Miami canal, especially in urbanized areas which are under the influence of more domestic and industrial wastewater.

The second pattern showed higher average concentrations of TP in the Caloosahatchee River and the Kissimmee River, which consists of two highly polluted sites of CES03 and S154C, respectively. The asterisks or stars are extreme outliers observed in these two sites that represent cases that have values more than three times the height of the boxes. Previous analysis (Haji-Gholizadeh et al. 2016) indicated that these two highly polluted sites are extremely affected by urbanized areas, and also high-density environmental resource permits with more industrial effluent and domestic sewage.

The third identified pattern of the most important discriminating variables in the dry season showed that the average concentrations of TKN, magnesium, and chloride in the Miami Canal are worse than the other two rivers. The Kissimmee River demonstrated lower average values. Nonetheless, the outliers in Figure 6 are related to the average concentration of the represented variables in two highly

Table 12 | CMs for the spatial DA of water quality variations across three studied rivers in dry season

| Monitoring rivers | % correct | Rivers assigned by DA | | |
|----------------------|-----------|-----------------------|----------------|-------|
| | | Kissimmee | Caloosahatchee | Miami |
| Standard mode | | | | |
| Kissimmee | 83.3 | 25 | 4 | 1 |
| Caloosahatchee | 76.7 | 4 | 23 | 3 |
| Miami | 77.8 | 5 | 3 | 28 |
| Total | 79.2 | 34 | 30 | 32 |
| Stepwise mode | | | | |
| Kissimmee | 80.0 | 24 | 5 | 1 |
| Caloosahatchee | 80.0 | 4 | 24 | 2 |
| Miami | 83.3 | 3 | 3 | 30 |
| Total | 81.3 | 31 | 32 | 33 |

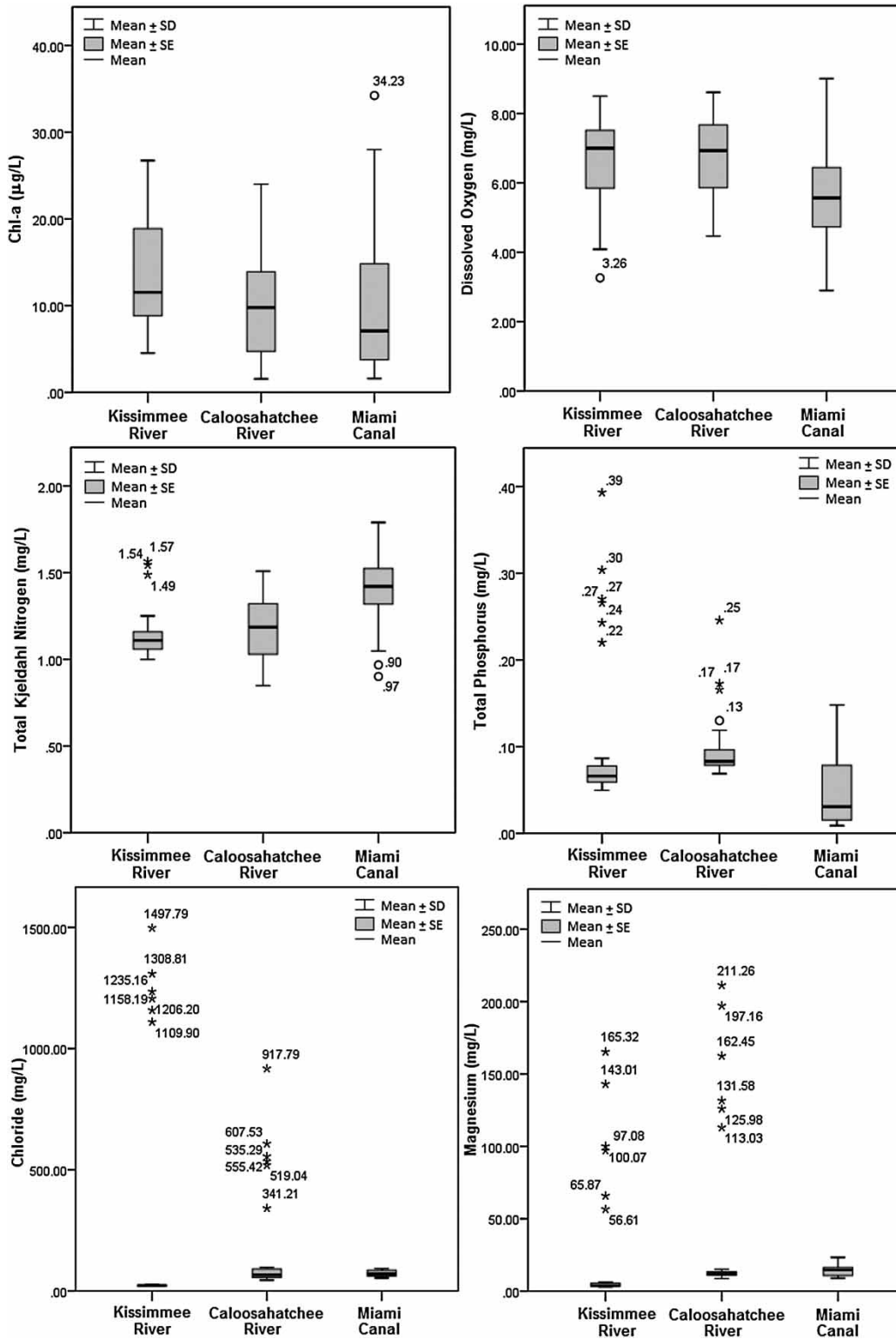


Figure 6 | Spatial variations in water quality of three studied rivers in dry season: chl-a, DO, TKN, TP, ammonia-N, magnesium, and chloride.

polluted sites of S154C and CES03 in the Kissimmee River and the Caloosahatchee River, respectively.

CONCLUSIONS

In this study, DA was applied to evaluate spatial and temporal variations in surface water quality of three major rivers of South Florida using 15 years (2000–2014) data sets of 12 water quality variables covering 16 sampling stations, with approximately 35,000 observations. DA, as an important data reduction method, was used to assess the water pollution status and analysis of its spatiotemporal variation. In temporal DA, 12 months of raw data were divided into two seasonal groups (wet and dry season) as the dependent variable, while all observed water quality parameters were independent variables. In the spatial DA, each river was separately considered as one spatial region to evaluate the patterns associated with spatial variations in each river's water quality. The three major rivers of South Florida were the grouping (dependent) variable, while the observed parameters in each season constituted the independent variables.

It was found by the stepwise DA that five variables (chl-a, DO, TKN, TP and WT) are the most important discriminating water quality parameters responsible for temporal variations. In spatial DA, the stepwise mode identified only five variables (TKN, TP, ammonia-N, magnesium, and sodium) and seven variables (chl-a, DO, TKN, TP, ammonia-N, magnesium, and chloride) as the most significant discriminating variables responsible for spatial variations in the wet and dry season, respectively. There were also different patterns associated with spatial variations that were identified, depending on the variables and considered season. However, it was found that the average concentrations of the most significant discriminating variables in both the wet and dry seasons in the Miami Canal was worse than the other two rivers, and the Kissimmee River demonstrated lower average values. Nonetheless, two highly polluted sites of S154C and CES03 in the Kissimmee River and the Caloosahatchee River require more attention and consideration.

This study showed the feasibility and reliability of DA in river water quality research. It is desirable that both state and local agencies pay more attention and consideration

in order to improve and protect the vulnerable river quality. Additional studies will be required to assess precisely the unidentified sources of pollution and variation of further water quality parameters that were not analyzed in this study. Furthermore, the conclusion would be beneficial to water environment protection and water resources management in the future. The results of the spatial and temporal variations could be used to select the polluted areas and set the priority areas for the river water quality management in the study area.

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