ANALYSIS OF LOAD VERSUS CONCENTRATION AS WATER QUALITY MEASURES

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ABSTRACT

Water quality is a term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose. A number of variables are used to measure the health of the water: nutrients, bacteria, salts, metals and pesticides. With the increase in water consumption to satisfy different demands, quantities of disposed waste water are rapidly increased. The continued release of waste water has had serious impact on the water quality of the rivers. Because of stricter environmental regulations and the increasing awareness of the negative impact on human activities on surface water quality, large efforts are made nowadays to prevent further degradation and to recover the water quality. This paper presents the two ways to measure water quality: 1) concentration: amount of material per unit volume (e.g. mg/l or counts/100 ml); 2) load: quantity of material (tonnes/time based on stream flow and concentration). In this study, analysis of water quality status in terms of concentrations and loads has been given with an application on the Egyptian drains. The national standards of Law 48/1982 are used as guidelines to provide a general assessment of the drainage water quality. The environmental effect of a pollutant depends mainly on its concentration or the total loading. The high concentration in the stream gives sometimes the impression that the water has a poor quality but when taking the flow discharge into account, the total pollution load could be small which gives the decision makers the opportunity to design and manage the appropriate water policies for different uses. As a consequence, huge amount of water can be used depending on load quality limitations. Furthermore, the research indicated that the load limitations should be used to express the water quality standards to take the effect of the stream discharge into consideration.

Key Words: Water Quality; Concentration; Load; Discharge

INTRODUCTION

Water quality monitoring is the integrated activity for evaluating the physical, chemical and biological character of water in relation to human health, ecological conditions and designated water uses. It is a critical decision-support system for any water management program. Information from a monitoring program can assist resource and program managers in making decisions or targeting community programming. Monitoring requires the collection and interpretation of water quality data to provide information about water quality conditions. Those interpretations require additional information on hydrology, soils, land management activities and whether to make informed decisions to protect the quality of a water resource. There are two ways to measure water quality (Cooke et al., 2000 [2]):

a- Concentration: amount of material per unit volume (e.g. mg/l or counts/100 ml);
b- Load: quantity of material (tones/time based on stream flow and concentration.

Understanding the contamination source assists in developing an appropriate design for the monitoring program. There are two sources of contamination: point and non-point source pollution (Baker, 1988 [1]; El-Sadek, 2002 [3]). Point source pollution is the release of contaminants through the outlet of a single conduit, such as a pipe or ditch. Discharges into streams, lakes and rivers by wastewater treatment plants, paper mills, and other industrial facilities are classified as point sources of pollution. Runoff from a feed lot pen or overflows from a hog lagoon to a stream or lake are examples of agricultural point sources of contamination. Because point source pollution is usually concentrated, it is the most significant contamination source, but it is also the easiest to resolve. For example, runoff ponds or catch basins can be constructed to contain point sources. Non-point source pollution is pollution that does not originate from one location. Diffuse runoff from land and atmospheric-deposited pollutants not attributed to a single point of origin are considered non-point sources. Agricultural examples include runoff from agricultural land and water erosion from cropped fields. Controlling non-point source pollution tends to very difficult and usually requires a change in land management practices. The aim of this paper is to analyze the water quality status in terms of concentrations and loads and give both advantages and disadvantages of concentrations and loads to express the measurements of the water quality parameters with an application on the Egyptian Drains.

WATER QUALITY VARIABLES

Water quality is generally described according to biological, chemical and physical properties. Examples of different water quality attributes are listed in Table 1 (Cooke et al., 2000 [2]).

Table 1: Examples of water quality variables

Chemical	Biological	Physical
Nitrogen (e.g. nitrate, nitrite, ammonia) Phosphorus Dissolved oxygen pH (acidity, alkalinity) Major ions (e.g. Ca^{++}, Na^{+}, Cl^{-}) Pesticides (e.g. herbicides, insecticides, fungicides) Biochemical oxygen demand	Bacteria: Faecal coliforms Total coliforms Escherichia coli Enterococci Viruses Parasites: Giardia Cryptosporidium	Colour Temperature Odour Total dissolved solids Suspended solids Turbidity

Pollutants entering water bodies from non-point sources include sediment, nutrients such as nitrogen (N) and phosphorus (P) which are essential components of plant and animal diets, microorganisms from human sewage or animal manure, and pesticides used to protect crops from plant diseases, destructive insects and weed competition. Although most of these pollutants are transported in surface runoff, some may enter water bodies through atmospheric deposition, from direct application, or from sub-surface or shallow groundwater flow (U.S. EPA, 2003[9]).

Table 2: Some examples of water pollutants and their implications

Pollutant	Primary Concern
Microorganisms	Public and animal health risk: water-borne diseases, livestock health
Nitrogen	Drinking water: high nitrates can be a risk to human health
Phosphorus	Protection of aquatic life: eutrophication
Pesticides	Protection of aquatic life; human health risk
Sediment	Protection of aquatic life; contaminant transport
Dissolved solids	Agricultural uses: salinity and livestock watering

COMPLIANCE WITH WATER QUALITY GUIDELINES

Surface water quality guidelines have been developed for the protection of aquatic life, agricultural uses, and recreation and aesthetics. Water quality data that fall between the range of recommended values outlined by the guideline for a particular use are considered compliant. The minimum-maximum concentration range and the average amount, by which samples exceed guidelines, can also be relative measures of the degree of non-compliance. Some water quality guidelines provide a relative threshold, such as an increase in concentration above background levels (Harris, 2001 [6]). The definition of background level is critical. Background levels may be defined by sampling a reference or control site, or by comparing paired samples, such as upstream and downstream samples.

If downstream concentrations do not exceed upstream concentrations, or if a study site does not exceed the concentrations found at a control or reference site by the amount defined in the guideline, the concentration is considered to be compliant. In this study, the national standard (Law 48/1982) is used as guidelines to provide a general guidance in evaluating the drains water quality.

CALCULATING MASS LOADS

The calculation of the total mass load of a contaminant being carried in a stream assists in determining the magnitude of impact on a downstream water body. Mass load is a calculation of the total mass of a substance, usually expressed in kilograms, that is carried past a particular point on a stream or river for a given time period (e.g. year). To calculate a mass load of a substance, an estimate of stream flow must be taken concurrently with water quality samples. In a flow-proportionate sampling program, an individual water sample does not characterize the stream for equal lengths of time. Therefore, to estimate the average concentration, each sample has to be weighted according to the length of time it is used to represent the stream system (Baker, 1988[1]). Thus, mass load is the sum over a particular time period (e.g. month or year) of each sample's concentration multiplied by the instantaneous stream flow rate when the sample was taken, multiplied by the length of time that the sample represents:

$$\text{Mass Load} = c_i \; q_i \; t_i \qquad (1)$$

where i = 1 to n (number of samples)

c_i = samples concentration (mg/m^3)

q_i = instantaneous stream flow (m^3/sec)

t_i = time interval (seconds)

The time interval is equivalent to one-half of the time interval of that sample and the preceding sample, and one-half of the time interval between that sample and the following sample. Computer programs can be used to automatically calculate total mass loads. Pollutants from non-point sources tend to be delivered during periods of high stream flow. Consequently, a flow-proportionate sampling program must be used to obtain accurate estimates of total mass load of a pollutant. Concentrations and loads of COD, BOD and heavy metals discharged into the Nile River from Upper Egypt drains are shown in Table 3.

Table 3: Water Quality of Agricultural Drains: Upper Egypt (Water Policy Program, 2002[10])

No.	Drain Name	Location (KM)	Discharge Mm^3/day	COD Mg O_2/l	BOD Mg O_2	Heavy Metals	COD kg/day	BOD kg/day	Heavy Metals kg/day
1.	Khour El Sail Aswan	9.9	0.10	102	32.80	0.31	10.08137	3.241854	0.030333075
2.	El Tawansa	37.3	0.01	8	1.01	0.50	0.051872	0.006549	0.003245242
3.	El Ghaba	46.6	0.19	11	1.00	0.75	2.134957	0.194087	0.146341598
4.	Abu Wanass	47.2	0.20	7	1.28	0.39	1.393427	0.254798	0.078330504
5.	Main Draw	48.9	40 l/s	17	1.48	0.61	0.058752	0.005115	0.002106432
6.	El Berba	49.1	0.15	113	42.70	0.70	172.6866	65.25414	0.107202323
7.	Com Ombo	51.0	0.14	151.6	41.50	2.15	218.0993	59.70398	0.309122726
8.	Menaha	55.0	-	4	1.52	0.26	0	0	0
9.	Main Ekleet	57.0	0.02	4	1.53	2.44	0.080664	0.030854	0.049174791
10.	El Raghama	64.7	0.04	10	1.55	0.30	0.44712	0.069304	0.013346532
11.	Fatera	70.5	0.78	5	2.04	0.54	3.89746	1.590164	0.418197458
12.	Khour El Sail	70.8	0.17	2	1.05	0.34	0.340774	0.178906	0.058016774
13.	Selsela	73.9	50 l/s	3	1.25	1.26	0.01296	0.0054	0.005454
14.	Radisia	99.9	0.13	16	3.06	0.22	2.0912	0.399942	0.02908075
15.	Edfu	116.2	0.27	15	1.59	2.37	4.0335	0.427551	0.63742745
16.	Houd El Sebaia	139.5	0.05	16	1.83	0.76	0.783824	0.08965	0.037256135
17.	Hegr El Sebaia	149.1	0.05	19	2.55	0.51	0.941279	0.12633	0.02524114
18.	Mataana	187.7	0.12	39	3.15	1.29	4.777461	0.385872	0.158207459
19.	Habil El Sharky	237.7	0.08	30	1.78	1.06	2.37357	0.140832	0.084222176
20.	Danfik	251.6	0.01	34	2.52	1.05	0.279616	0.020724	0.00865576
21.	Sheikia	265.3	0.06	37	1.72	4.68	2.221371	0.102908	0.279794995
22.	El Ballas	270.7	0.01	144	10.78	0.59	0.919152	0.068809	0.003788311
23.	Qift	275.9	0.03	30	1.60	0.39	0.97911	0.052219	0.012744749
24.	Hamed	331.2	0.07	11	1.00	0.35	0.737748	0.067068	0.023239062
25.	Magrour Hoe	340.4	0.06	21	3.24	1.05	1.232889	0.190217	0.061497678
26.	Naga Hammadie	377.8	0.21	13	2.17	1.67	2.7937	0.466333	0.35920535
27.	Mazata	392.8	0.01	10	2.19	0.23	0.05868	0.012851	0.001329102
28.	Essawi	432.7	0.07	9	2.43	0.51	0.667818	0.810311	0.037731717
29.	Souhag	444.6	0.05	9	2.81	0.38	0.4275	0.133475	0.01826375

30.	Tahta	486.4	0.01	21	2.01	0.29	0.131796	0.012615	0.001829454
31.	El Badary	525.4	0.12	6	3.27	0.48	0.71964	0.392204	0.05703147
32.	Bany Shaker	588.6	0.02	13	2.25	0.30	0.254826	0.044105	0.005968809
33.	El Rayamoun	637.4	NA	21	15.85	1.16	0	0	0
34.	Etsa	701.2	0.57	100	38.00	1.19	56.7976	21.58309	0.105359548
35.	Absoug	780.5	0.19	29	1.89	0.34	5.637194	0.36739	0.066965977
36.	Ahnasia	807.2	0.54	14	1.31	0.26	7.583128	0.709564	0.138933738
37.	El Saff	871.3	NA	NA	NA	NA	0	0	0
38.	El Massanda	879.6	0.14	45	4.99	0.19	6.3666	0.705985	0.02624454
39.	Ghamaza El Soghra	884.5	0.06	42	2.52	0.46	2.503872	0.150232	0.027214704
40.	Gamaza El Kobra	885.0	0.05	32	3.79	0.28	1.537152	0.182056	0.013618206
41.	El Tibeen	898.1	0.02	25	15.20	3.71	0.50425	0.306584	0.007795705

CALCULATING MASS EXPORT COEFFICIENTS OR UNIT AREA LOADS

The total mass export coefficient or unit area load is the estimate of the amount of contaminant lost per acre or square kilometre of watershed. Export coefficients are calculated by dividing the total mass load of a substance by the watershed area (actual or effective drainage area) upstream of the sampling station for a given period of time (e.g. year). Mass Export is defined as (Cooke et al., 2000 [2]):

Mass Export = *Mass Load (kg) / Watershed Area (km^2)* (2)

The calculation of mass export coefficients (as kg km^{-2} yr^{-1}) allows for general comparisons of pollutant export from watersheds with differing sizes. However, export coefficients are strongly influenced by runoff volume, and pollutant delivery of different water quality parameters may behave differently depending on watershed size or scale. Thus, comparisons between watershed export coefficients may be more qualitative than quantitative. Export coefficients also quantify how much of a substance is leaving a particular area. Export coefficients on nutrient loss from a field, for example, illustrate how much fertilizer may be lost from a farming operation. These export coefficients can be used with cost estimates for nutrients to see whether the loss is economically significant to the farmer (Radwan et al., 2001 [7]). An example of calculating a total mass load and mass export is given below.

The predicted discharge outflows are used with a flow-weighted concentration to obtain N loadings at the individual outlets of the fields with different management scenarios (El-Sadek et al., 2004 [5]). The annual measured and simulated NO_3-N load, in kg ha^{-1}, at the river outlet is given in Figure 1.

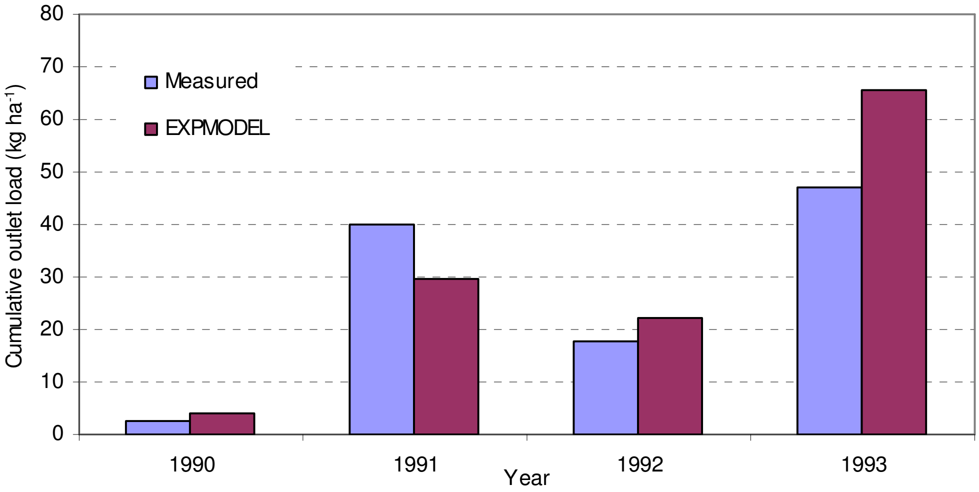

Figure 1: Annual measured and simulated NO_3-N load, in kg ha^{-1}, at the river outlet

Concentration peaks within the period of fertilizer application between March and May can be clearly seen in years 1991 and 1993. The nitrate load peaks correspond to the rainfall events in these years. This occurs as the upper layers of the soil become saturated allowing the fertilizer to dissolve in the available moisture and to be transported to the river. The low load in 1990 is the result of a dry year. The agreement between the measured and predicted nitrate load in Figure 1 is good. However, it is recognized that daily time series output can not be compared in detail against monthly point measurements. Approximately 60% of the applied nitrogen is taken by plants with 30% transported via groundwater and surface waters to the river (El-Sadek et al., 2003 [4]).

The sampling time period for this example would be less than one day; however, export coefficients are usually computed for an entire year.

COMPARISON EXAMPLES

Depending on concentration criteria, in March 2002, the percentage of the drains violates the nitrate (NO_3-N) standards is 17.2% and the percentage which violates the standard by 50% is 10.3%. The worst conditions are registered at Radisia and Khour sail Aswan drains. For August 2002 the conditions are better as 6.9% of the drains exceeds the standard, 3.4% from them exceeds the standard by 50%. For BOD, for March and August 2002 the percentage of the drains that does not comply with the standard is 13.8%. The percentages of the drains violate the standard by 50% are 13.8% and 10.3% for March 2002 and August 2002 respectively. The worst conditions for March 2002 are registered at El Berba and Kom Ombo drains where the concentrations are 410 mg/l and 380 mg/l respectively. In March 2002, the percentage of the drains violates the nitrate standards is 17.2% and the percentage which violates the standard by 50% is 10.3%. The worst conditions are registered at Radisia and Khour sail Aswan drains. For August 2002 the conditions are better as 6.9% of the drains exceeds the standard, 3.4% from them exceeds the standard by 50%. Total–p concentrations in different drains implied that the percentages of the drains violate the standard for March and August are 10.3% and 3.4% respectively. From these drains 3.4% violates the standard by 50% for both March and August 2002. TDS results indicated that the percentages of the drains violate the standard are 62.1% and 72.4% for March and August 2002 respectively. The percentages of the standard violation by 50% are 27.6% for both March and August 2002. The worst condition is registered at Radisia drain.

Figures 2 to 5 present the comparison between the different parameters load and concentration. From these figures, it can be seen that the load is more representative than the concentration for the quality conditions. For NO_3-N and total-p (Figures 2 and 3), Khour Sail Aswan drain has the highest concentration while, the concentration at Fetera drain is seven times less, it has the highest load (1.5 and 2.7 times higher for NO_3-N and total-p respectively). Comparing Biological Oxygen Demand load and concentration of different drains, Khour Sail Aswan drain and Etsa drain have almost same load (Khour Sail Aswan drain is 0.6 ton/day higher than Etsa drain). Khour Sail Aswan drain concentration is 4.25 times than Etsa drain. For TDS, Radisia drain concentration is two times higher than Fetera drain. The load of Radisia drain is eight times less than Fetera drain.

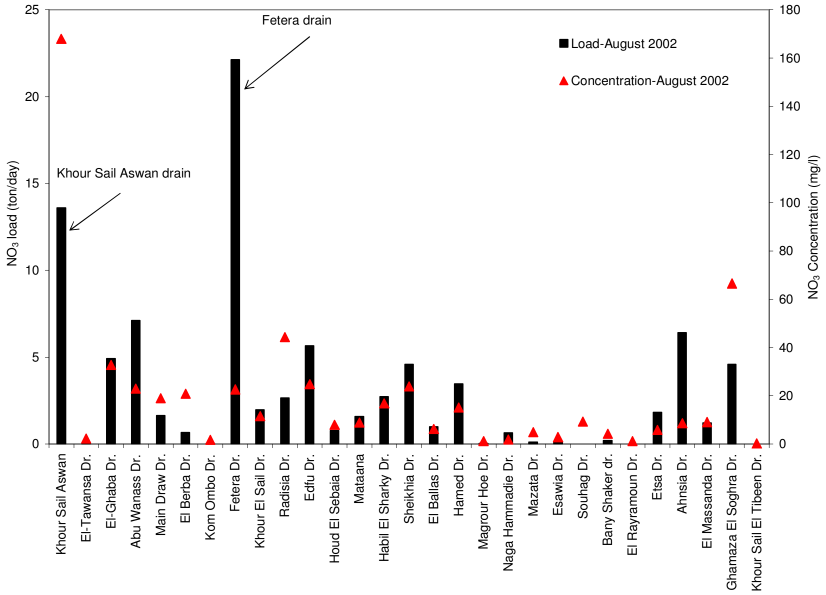

Figure 2: NO_3-N load and concentration for different drains

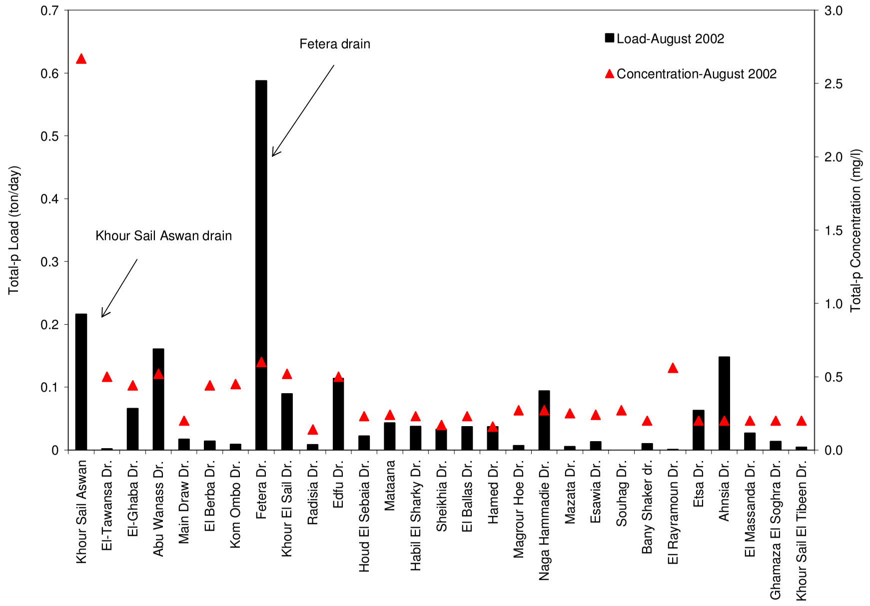

Figure 3: Total-p load and concentration for different drains

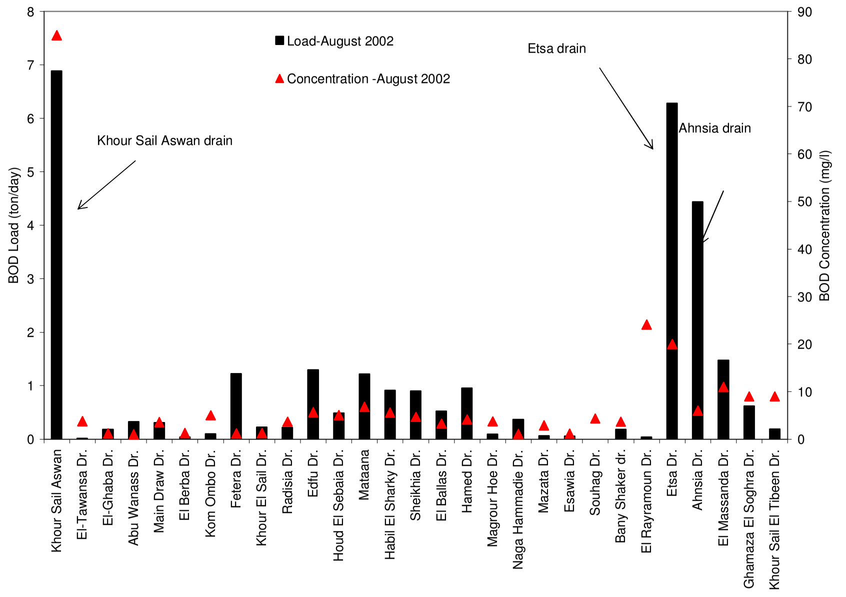

Figure 4: BOD load and concentration for different drains

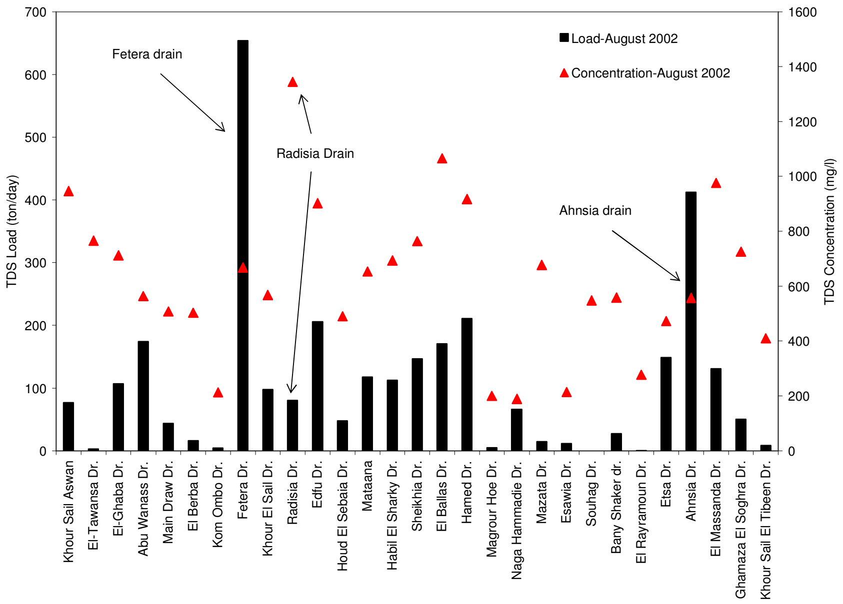

Figure 5: TDS load and concentration for different drains

DISCUSSION

It is important to determine the quality of the water and its suitability for particular purposes by setting guidelines to put standard limitations. For example, nutrients such as nitrogen and phosphorus are essential for crop growth. However, very small amounts in water can cause excess algae and weed growth, oxygen depletion and taste and odour problems. Nitrate, a form of nitrogen, can also cause health problems in cattle and young children. The principal problem in load calculations is that there are many flow data are missing. Stream flow should be measured in the field and discharge results compiled in the office. Stream flow measurements should be taken at specific locations at the other water quality parameters are sampled. In most situations, the flows and concentrations are correlated, and it should be possible to extrapolate from known flow and concentration to the whole flow data set.

The sensitivity to detect changes in water quality as well as attribute water quality changes to specific land use practices is much lower when stream flow is not recorded during a water quality sampling program (Spooner et al., 1987 [8]). Ideally, each stream site being monitored should have an active stream flow gauging station.

Discharge is the rate of stream flow expressed in volume per unit time. Stream discharge can account for much of the variability in water quality data. Thus, it is very important to collect stream flow data from an established stream gauging station and to establish the relationship between stream stage (the height of the water surface, measured by the stream gauge) and stream discharge. For example, a greater amount of phosphorus tends to be delivered during periods of high flow. If stream samples are collected randomly without any information on stream flow, the water quality in the stream cannot be fully characterized and the information generated from such a sampling program is limited. Stream discharge is a critical explanatory variable for quantifying the mass load of pollutants. Therefore, conducting flow-proportionate sampling or sampling during the range of stream flows for a particular stream or river system is recommended for all monitoring programs. The discharge at the time a sample is taken can affect water-quality concentrations. For certain constituents that are associated with suspended particles (for example, total metals, total nutrients, suspended sediment), high discharge produces high concentrations as the suspended particles are flushed through the system. For other constituents which have relatively constant loading rates (for example, many dissolved ions, total dissolved solids, and constituents that arise primarily from waste inputs), high discharge may produce low concentrations in streams because of dilution (Cooke et al., 2000 [2]; Spooner et al., 1987 [8]). Finally, the results of the comparison as shown in Figures 2 to 5 indicated that the decision of the drains quality conditions should be based on pollutant load not on concentration. As the concentration for drains can be high but its load (effect on the quality condition) is minor as presented in this research.

CONCLUSIONS

In this study, analysis of water quality status in terms of concentrations and loads has been given with an application on the Egyptian Drains. The principal problem in load calculations is that there are many flow data are missing. Stream flow should be measured in the field and discharge results compiled in the office. Stream flow measurements should be taken at specific locations at the water quality parameters are sampled. The recommended standard (Law 48/1982) is used as guidelines in this study to provide general guidance in evaluating surface water quality throughout drains. The high concentration in the stream gives sometimes the impression that the water has a poor quality but when taking the flow discharge into account, the total pollution load could be small which gives the decision makers the opportunity to design and manage the appropriate water policies for different uses. As a consequence, huge amount of water can be saved and used depending on quality load limitations. The results indicated that the decision of the drains quality conditions should be based on pollutant load not on concentration. Furthermore, the research indicated that the load limitations should be used to express the water quality standards to take the effect of the stream discharge into consideration.

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