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Time Series Statistical Analysis of Water Quality Model Results for the Rosetta Branch of the Nile River

التحليل الاحصائى لبيانات نوعيه المياه الخاصه بفرع رشيد بنهر النيل

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Abstract: A physico-chemical water quality model has been developed and tested for the Rosetta Branch in the Nile Delta. Water quality models are tools for analysing, extrapolating and predicting the concentrations of dissolved oxygen (DO), biochemical oxygen demand (BOD), nitrogen in the form of ammonium (NH_4-N) and nitrate (NO_3-N), temperature (T) and total dissolved solids (TDS), taking into consideration advection, dispersion and the most important biological, chemical and physical processes. In this paper, the results of that model have been examined statistically based on the time series of hourly values of water quality parameters and discharges at km 125 along the Rosetta Brach. Relationships have been investigated between the water quality concentrations and loads and the river discharges. Theoretical distributions have been searched which best fit the time series for the different water quality parameters. They are applied to calculate exceedence probabilities for the thresholds involved in recommended water quality standards. The study concludes that, for DO, NO_3-N and TDS parameters, average concentration values are within the recommended standard by law 481982/ (Egyptian standard). Moreover, the average concentration values for BOD and NH_4-N violate the recommended standard. Also, the probability of exceedance of the recommended standard for BOD, NO_3-N, NH_4-N, DO and TDS concentrations are 72%, 15%, 99%, 9% and 19% respectively. Correlation analysis indicated that strong load-discharge relationships exist. The highest correlation coefficients for the load-discharge relationships were recorded for TDS and DO and the lowest correlation coefficient was recorded for NH_4-N.

Keywords: *water quality modeling, time series analysis, statistical analysis*.

المستخلص: تعتبر النماذج الرياضية وسيله مفيده وفعالة للتقييم والتنبؤ بحالة نوعية المياه للمجارى المائية المختلفة. فى دراسة سابقة تم إعداد ومعايرة نموذج رياضى لمحاكاة نوعية المياه لفرع رشيد بدلتا نهر النيل بجمهوريه مصر العربيه. حيث يقوم النموذج بمحاكاه تركيز العناصر المعبرة عن حالة نوعية المياه وهى: الأكسجين الذائب- الأكسجين الحيوى الممتص- الأمونيا- النيترات – درجة الحراره – الأملاح الكلية الذائبة مع الأخذ فى الإعتبار إنتقال وإنتشار العناصر بالإضافه الى التفاعلات البيولوجية والكيميائية والفيزيائية المهمة. يتركز البحث على اختيار موقع (كم125) على فرع رشيد والذى يقع خلف الثلاث مصارف الرئيسية الواقعة على الفرع لتحليل نتائج النموذج الرياضى (سلسله نتائج لتركيزات العناصر المختلفه كل ساعه لمدة 4 سنوات) بعدة طرق إحصائيه متقدمة. أولاً تم حساب الدلائل الإحصائية الوصفية لكل عنصر وذلك لدراسه المتوسط الحسابى

وعلاقته بالحد المسموح به طبقا للمواصفات المصرية بالإضافة إلى الإنحراف المعيارى عن المتوسط الحسابى وأيضاً لدراسة العلاقة بين القيم الصغرى والعظمى المسجلة للعناصر المختلفة. ثانيا تم إختبار العلاقة بين التركيزات والاحمال للعناصر المختلفة مع التصرف المار بالفرع بالإضافة الى دراسة امكانية وجود علاقه بين العناصر المختلفه وبعضها البعض. ثالثا دراسة مدى التطابق بين بيانات العناصر المختلفه والتوزيعات النظريه. أخيراً تم تطبيق نظرية القيمة المطلقة لإختبار احتماليه زياده تركيز العناصر المختلفه عن الحد المسموح طبقا للمواصفات المصريه. أظهرت النتائج أن متوسط تركيز الاكسجين الحيوى المتص والامونيا يتعدى الحد المسموح به طبقا للمواصفات المصرية، وأن احتمالية تعدى الحد المسموح به هو 72%، 15%، 99 %، 9% و 19% على التوالى بالنسبه للأكسجين الحيوى الممتص، النيترات، الأمونيا، الأكسجين الذائب و الأملاح الكلية الذائبة. وبدراسة إمكانية وجود علاقة متبادلة بين العناصر المختلفة التى تم دراستها، وجدت علاقة قوية بين الاحمال للعناصر المختلفه والتصرف وسجلت افضل نتيجة للأملاح الكلية الذائبة بينما سجلت الامونيا أسوأ النتائج.

كلمات مدخلية : *نمذجة نوعية المياه ، تحليل سلسلة بيانات ، تحاليل احصائية.*

INTRODUCTION

Problems of understanding the different relations between the water quality evolution, estimating the effect of river flow and water quality management projects, etc. can not be solved by analysis of monitoring results and it is here that models can have a significant and decisive role. Water quality models are tools for analyzing, extrapolating and predicting the water quality. In reality, the processes occurring in a river are very complex and models are only very simple descriptions of the real system as they attempt to simulate changes in the concentration of pollutants while they are moving through the environment. Nevertheless, good models are still able to describe the overall trend and the average behavior of water quality parameters and processes, which usually will be sufficient for practical purposes.

A physico-chemical water quality model has been developed and tested for the Rosetta Branch in the Nile Delta. The model has been set up making use of the MIKE11 river modelling software of Danish Hydraulic Institute for Water & Environment (DHI, 2002). The physico-chemical water quality (WQ) model is linked with a detailed full hydrodynamic (HD) model developed for the same Rosetta branch, and also implemented in the MIKE11 modeling system. The description of this hydrodynamic model is given in the paper of Willems, *et al*. (2005). The WQ model aims to describe and predict concentrations of DO, BOD, NH_4-N, NO_3-N, T and TDS, taking into consideration advection, dispersion and the most important biological, chemical and physical processes. All significant pollution sources along the Rosetta branch were considered (Radwan, *et al*. 2005).

The assessment of long term water quality changes is a challenging problem. This paper discusses the statistical analysis of the time series of the hourly time series of water quality model results for the selected water quality parameters at km 125 along the Rosetta Branch.

Rosetta Branch as A Case Study

The Nile Delta is formed in Northern Egypt where the Nile River spreads out to two branches (Rosetta and Damietta) and finally drains into the Mediterranean Sea (Figure 1). The two branches are: the eastern branch, Damietta, which is 240 kilometers long and the western branch, Rosetta, which is 235 kilometers long.

Deterioration in water quality of the Damietta and Rosetta branches in the Nile Delta of Egypt occurs in the northward direction due to disposal of municipal and industrial effluents and agricultural drainage. Both branches suffer from organic pollution and deficiency of dissolved oxygen. The Rosetta branch is more polluted than the Damietta branch (El-Sadek, *et al*. 2008). The major sources of pollution of the Rosetta branch are the pollution originating from the El-Rahawy drain, which is located at km 9, the Sabal drain located at km 70.4, and the Tala drain at km 119.3 (considering Delta Barrage is km 0) (Willems, *et al*. 2005).

Water Quality Input Data and Model Boundaries

For the different drains, water quality loads were specified (discharge and concentration for the different water quality variables). This was done for the three monitored drains, based on the monthly measurements of discharge and concentrations in the period 1997-2003. For the periods between the dates where the water quality samples have been taken, linear interpolations are assumed. Also, at the upstream boundary of the model (the inflow), time series were specified for the discharges and the different water quality variables. For temperature, no measurements were available at the upstream boundary. Because similar values were observed along the different drains, the average temperature value was calculated from the measurements along the drains and assumed at the upstream boundary.

For the concentrations of the water quality variables at the upstream boundary, constant monthly values were used as first approximation. They were estimated based on the water quality measurements upstream of Delta Barrage. Because these values are limited to two samples per year, upstream concentrations were basically assumed constant and equal to the long-term mean values. The DO concentration at the upstream boundary was calculated based on the equation of APHA (1985) for the DO saturation value (C_s) making use of the temperature values.

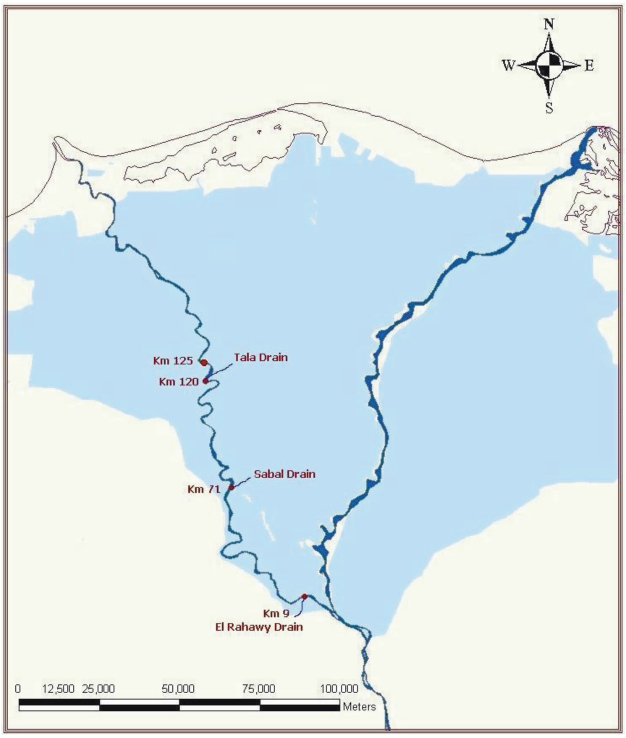


Fig. 1. Rosetta Branch within the Nile Delta.

Water Quality Model Calibration

Validation of the model results is made by comparison with available measurements. At the different locations along the Rosetta Branch where water quality samples are available, the full simulated hourly time series for the period 1997-2003 is compared with the limited number of water quality sampling results during the same period. The locations are: km 0 (at Delta Barrage), km 122, km 124, km 170, km 183, and km 203.

Results are calibrated by means of the following types of plots:

- Longitudinal profiles: variation of the concentration or load versus the distance along the Rosetta Branch: comparison of model derived profiles with observed data at the 6 locations of the measurement campaigns;
- Scatterplot of modelled versus observed concentrations and loads for all 6 measurement campaigns and all 6 locations;
- Modelled and observed concentrations or loads versus discharge;
- Difference in load from up- to downstream along the different reaches (in between locations where water quality measurements are available).

After model refinement, higher accuracy was reached for the model results. Figure (2) shows an example of the BOD concentrations for km 122 and the comparison with the observed data. The observed and modelled concentrations were also plotted against the bisector, as presented in Figure (3) and Figure (4), to analyse the accuracy of the model in a statistical way. By means of these scatterplots, systematic over-and/or underestimation of the model results can be checked for given ranges of concentrations. From Figure (3) and Figure 4, it can be seen that the calibrated models do not show systematic differences for the NO_3-N and TDS concentrations. More figures are presented in (Radwan, *et al*. 2005).

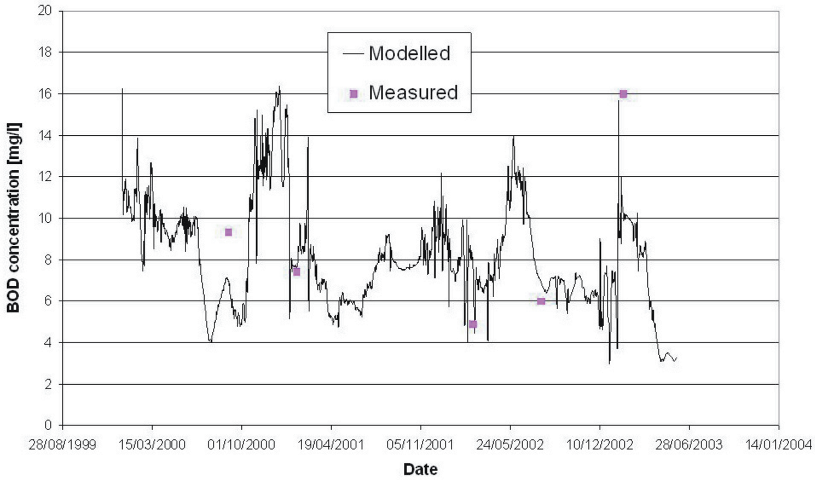


Fig. 2. Comparison of BOD concentration time series with the measurements.

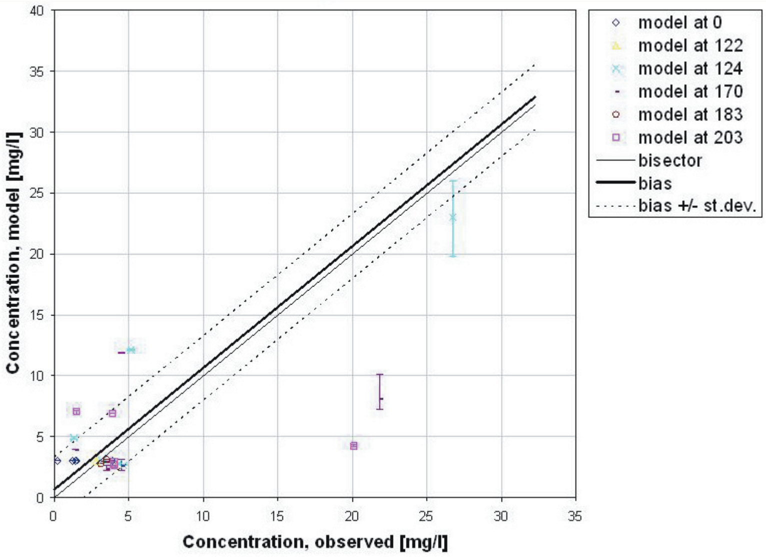


Fig. 3. Scatterplot of modelled versus observed concentrations for NO_3-N.

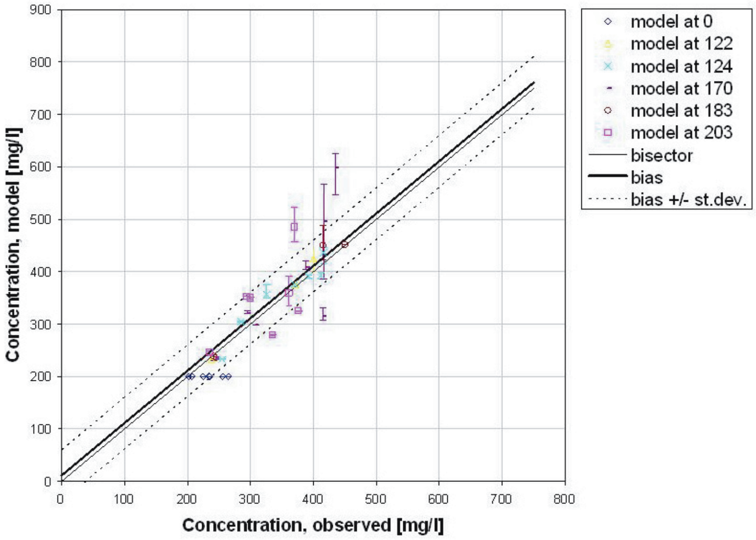


Fig. 4. Scatterplot of modelled versus observed concentrations for TDS.

The simulation results could be considered acceptable after applying the previous mentioned calibration steps (Radwan, et al. 2005).

METHODOLOGY

In planning, control and management programme of streams, statistical analysis as well as the analysis of relations between concentrations or loads and discharge are important steps for understanding the behaviour and the variation of water quality parameters along the stream flow. This variation is affected by different factors such as natural events or human induced activities that occur separately or simultaneously. Location at km 125 is selected to perform the statistical analysis and to check the water quality status. This location down stream the three major drains that are the main source of pollution along the Rosetta Branch.

Descriptive statistics are used to present quantitative descriptions in a manageable form: see (Table 1). They provide simple summaries about the time series of the different water quality parameters.

Results in (Table 1) indicate that for the DO, NO_3-N and TDS parameters, the average concentration values are within the recommended standard by law 48/1982 (Egyptian standard). Law 48/1982 regulates the discharge of wastes & wastewater along the Nile and its waterways and sets the standards of effluents quality. Moreover, the average concentration values for BOD and NH_4-N violate the recommended standard. In addition to this, a seasonal variation of temperature is recorded, which can explain the DO time series variation and as a result of this also the BOD, NO_3-N and NH_4-N variations. For the TDS, the seasonal variation is due to the discharge seasonal variation. The ratio of the highest to lowest concentrations for the different parameters is presented in (Table 2). The highest ratio is recorded for the discharge, due to the winter closure period (for the river maintenance works) where the discharge reaches the minimum values.

Boxplots

Boxplots are even more useful in comparing these attributes for different time series. They do not present all of the data, as do stem-and-leaf or quantile plots (Helsel, *et al*. 1992), but this often is not required. The boxplots instead provides concise visual summaries of essential data characteristics. They provides visual summaries of:

1. the center of the data (the median--the center line of the box)
2. the variation or spread (interquartile range (IQR)--the box height)
3. the skewness (quartile skew--the relative size of box halves)
4. presence or absence of unusual values (outlier values).

Table 1. Statistical properties of the concentrations for the different water quality parameters.

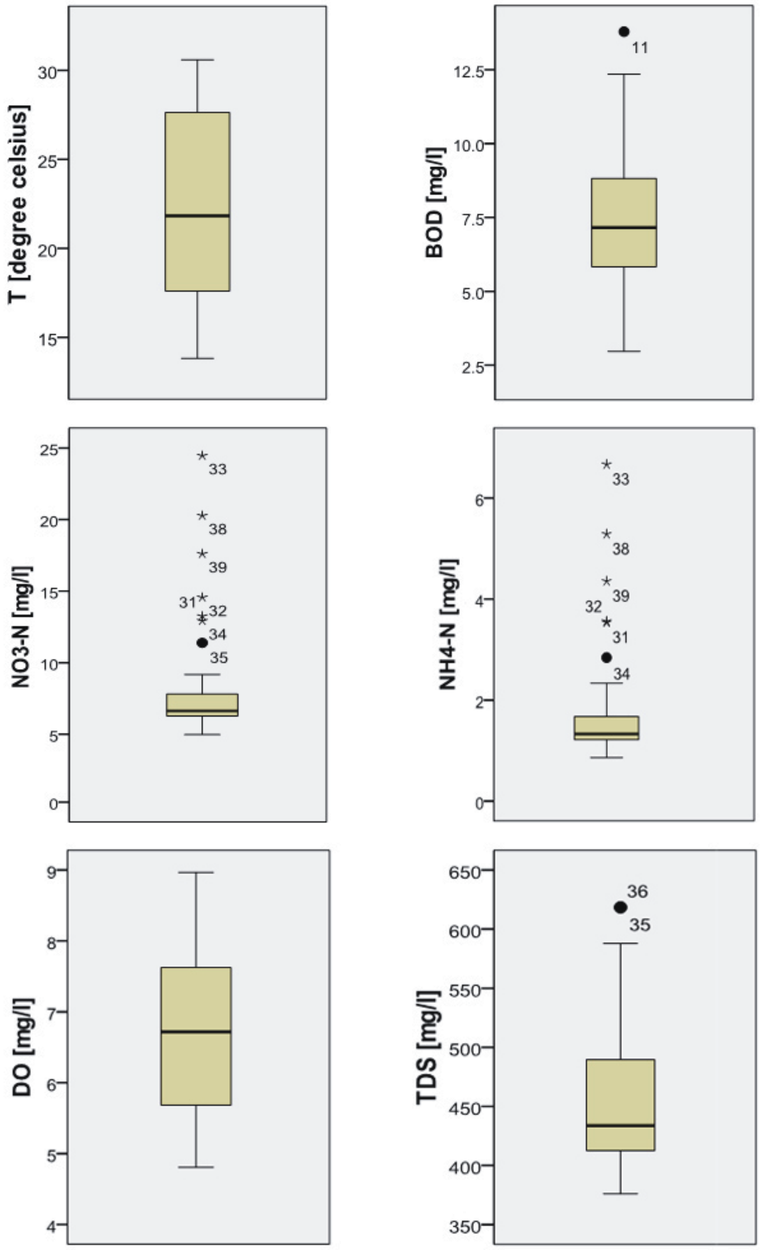
		Discharge ($M.m^3$/day)	BOD (mg/l)	DO (mg/l)	NH_4-N (mg/l)	NO_3-N (mg/l)	T (°C)	TDS (mg/l)
Standard (Law 48/1982)			6	5	0.5	10		500
Mean		188.34	7.43	6.73	1.78	8.07	22.44	451.74
Median		136.03	7.01	6.61	1.32	6.64	21.85	428.37
Std. Deviation		168.36	2.484	1.32	1.26	4.270	5.51	76.52
Variance		28347.58	6.17	1.76	1.59	18.23	30.36	5856.24
Skewness		2.80	0.653	0.11	3.08	2.87	-0.09	1.175
Kurtosis		9.04	0.632	-0.33	9.99	8.63	-1.38	7.00
Minimum		6	3	3	1	2	13.22	354
Maximum		1083	16	10	9	30	31.00	875
	25	93.53	5.81	5.69	1.18	6.32	17.77	407.28
Percentiles	50	136.03	7.01	6.61	1.32	6.64	21.85	428.37
	75	213.44	8.91	7.68	1.79	7.79	27.81	484.50

Table 2. Ratio of the highest to lowest concentrations.

Parameters	Ratio
Discharge (M.m^3/day)	180:1
BOD (mg/l)	5:1
DO (mg/l)	3:1
NH_4-N (mg/l)	9:1
NO_3-N (mg/l)	15:1
T (°C)	2:1
TDS (mg/l)	2:1

Figure (5) indicates that NO_3-N and NH_4-N have a major outliers on the upper side of the box. These outliers are mainly because the maximum measured concentrations are greater than the 3 IQR. For BOD and TDS, the outliers are minor (the maximum measured concentrations are greater than 1.5 IQR and less than 3 IQR.

Results are presented in (Figure 5) for the monthly average values of DO, Temp., NO_3-N, BOD, TDS and NH_4-N. It is shown that the



• A minor outlier is an observation 1.5 x IQR outside the central box.
*A major outlier is an observation 3.0 x IQR outside the central box.

Fig. 5. Boxplots of water quality parameter concentrations.

distributions of NO_3-N, BOD, TDS and NH_4-N depart from a normal distribution not only in skewness, but also by the number of outliers. Data of temperature depart from a normal distribution only in the skewness. Finally, DO values are approaching normality. The results could be used as a guide to know how the time series of the different water quality parameters are distributed. In addition to, define if outliers (extreme values) exist or not. For water quality parameters, it is very important to study the locations and the time moments where the outliers exist and report to the decision makers with these hot spots for their actions.

Probability Distribution of Water Quality Parameters

Probability plots are used to determine how well the data fit a theoretical distribution. This could be achieved by comparing visually the observed cumulative probability versus the expected cumulative probability for selected distributions. When the scatter points are close to the bisector line, the data best fit the distribution. Although it was believed that water quality data do not usually follow convenient probability distributions such as the well-known normal and lognormal distributions (on which many classical statistical methods are based; e.g. Lettenmaier, *et al*. 1991). Results indicate that BOD, DO concentrations best fit to the normal distribution. Discharge and Temp. fit better the lognormal distribution. TDS could be considered fitting the normal distribution. Finally, NO_3-N and NH_4-N could not be considered fitting either normal or lognormal distributions. Examples of distribution goodness-of-fit results are presented in (Figure 6) for BOD and DO. A summary of the best –fitted distributions is presented in (Table 3).

The main point to define the theoretical distributions is that they represent the best estimate of how events would actually occur. This would help for further analysis to study the exceedence probability for the different water quality parameters.

Table 3. The best fitted distribution for the concentrations of the different water quality parameters.

Parameter	Distribution
BOD (mg/l)	Normal
DO (mg/l)	Normal
TDS (mg/l)	Normal
NO_3-N (mg/l)	---
NH_4-N (mg/l)	---
Discharge (M.m3/day)	Lognormal
Temp(^{o}C)	Lognormal

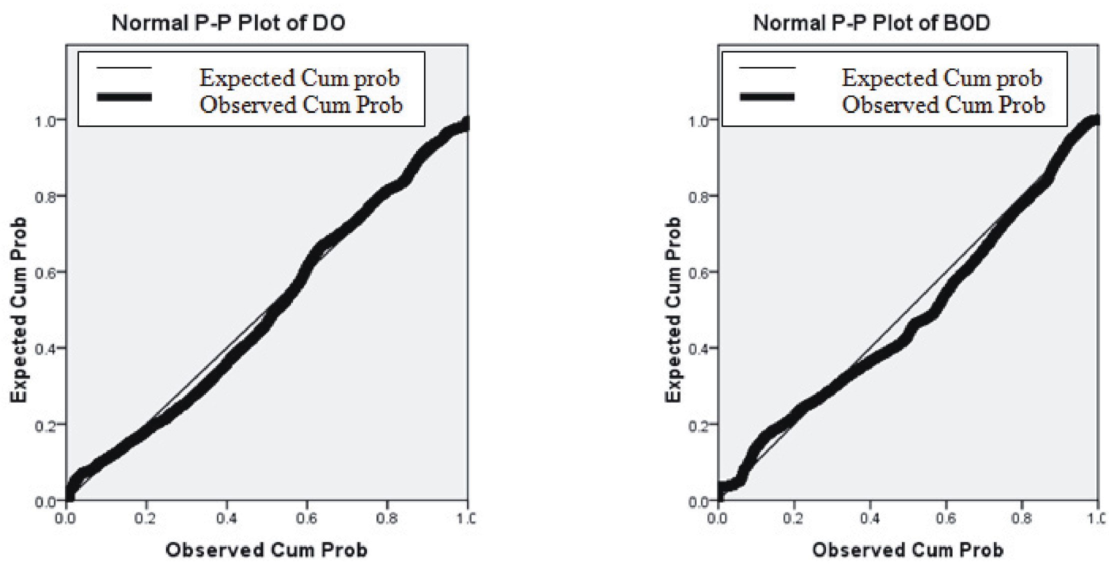


Fig. 6. Observed cumulative probability vs expected cumulative probability for the concentrations of different water quality parameters.

Concentrations-Discharge and Load-Discharge Relationships

Different models were proposed to describe the relationship between concentration and discharge and between load and discharge (Edwards, 1973; Oborne, *et al*. 1980; Pinol, *et al*. 1992). These relationships give information on the variation of quality parameters due to discharge. Hirsch, *et al*. (1982) suggested that, for water quality variables that are highly dependent on stream flow, the confounding effects of discharge variations be removed by analysing the residuals from a discharge-concentration relationship for trend, rather than the raw data. In this study, the linear ($C=a+bQ$), the power ($C=aQ^b$), the exponential ($C=a\exp(bQ)$), and the logarithmic ($C=a+b\ln(Q)$) models were used. The method of least squares for the pairs of hourly modeled values of each variable and the discharge are considered for calibration of these models.

The results of the regression between each water quality parameter concentration (dependent variable) and the discharge (independent variable) as well as between each water quality parameter load (dependent variable) and the discharge (independent variable) are given in (Table 4). In this table, the parameters a and b of the different models (linear, power, exponential, and logarithmic) are given as well as the correlation coefficients. The TDS based regression relationships are presented in (Figures 7 and 8). Results indicate that the best correlation coefficient between discharge and water quality parameters concentration is recorded for TDS ($r^2=0.5418$). The strength of the regression is weak for the other parameters. The regressions for NO_3-N, NH_4-N and TDS against discharge show a decreasing relationship. This can be explained by the dilution effects of the discharge. The logarithmic and the power models describe best the concentration-discharge relationships.

The load-concentration relationships show clearly and obviously better correlations than the concentration-discharge relationships. The highest correlation coefficients are recorded for TDS and DO ($r^2= 0.982$ and 0.962 respectively). Also BOD and NO_3-N show high correlation coefficients ($r^2= 0.899$ and 0.815 respectively). The lowest correlation coefficient is recorded for NH_4-N ($r^2 = 0.524$). These results indicate that the relation between load and discharge is nearly constant.

To check further if there is any correlation between the studied parameters, correlation analysis is carried out. Results of the correlation presented in Figure 9 indicate that, there is a good correlation between DO and Temp. The relationship is of the reverse linear type and has a coefficient of determination of $r^2 = 0.79$. This is due to the physical relation that the amount of oxygen that can be held by the water depends on the water temperature. In another words, cold water holds more oxygen. Also between BOD and NH_4-N, a good correlation is recorded. After polynomial regression, r^2 value of 0.95 is found. This could be explained by the organic substances break down, which produces ammonia through the ammonification process. Finally, NO_3-N is linearly correlated to NH_4-N with $r^2 = 0.89$. This is due to the oxidation of ammonia to nitrate through nitrification process. The results of this correlation analysis are site specific and can be used only for similar conditions. It is clear that the correlation between variables is strong and that there is no need to measure all variables. This can lead to a strong reduction in the laboratory analysis cost.

Table 4. Different model parameters and correlation coefficients.

Concentration - discharge					Load - discharge				
Variable	**Equation**	**a**	**b**	**r^2**	**Variable**	**Equation**	**a**	**b**	**r^2**
DO	Log	3.9	0.56	0.077	DO	Linear	-142	7.763	0.962
BOD	Power	2.73	0.188	0.125	BOD	Linear	-42.8	8.07	0.899
TDS	Power	1020.4	-0.16	0.5418	TDS	Linear	12732	356.9	0.982
NO_3-N	Log	17.05	-1.79	0.072	NO3	Linear	226.3	6.22	0.815
NH_4-N	Log	4.795	-0.60	0.098	NH4	Power	6.36	0.72	0.524

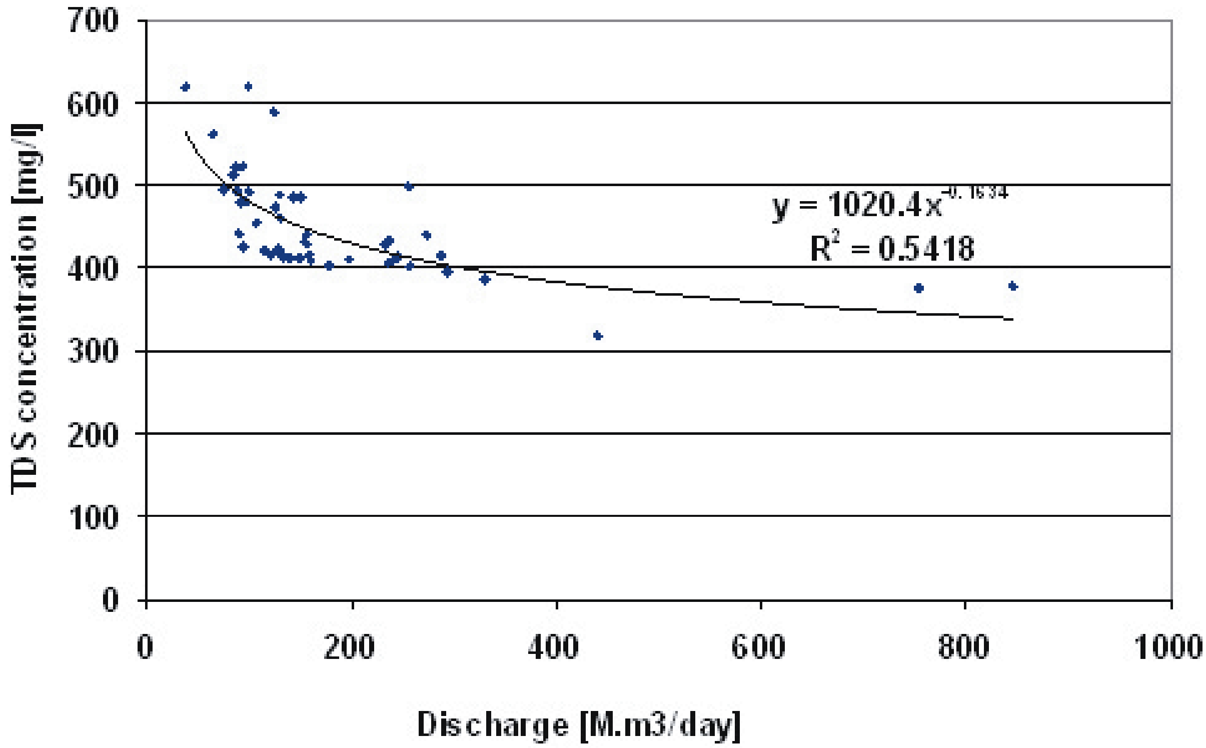


Fig. 7. Power regression between TDS concentration and discharge.

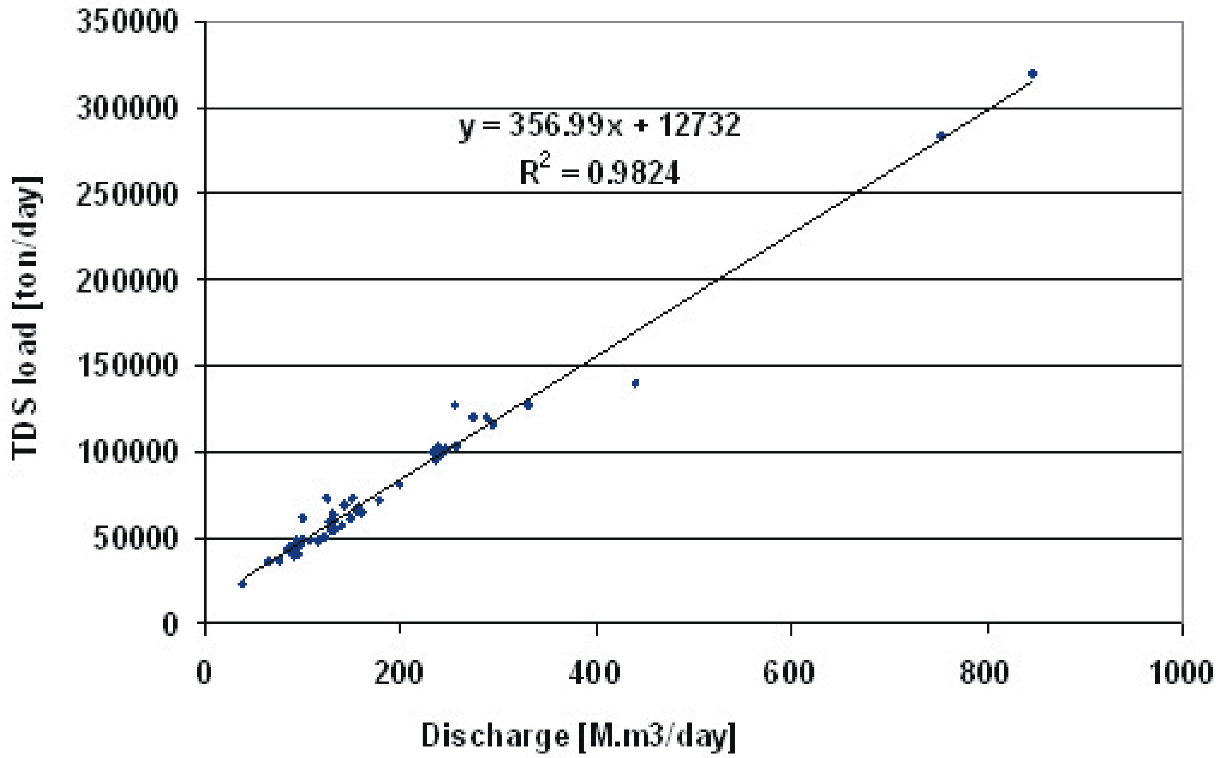


Fig. 8. Linear regression between TDS load and discharge.

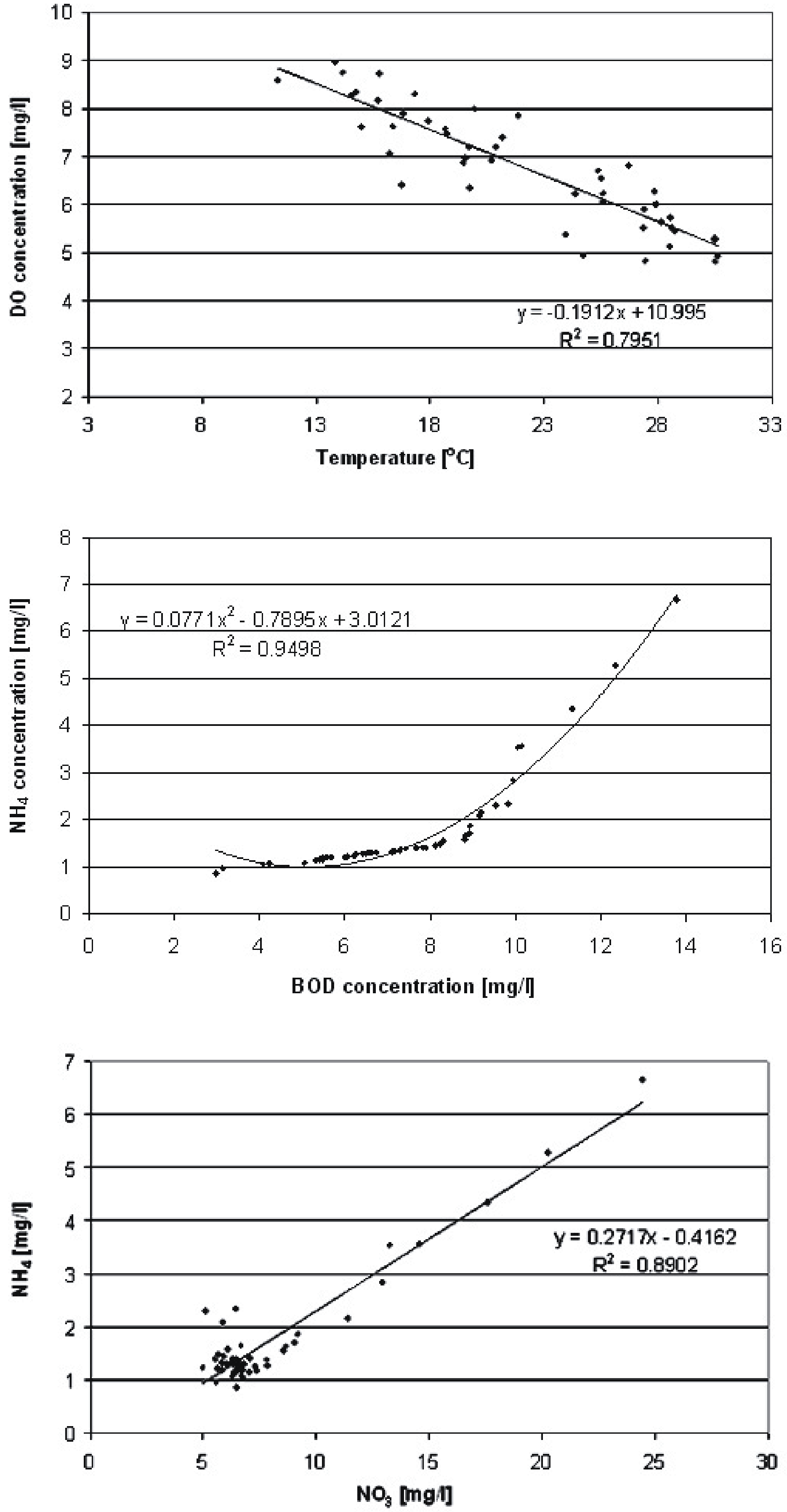


Fig. 9. Correlation between different water quality parameters.

Extreme Value analysis

The accurate description of extreme surface water quality status and their recurrence rates is of primary importance (Willems, 2000). The frequency distributions of the different studied water quality concentrations are presented in Figure 10. The extreme concentration values are compared with the recommended standard. They are derived from a detailed Mike11 simulation for 4 years (Radwan, et al. 2005). In these figures, 1-G(x) represents the exceedence probability. The 90% percentiles correspond with an exceedence probability of 1-G(x)=0.1. For BOD, NO_3-N, NH_4-N, Temp., DO and TDS, the 90% percentiles correspond with 10.6mg/l, 12.3mg/l, 2.8mg/l, 28.5°C, 8.6mg/l and 538mg/l respectively.

After comparison with the Egyptian recommended standard, the exceedence probabilities recorded for the different water quality parameters are presented in(Table 5).

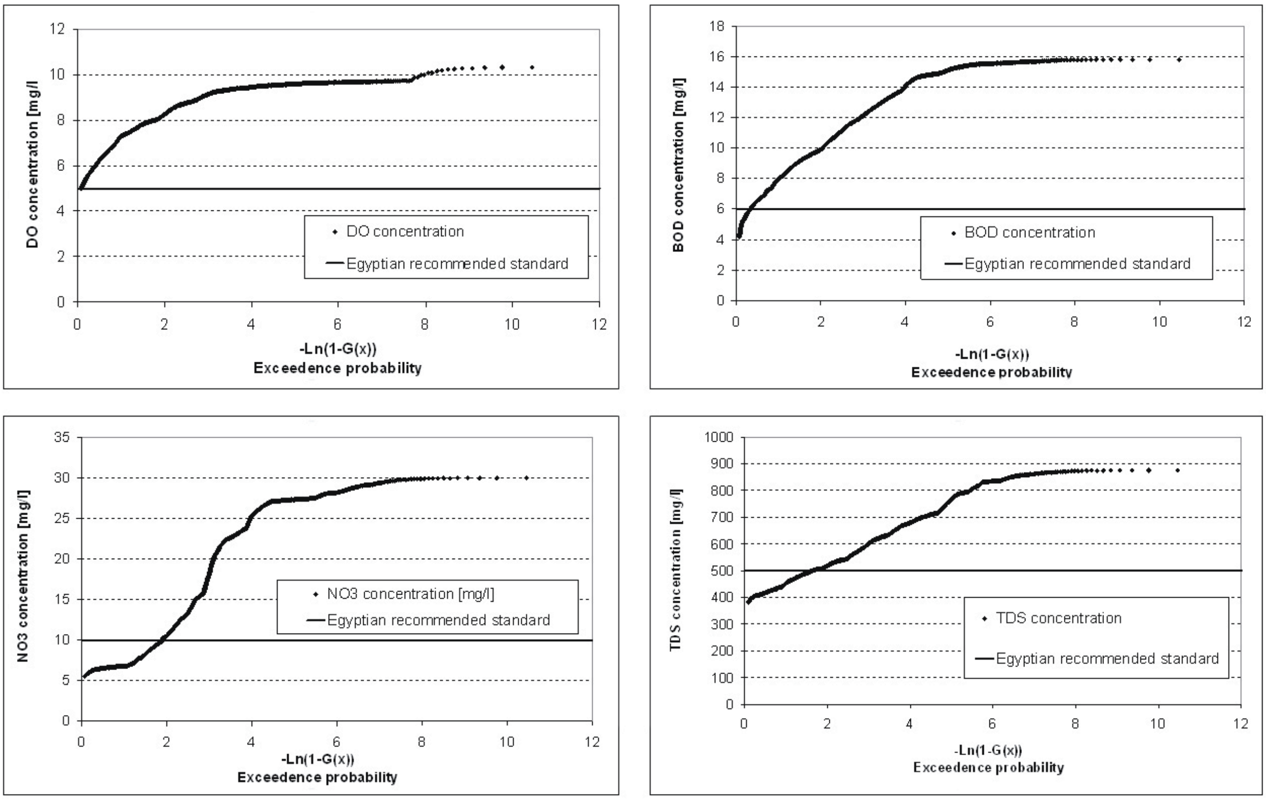


Fig. 10. Comparison of CDF relationships for the different water quality parameters with the Egyptian recommended standard.

Table 5. Exceedence probability for the different water quality parameters.

Parameter	-Ln(1-G(x)	Exceedence probability	Exceedence probability (%)
BOD	0.33	0.72	72
NO_3-N	1.89	0.15	15
NH_4-N	0.0036	0.99	99
DO	0.085	1-0.91	9
TDS	1.65	0.19	19

CONCLUSION

This paper discusses the statistical analysis of hourly time series of selected water quality parameters (DO, BOD, NO_3-N, NH_4-N, T and TDS) at km 125 along the Rosetta Branch. The time series were obtained as a result of combined hydrodynamic and physic-chemical water quality model simulations.

The analysis involves investigation of the relationships between the water quality concentrations and loads and the river discharges, probability and extreme value distributions,etc. The distributions give a description of the surface water quality status, with particular focus to the extremes. They also were applied to obtain estimates on the recurrence rates of specific thresholds for the extreme concentrations (based on recommended surface water quality standards).

Descriptive statistics analysis indicates that, for DO, NO_3-N and TDS parameters, average concentration values are within the recommended standard by law 48/1982 (Egyptian standard). Moreover, the average concentration values for BOD and NH_4-N violate the recommended standard. When the probability of exceedance of the recommended standard was calculated, it was found that BOD, NO_3-N, NH_4-N, DO and TDS concentrations are exceeded by respectively 72%, 15%, 99%, 9% and 19% of the hourly time moments.

The seasonal time series variations of the different water quality parameters were found to be very strong. The ratios of the highest to lowest concentration were found to be 180:1 for discharge, 5:1 for BOD, 3:1 for DO, 9:1 for NH_4-N, 15:1 for NO_3-N, 2:1 for Temp. and 2:1 for TDS. A large portion of these variations could be explained for DO, and consequently also for BOD, NO_3-N and NH_4-N by the seasonal variation of temperature. For the TDS, the seasonal variation is largely due to the discharge seasonal variation.

Boxplot figures show that the concentrations of NO_3-N, BOD, TDS and NH_4-N depart from a normal distribution not only in skewness, but also by the number of outliers. Data of temperature depart from a normal distribution only in the skewness. Finally, DO values are approaching normality. Discharge and temperature values were found to fit better the lognormal distribution.

Correlation analysis indicated that strong load-discharge relationships exist. The highest correlation coefficients for the load-discharge relationships were recorded for TDS and DO (r^2= 0.982 and 0.962 respectively), and for BOD and NO_3-N (r^2= 0.899 and 0.815 respectively). The lowest correlation coefficient was recorded for NH_4-N (r^2 = 0.524).

Moreover, good correlation has been found between DO and Temp (reverse linear relationship with r^2 = 0.79) because the amount of oxygen in the water strongly depends on the water temperature. Also between BOD and NH_4-N, a good correlation is recorded (polynomial regression with r^2 = 0.95) due to the ammonification process. Finally, NO_3-N was found linearly correlated to NH_4-N (r^2 = 0.89) due to the nitrification process. The results of this correlation analysis are site specific and can be used only for similar conditions. It is clear that the correlation between variables is strong and that there is no need to measure all variables. This can lead to a strong reduction in the laboratory analysis cost.

The results can be considered as a useful decision support tool in the integrated water resources management in the Nile Delta. Decisions can be based on prediction of future evolutions in the water quality concentrations. Moreover, such statistical analysis can be performed only based on long time series of the water quality variables which implies the importance of applying modeling techniques to simulate such series.

REFERENCES

DHI (2002) *MIKE11 Reference and User Manual*. DHI Water and Environment, Denmark.

Edwards, AMC (1973) The variation of dissolved constituents with discharge in some Norfolk rivers. *J. Hydrol*. **18:** 219–242.

El-Sadek, A, El Kahloun, M, and Meire, P (2008). Ecohydrology for integrated water resources management in the Nile Basin. *Ecohydrology & Hydrobiology* **8(2-4):** 237-244.

Helsel, DR and **Hirsch, RM** (1992) *Statistical*

Methods in Water Resources. Elsevier, The Netherlands.

Hirsch, RM, Slack, JR, and **Smith RA** (1982) Techniques of trend analysis for monthly water quality data. *Water Resour.Res*. **18:** 107–121.

Lettenmaier, RP, Hooper, ER, Wagoner, C, and **Fans, KB** (1991) Trends in stream quality in continental United States, 1978-1987. *Water Resour. Res*. **27:** 327–339.

Oborne, AC, Brooker, MP and **Edwards, RW** (1980) The chemistry of the River Wye. *J. Hydrol*., **45:**233–252.

Pinol, J, Avila, A, and **Roda, F** (1992) The Seasonal variation of steamflow chemistry in three forested Mediterranean catchments. *J. Hydrol*. **140:**119–141.

Radwan M, Willems P, El-Sadek A, and **Abdel-Gawad S** (2005) Physico-chemical water quality modelling of the Rosetta Branch in the Nile Delta. *Towards A Better Cooperation, International Conference of Unesco Flanders fit Friend/Nile project, 12-15 November*. Sharm El-Sheigh, Egypt.

Willems, P (2000) *Probabilistic Immission Modelling of Receiving Surface Waters*. **Ph.D. thesis, Catholic University of Leuven, Belgium.**

Willems, P, Radwan, M, El-Sadek, A, and Abdel-Gawad, S (2005) Hydrodynamic modelling of the Rosetta Branch in the Nile Delta. *International Conference of UNESCO Flanders FIT FRIEND/Nile Project –Towards A Better Cooperation*, **Sharm El-Sheikh, Egypt, 20-23 November 2005.**

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