Assessment of the National Water Quality Monitoring Program of Egypt

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Biographical sketches of authors

Dr. Rasha is a water quality specialist with a civil/environmental engineering background. She has 10 years experience working a researcher in the National Water Research Center, Egypt. She is the assistant manager of the National Water Quality Monitoring Program, a part of a bilateral national project with Canada. She was nominated by the Ministry of Water Resources and Irrigation MWRI as the ideal engineer of year 1997. She is experienced in water quality management including: data analysis and interpretation, modeling, information systems and networks development. She has a various range of published papers in Canada, Spain, Portugal, Australia and Egypt.

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Dr. Shaden is the Vice-Chairperson of the National Water Research Center, Ministry of Water Resources and Irrigation, Egypt. She is also the Manager of National Water Quality Monitoring Program. She has over 25 years experience in water quality management and environmental protection. She has supervised and managed several foreign funded projects as well as local programs in the field of water quality monitoring, modeling and assessment. She has organized and implemented several training programs in her fields of specialty. She has more than 100 technical papers published in scientific journals in addition to chapters in international books and many technical reports.

Abstract

The first step towards water quality management is the establishment of a monitoring network. Monitoring in the logical sense, implies watching the ongoing water characteristics and activities in order to ensure the laws and regulations are properly enforced besides detecting trends for modeling and prediction processes. The design of a network must clearly define the monitoring objectives, and accordingly the necessary simplifying assumptions have to be established. Based on the assumptions made, there are many levels of design that could be applied. The supreme aspiration of the national water quality monitoring program in Egypt is to bridge the gap between simple water quality monitoring and trustworthy decision making.

This research presents the process of redesigning the water quality monitoring network of Egypt to produce the national water quality-monitoring network using the statistical approach proposed by Sanders and Adrian (1978) of the expected confidence interval for the mean value. An evaluation of the network is implemented using the additional data produced after the design phase as well as a verification of the considered assumptions within the scope of work. Through the assessment, some reduction was perceived in the percentage of error associated with the design phase.

Introduction

Several recent initiatives on water quality have been conducted by the Government of Egypt to provide a conceptual design of an integrated national water quality monitoring network. The main objectives of the surface water quality monitoring network are:

- to assess the water quality entering Egypt and released from HAD by monitoring Lake Nasser;
- to monitor the seasonal variation of the water quality along the Nile and irrigation canals;
- to quantify the variation in the drainage water quality in relation to the existing different pollution sources; and
- to identify the quality and quantity of drainage water reuse in agriculture.

This research presents an assessment of the Nile Delta drainage network. Figure 1 shows the monitoring sites for the Nile Delta drainage and irrigation systems

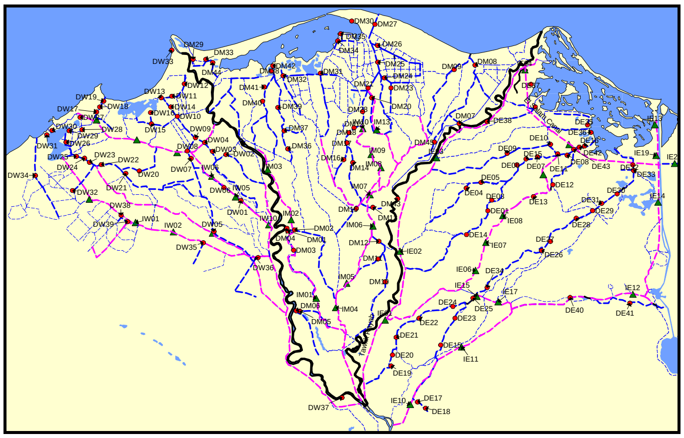

Figure 1. Water quality monitoring sites

Network Optimization Approaches

The design and optimization of the monitoring network, is based on three main design aspects commonly referred to as: 1) Monitoring locations and its spatial distribution; 2) Sampled parameters; and 3) Frequency of sampling. Through this research, the third aspect will be studied and discussed in details.

Statistical Analyses Approach

Due to the stochastic nature of the collected information, the design, optimization, and evaluation of the monitoring network, have to be based on statistical analyses to justify and guarantee the quality of the collected data. The network design and evaluation are based on the selection of the optimum number and distribution of the sampling sites, the frequency of sampling, and the sampled parameters. The frequency of sampling is dependant on a number of factors, including the desired statistical power and level of confidence in the final decision and the variability of the environmental attribute of interest.

It is important to note that, due to the large size of available data, sites and time frame limitations, the most significant approach (single station - single variable) has been fully studied. The leftover approaches may be recommended in future studies.

Sampling Frequency Analysis

Based on the statistical analysis of the collected data from the existing monitoring network, the sampling frequency can be treated objectively, which is one of the main aspects of the monitoring network assessment and redesign. Since the variation in water quality variable prevents exact determination of the statistical parameters with enough reliability to yield information to assist decision markers, so it is necessary to consider variation (variance) in determining sampling frequency. Simply stated, the more water quality varies the more samples will be required to obtain a reliable estimate of statistical parameters used to describe its behaviour (Sanders, et al., 1983).

Single Station, Single variable

The simplest case of sampling frequency design would be to select the sampling frequency, which results in the desired confidence interval width about the annual mean (or geometric mean) for a specified water quality variable at a specified station (Sanders and Adrian 1978). Assuming that the population variance is known and that the samples are independent, the variance of the sample may be computed from Equation 1.

$$\mathrm{var}(\bar{x}) = \frac{\sigma^2}{n} \qquad (1)$$

where σ = population variance and n = number of samples

In general, the population variance, σ^2, will not be known but can be estimated from existing data. If s^2 the sample variance, is assumed to be the population variance σ^2, then n required to obtain a given degree of confidence can be derived from Equation 2.

$$\left[\bar{x} - z_{\alpha/2}\,\mathrm{var}(\bar{x})^{\frac{1}{2}} \le \mu \le, \bar{x} + z_{\alpha/2}\,\mathrm{var}(\bar{x})^{\frac{1}{2}}\right] \qquad (2)$$

With var $(\bar{x})$ replaced by σ^2 / N (Where N is the number of samples used to compute σ^2) and rearranging terms, n required to obtain a future estimate of the mean, with a known level of confidence, can be computed by:

$$n \ge \left[\frac{z_{\alpha/2}\sigma}{\mu - \bar{x}}\right]^2 \qquad (3)$$

Substitution of s in place of σ in Equation 2 requires the use of the Student's "t" statistic (t) instead of z. The difference between the true population mean and the sample mean, $\mu - \bar{x}$, is sometimes referred to as the error, E. This substitution results in:

$$n \ge \left[\frac{t_{\alpha/2}s}{E}\right]^2 \qquad (4)$$

In both Equations 3 and 4, three quantities are required to determine n. An acceptable confidence level, 1-α, and error, E, must be specified. The third quantity, s^2 is derived from data. If the estimate s^2 is used, the computation of n becomes an iteration problem. To use t, the number of degrees of freedom must be known. However, the number of degrees of freedom is n-1, and n is not known. It cannot be determined without knowing t. To solve the problem, a value for n is estimated, the degrees of freedom are determined, and a first approximation of n is computed using Equation 3. A new n is selected between the initial estimate and the first approximation, but closer to the latter. A second approximation is then computed. The procedure is repeated until successive approximations are nearly equal.

In the design phase, the first assumption made was that the data is random. The second assumption was that the samples are normally distributed; the sampling frequencies were calculated using equation 4, which has three unknowns, sampling frequency (n), Student t statistics and the Error (E). It is clear that "t" statistics can only be found by knowing the confidence level (α) and number of samples (n). To perform these iterative computations, the confidence level was considered to be 95% and the sampling frequency starts with 12 samples per year. The standard deviation (s) was calculated from the raw data. The Error (E) was assumed as a percentage of the sample mean as 10%, 15%, 20% and 25%. This is to declare the effect of the accepted errors in the sampling frequency calculations.

Water Quality Parameters and Indicators

Water quality indicators are good tools for rapid assessment; they may be also used to represent the overall compliance of water quality with specific law (DRTPC, 2002). Variables that are selected to be the representative indicators show the highest coefficient of variation among their groups. An indicator is statistically identified for each group. DO is the factor that influences all chemical and biological processes within water bodies. The measurement of DO is used to indicate the degree of pollution by organic matter and the level of self-purification of surface water. BOD is an indicator for the amount of oxygen that is needed for the biological degradation of organic materials. TDS mainly consist of inorganic salts; it determines the suitability of water for agricultural uses. Although iron is not harmful to humans, it is selected because it showed the highest coefficient of variation among its group.

Discussion

Considering the drainage locations, the results for the four cases of the assumed error percentages of Eastern, Middle and Western Delta are summarized in Table 1.

Table 1. Number of samples / year, Delta Drainage Locations, (summary)

Region	Cases	Error %	BOD	Fe	TDS	DO
East	**1**	10 %	55	12	7	47
	2	15 %	25	6	4	21
	3	20 %	14	3	2	12
	4	25 %	10	3	2	8
Middle	**1**	10 %	60	13	8	64
	2	15 %	27	6	4	29
	3	20 %	16	4	3	16
	4	25 %	10	3	2	11
West	**1**	10 %	66	15	7	29
	2	15 %	30	7	4	13
	3	20 %	17	4	2	8
	4	25 %	11	3	2	5

By viewing the four cases of East Delta, it is clear that to fix an error percentage to the four parameters would not be the ideal solution. Case (3), with 20% error appears to be the most suitable solution for BOD and DO, while case (2) with 15 % error is the most suitable solution for Fe and TDS

On comparing the cases of Middle Delta, it is clear that there is no significant difference between Middle and East Delta except for DO. Case (4) with 25% error is the most suitable solution for BOD and DO, while case (2) with 15 % error is the most suitable solution for Fe and TDS

Considering the four cases of West Delta, it is clear that there is a slight difference between West, Middle and East Delta except for BOD and DO. Case (4) with 25% error is the most suitable solution for BOD. While case (2) with 15 % error is the most suitable solution for Fe, TDS and DO.

Based on the above results, the proposed sampling frequency is 12 times/year for all parameters, while 6 times/year for heavy metals and salinity groups is recommended.

The Verification Process

The level of redesigning accuracy might have been affected by the simplifying assumptions. In this part of the study, the focus is directed on verifying the assumptions made. As an example, the process was confined to one strategic location.

Methodology

The first step is to draw the box plots and check if outliers are accepted or not using Grubb's test as follows:

$$Z = \frac{|\,\text{mean} - \text{value}\,|}{SD} \qquad (5)$$

H_o : value = mean and if $Z \geq Z_{cr}$ then reject H_o

In the second step, the refined data is used to produce descriptive statistics such as the mean, median, standard deviation, coefficient of variation, maximum, minimum and range. The third step is to check normality by visually comparing the observed and the theoretical frequency histograms and using the probability plot. One more technique for determining the form of distribution was used; the Chi-Square Goodness-of-Fit Test to compare the data distribution against any hypothesized distribution including the normal distribution. The steps are carried out using the SPSS software version 10 for windows.

The fourth step is rather complicated, which is studying the independency of the data by checking the existence of autocorrelation or not by constructing two sequences of time series on the same plot. The first sequence describes the measured refined data, while the other adjusts the data before plotting by removing any possible seasonality component. The later step is carried out using the STATISTICA software version 6 for windows. Time series analysis could be described in terms of two basic classes of components: trend and seasonality. The purpose of seasonal decomposition method is to isolate those components, that is, to de-compose the series into trend effect, seasonal effects and remaining variability. Finally another descriptive statistics are computed that are to be used in the process of determining the sampling frequency.

The next example shows the results of applying the methodology to a single location (EH11) for a single parameter (TDS) for the period from 1997 to 2002 (57 records).

Analysis of TDS measurements in EH11

Using the Box plot for TDS measurements at EH11, sample number 55 appears as an outlier. By applying Grubb's test for the outlier detected the Z value calculated was (5.31) which exceeds Z critical (3.17) and accordingly rejected. Descriptive statistics were calculated on the rest of the samples after rejection of the outlier as shown in table 2.

Table 2. TDS descriptive statistics (EH11)

N	Mean	Median	Std. Deviation	Coeff. Variation	Range	Maximum	Minimum
56	1476.0	1404.25	335.15	0.227	1507.5	801.32	2308.82

From table 2 the standard deviation is about 23% of the mean, which appears to be reasonable in water quality data. Both the median and the mean look close to each other, as a good indicator that the sample seems to follow the normal distribution. In order to discern the sample distribution a histogram with normal curve and probability plot curve were plotted as shown in figures 2 and 3.

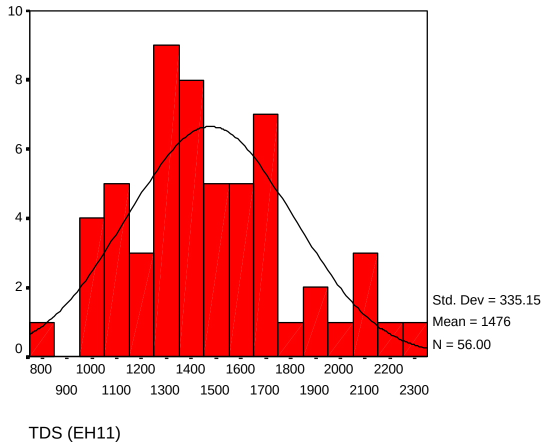

Figure 2. TDS Frequency histogram with (EH11)

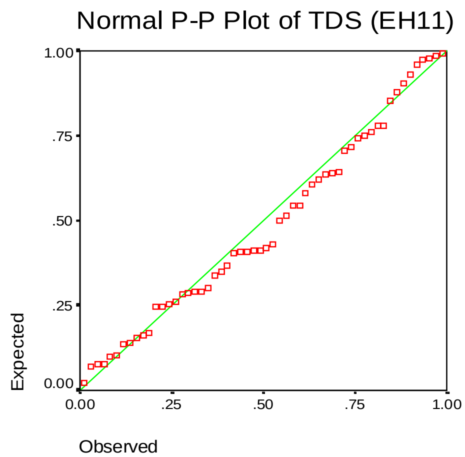

Figure 3. Probability Plot for TDS Normal curve measurements of EH11

Figures 2 and 3 show that the TDS measurements (mg/l) at (EH11) for the period from August 1997 to April 2002 followed the normal distribution. As a checking step to be sure of the visual results obtained from the two figures the Chi-Square Goodness-of-Fit Test was performed for the distribution of the TDS measurements for (EH11) as shown in table 3. In the Chi-Square test, the range of possible values for the TDS measurements is divided into intervals. The actual number of observations falling into each interval (O_i) is then compared with the expected number based on the hypothesized distribution (E_i). By calculating (X^2) as given in equation 7, which is approximately Chi-Square distribution when the sample is "large enough" and the null hypothesis is true, the criterion for rejection of the null hypothesis is $X^2 > X^2_{tabulated}$, at the desired level of confidence (95%) and the degrees of freedom associated. The output of the Chi-Square Goodness-of-Fit Test shows that $X^2 < X^2_{tabulated}$, then the distribution of the TDS measurements in EH11 follows the normal distribution function.

Where $$X^2 = \sum \frac{(O_i - E_i)^2}{E_i} \qquad (6)$$

Table 3. Chi- Square Goodness-of-Fit

Count	No. of classes	E_i	X^2	df	Confidence Level	$X^2_{tabulated}$
56	10	5.6	**11.03**	7	95%	**14.07**

Figure 4 shows the autocorrelation correlogram for the TDS measurements raw data (EH11) to examine the seasonal patterns of time series. The correlogram (autocorrelogram) displays graphically the autocorrelation function (ACF) that is, serial correlation coefficients for consecutive lags in a specified range of lags (e.g., 1 through 12). It is clear from the graph that there is a seasonal pattern in the TDS measurements and a significant serial correlation for the measurements lagged one time interval (r_1 = 0.36). Table 4 presents the autocorrelation coefficient for the TDS measurements.

Time series plots were generated from both the refined data and adjusted data where the seasonality effects have been removed. Figure 5 shows time sequence plot for the TDS measurements refined and seasonality-adjusted data at the same location.

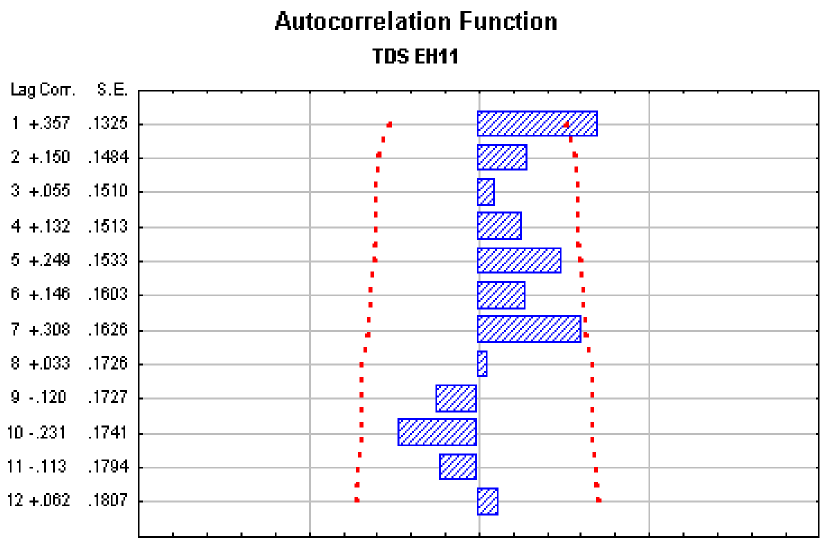

Figure 4. Autocorrelogram for the TDS measurements (EH11)

Table 4. Autocorrelation coefficients for the TDS measurements (EH11)

Lag	Estimate	Lag	Estimate
1	0.357	7	0.308
2	0.150	8	0.033
3	0.055	9	-0.120
4	0.132	10	-0.231
5	0.249	11	-0.113
6	0.146	12	0.062

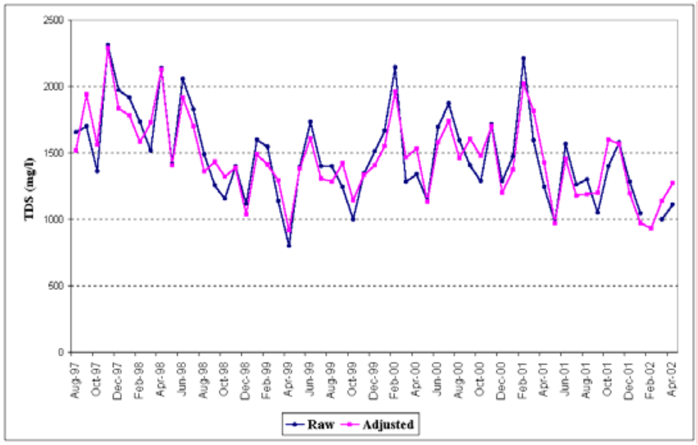

Figure 5. Time sequence plot for the refined and seasonality-adjusted TDS measurements

Descriptive statistics for the seasonally adjusted TDS measurements are presented in Table 5. It could be noticed that the value of the standard deviation decreased from 335 mg/l (Table 5) to 298 mg/l (Table 8).

Table 8. Descriptive Statistics for the seasonally adjusted TDS measurements

Mean	**Median**	**Std. Deviation**	**Coeff. Variation**	**Range**	**Maximum**	**Minimum**
1467.4	1431.88	298.70	0.21	1369.95	918.30	2288.25

The Evaluation Process

Up to this point of analysis, the obtained results are ready to be applied using the method mentioned before. The sampling frequency results are classified to the earlier mentioned four cases (10%, 15%, 20 and 25% error) in estimating the population mean, using those results to obtain a regression equation between error percent and the number of samples desired per year as shown in figure 6 that is to easily detect the number of samples associated with the error percent accepted.

Figure 6 shows the number of samples per year against error percentage in estimating the mean of TDS measurements. The sampling frequency for other error percentages can be estimated by extrapolating the trend curve.

Sampling frequency analysis was carried out for the three locations over the extended period. The sampling frequency results for each monitoring location are classified to the earlier mentioned four cases (10%, 15%, 20% and 25% error) in estimating the population – mean. Table 6 presents the number of samples per year for the selected water quality variables for the four cases of error percentages.

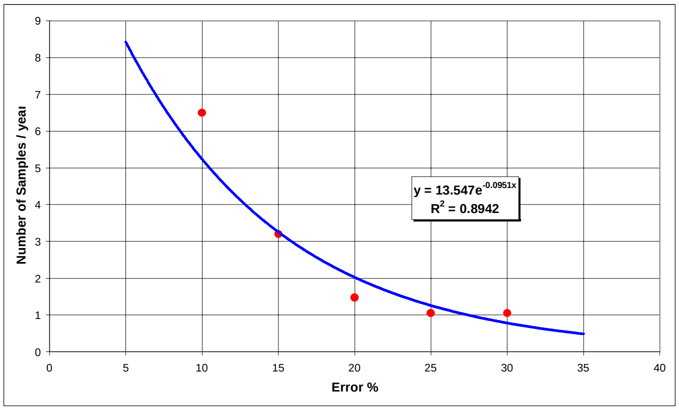

Figure 6. Location EH11 sampling frequency for TDS measurements

Table 6. Number of samples/year for water quality variables

Location	Error %	BOD	Fe	TDS	DO
EH11	10 %	24	19	7	19
	15 %	11	8	4	10
	20 %	7	5	2	6
	25 %	5	3	2	5
EH14	10 %	16	14	6	25
	15 %	9	7	3	12
	20 %	6	4	2	8
	25 %	4	3	2	6
EH15	10 %	14	15	5	23
	15 %	8	7	3	11
	20 %	5	4	2	7
	25 %	4	3	2	5

Conclusions

This research was initiated in order to describe the process of assessment of the national monitoring network of Egypt using specific statistical approaches. A methodology of multi step procedure is proposed to verify the assumptions made through the assessment. An evaluation of the sampling frequency is implemented using an additional data. Based on the analysis and results reached throughout the study, the following conclusions could be drawn:

- In all locations measuring TDS and Fe (with and without the additional data) six times per year might generate errors less than 15% from the mean.

- In all locations measuring BOD and DO twelve times per year might generate errors less than 25% from the mean, while on using the additional data it was reduced to less than 15% from the mean. This could be either due to the accuracy reached from extra data or due to the invalid assumptions within the redesign scope of work.

- Although the selection of three locations over a strategic drain is not representative of the whole drainage monitoring network yet the high correlation between the evaluation output and the whole network redesign is a ratification of the methodology applied.

References

Sanders, T.G., and Adrian, D.D., 1978, Sampling frequency for river quality monitoring, Water Resources Research **14**, pp 569-576

Sanders, T.G., R.C. Ward, J.C. Loftis, T.D. Steele, D.D. Adrian, and V. Yevjevich. 1983. Design of networks for monitoring water quality. Water Resources Publications, Littleton, CO.

DRTPC, 2002, Development of water quality indicators and atlas of drainage water quality using GIS tools, final report, Egypt.