# NUTRIENT VARIATIONS IN THE URBAN DRAINAGE WATER OF HARARE, ZIMBABWE - ASSESSMENT AND REGULATORY ASPECTS

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## ABSTRACT
Results from the water quality monitoring program of the City of Harare, Zimbabwe during the period 1995-2000 have been statistically analyzed. Two main drainage channels with different land use practice have been studied. DR2 drains the Central Business District and DR1 - a mixed residential and industrial area. The discussion includes time and spatial variations regarding pH, TKN, Nitrate and Phosphates. Phosphates pollution was found (median values exceed 2 to 7 times the prescribed limit), mainly at DR1, and was associated with informal discharges from the industrial site. It has been recommended that: the present water quality regulations in Zimbabwe need to be viewed as a step in the development of the country's water pollution control legislation and their scope should be broadened in order to provide the means for regulation of diffuse pollution sources; the pollution control practice should be viewed as a system of mutually interrelated activities, where the quality of the management and implementation of each one separately would reflect on the whole system outputs; the implementation of models, based on GIS, could support and improve the quality of the decision-making process.

**Keywords : nutrients, urban drainage, water quality regulation**

## INTRODUCTION
The City of Harare is the capital of the republic of Zimbabwe with an estimated population of 1 214 119 in 1992, and an average estimate of its population growth rate of 5% per annum (JICA/MLGRUD, 1996). Mean Annual Rainfall (MAR) is approximately 820mm, within a range of 440–1220mm, characterized by high intensities and falling between November and April (AQUASTAT, 2003). The sewer system is separated, where the sewerage is collected and treated before discharge to watercourses. The runoff is collected by a combined drainage system of open ditches and pipelines, associated with the municipal road structure, and is conveyed directly to natural watercourses, which discharge into the Lake Chivero, a dam constructed in 1952. Due to its downstream location (Fig.1), the Lake is the natural sink of the surface run-off and the treated effluents of the City, but also is its main water supply source. Enhanced eutrophication of the Lake was detected in late sixties, but due to proper control measures, concerning the sewage treatment and discharge (introduction of biological nutrient removal, and reuse of treated wastewater for irrigation), the level of eutrophication was contained during the seventies (Balinger and Thornton, 1982). Latest investigations show that during the nineties the Lake has been found to be in a state of advanced eutrophication (Moyo, 1997) due mainly to an accelerated urban population growth. It has been stated that the main causes for the Lakes eutrophication are associated with overloaded or poorly maintained treatment facilities and runoff from sludge and solid waste disposal sites (Mathuthu et al., 1993; Hranova et al., 2002). The influence of the urban drainage has not been investigated in details. The aim of this paper is to assess the status and variations of nutrients in the urban drainage, based on data from the water quality monitoring program of the City of Harare during the period 1995-2000, and discuss the results in a broader context, considering the impacts of the present regulatory instruments and the implementation of the monitoring process and pollution abatement measures, in order to provide environmentally sustainable development.

## METHODOLOGY
### *The study area*
The monitoring program of City of Harare, regarding urban drainage water quality, includes two major drainage channels. The Coventry Road Drainage Channel (earth ditch) is referred in the text as DR1 and the Central Business District Channel (CBD) is referred as DR2 (concrete pipeline). DR1 collects runoff from mixed suburban area of about 13km$^2$, from which 28% comprises of residential housing development and 33% comprises of light industrial enterprises, including meet processing, dairy production, detergents and washing materials, etc. The rest is undeveloped open ground, which during the last 5 years has been used for informal small-scale agriculture. DR1 discharges into Marimba River. DR2 collects the runoff from the town center (approximate area of 2.5 km$^2$), where the land use is predominantly commercial with high percentage of impermeable surfaces and intensive traffic. It discharges into Mukuvisi River. The location of the drainage areas of the two channels is shown on Fig.1. Results are based on data from the monitoring program of City of Harare for the sampling stations Coventry rd. Drainage channel No5 and Seke rd. Drainage Channel No 2, during the period 1995 to 2000. Both sampling points are located at the discharge point of the channels into the respective water bodies. The urban drainage system of Harare has numerous discharge points, but these two have been included in the monitoring program of the City because of the relatively high value of the drained area, compared to other discharge points, and the specific type of urban land use practice.

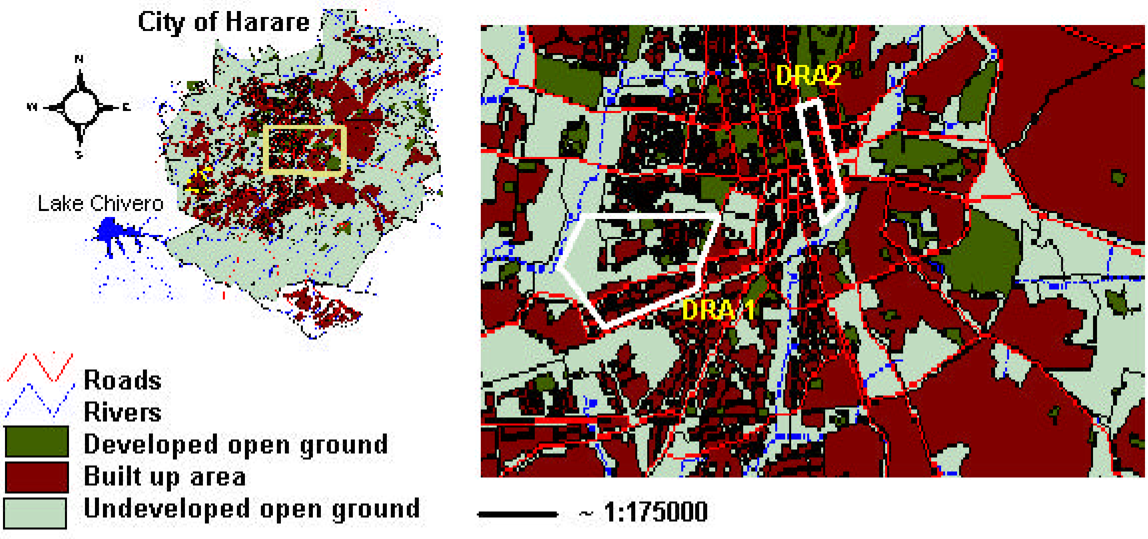


***Fig.1*** *Location of the study area. (DRA1 and DRA2 – drainage areas of channels DR1 and DR2 respectively)*

***Analytical Methods***

The parameters, describing nutrients variations, included in the City of Harare monitoring program are Phosphates, Ammonia and Nitrate. In addition, variations of pH have been included. The planned frequency of sampling was once per month, but at the end of the study period it has been reduced drastically. During 1999 and 2000 only few measurements for the whole year have been executed and for this reason data available has been averaged for both years. Analytical methods used are based on the Standard methods of examination of water and wastewater (1989), phosphates were directly determined by the Vanadomolybdophosphoric acid colorimetric method and represent total reactive phosphorous. Ammonia was determined by direct Nesslerization method, followed by spectrophotometric measurement at 425 nm wavelength. Nitrates were determined by the Cadmium reduction method, followed by spectrophotometric measurement at 540 nm wavelength.

***Data analysis***

Statistical calculations (descriptive statistics and one-tiled Student's t-test – unequal variance, at 90% of confidence) were performed using the Microsoft EXCEL statistical package. Throughout the text, significant difference means that $p< 0.1$ for mean's comparison.

## RESULTS AND DISCUSSION

***Nutrients variations***

Results for DR1 and DR2, as annual mean and median values, are shown on Fig. 2 and Fig.3 respectively. Additional statistical data is presented in Table 1. Results are discussed and compared to the blue classification of effluents discharged to surface water- the Zimbabwean Effluent Discharge Regulations (WWEDR, 2000), which could be regarded as the safe natural water quality limit and is referred in the text as the "prescribed" limit.

The data presented indicates a very high variability of the data set, with large differences between mean and median values, except for pH. For this reason, results are presented as mean and median values, and it is expected that median values of the corresponding data sets reflect more closely the true characteristic of the water quality in both channels. Also, it should be noted that despite of the distinct seasonal rainfall pattern, where no rainfall or extremely rare rainfall occasions are recorded during the months of April to November, water was flowing and samples were collected throughout the year at both sampling locations. This indicates to the presence of informal discharges into the drainage system or drainage of infiltrated ground water. The most probable source of perennial flow in both channels could be associated with informal discharges because the groundwater table in both areas is relatively low during the dry season. .

***Temporal Variations***

Values of pH do not show significant variations during the study period, with a normal distribution of the data set at both locations. Also, for both channels Nitrate values for the period 1995 to 1998 are low, with small difference between mean and median values. For the period 1998-2000 the median values are low too, but mean values are up to ten times higher due to few occasional high records, which could not be associated with runoff and most probably are due to informal discharges. In general, at both locations nitrate concentrations in both channels do not indicate to a form of pollution regarding this parameter. Median values are below the prescribed limits and within background pollution values.

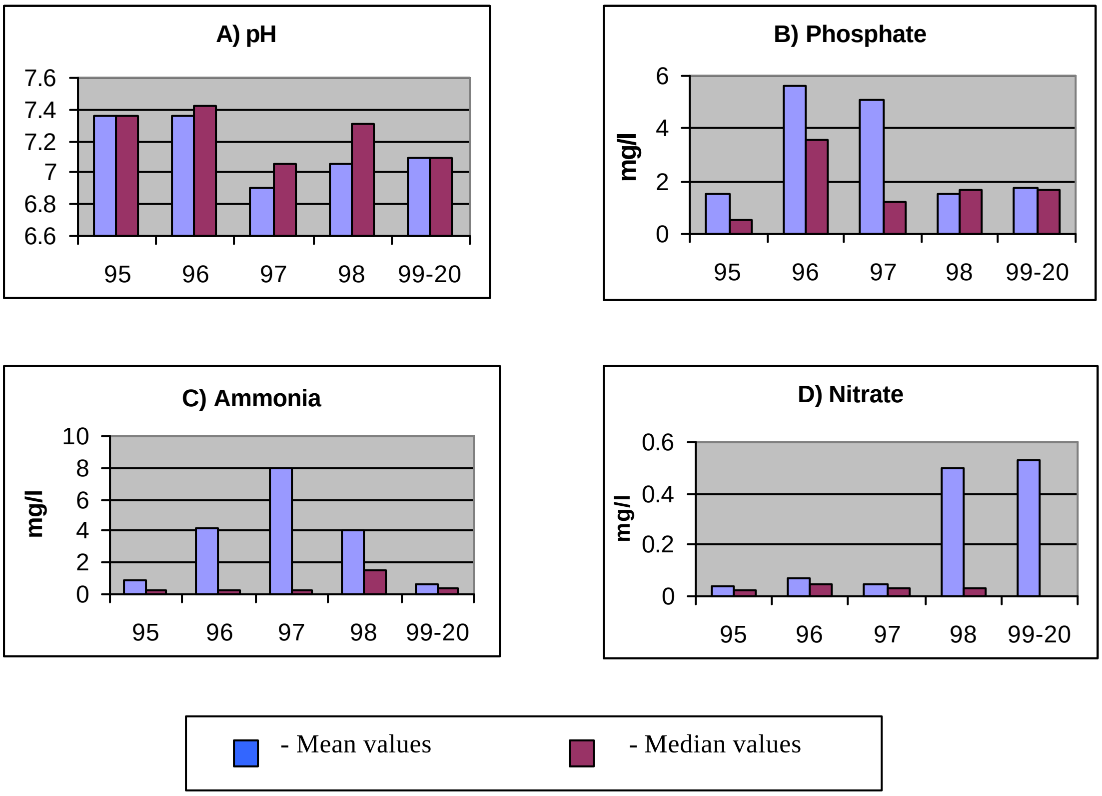


***Fig.2*** *Nutrients variations at DR1*

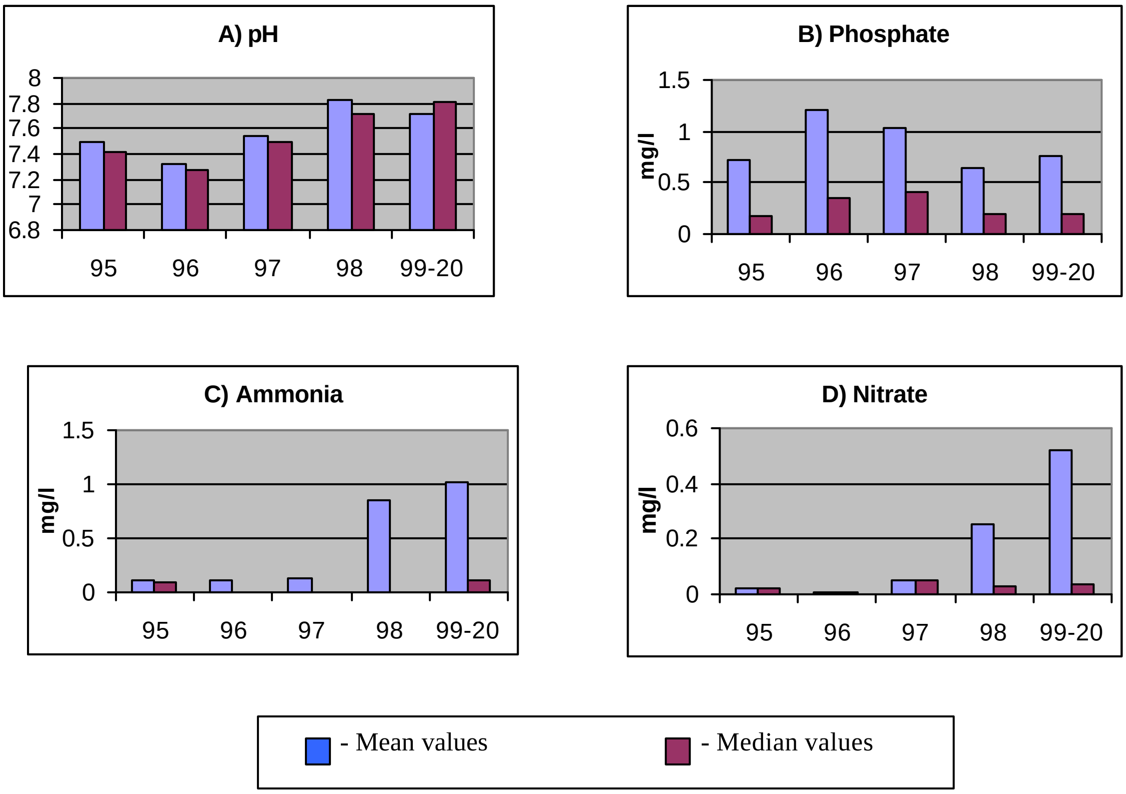


***Fig.3*** *Nutrients variations at DR2*

Ammonia variations of DR2 show low values regarding this parameter for the period 1995-1997. During 1998 to 2000 occasional high values were measured but the median values are within prescribed limit. The results regarding DR1 show very high mean values for the period 1996 to 1998, but the median values are within or near the prescribed limit, except for 1998, when the median value exceeded it 3 times. Background pollution values, which are 0.05 mg/l of ammonia for wet season conditions and 0.2mg/l for dry season conditions (Hranova et al., 2002) are exceeded by the median values of

DR1 throughout the study, which indicates pollution regarding this parameter. Results regarding phosphate variations at DR1 in respect to both - mean and median values exceed the prescribed limit of 0.5 mg/l, with peak mean values during 1996 and 1997. However, it should be noted that the variability of the data set for these two years is very high, resulting in high standard error values (Table 1). Phosphates variation (median values) during the study period was between 0.6 and 1.7 mg/l, except for the year 1996, when a peak of 3.6 mg/l was found. Background pollution values for the City of Harare area, regarding phosphorous, was reported to be ranging between 0.1 and 0.4 mg/l with no seasonal variation (Hranova et al., 2002). Therefore, annual median values for phosphates exceed both background pollution values and prescribed limits up to several times. Similar results regarding high phosphate concentrations at this drainage channel have been reported as well by Jarawaza, 1997. At DR2 median values of phosphates are below or equal to the background pollution, while mean values exceed up to two times the prescribed values throughout the study period with peak mean and median values in 1996 and 1997.

*Spatial variations* were analyzed by comparison of means of the data sets for each specific year, regarding pH and phosphates only, nitrogen compounds were not tested because of the high irregularity of the data sets. The test results show no significant difference for the annual mean pH values at DR1 and DR2. The test results regarding phosphates show significant difference between DR1 and DR2 annual mean values only for the years 1996, 1998 and 199-2000. DR1 shows much higher annual mean and median values of phosphates and there is a well-defined trend of increase of these concentrations after 1995. The lack of significant difference between the annual values in 1997 could be attributed to the irregularity of the data set (standard error =3.24) but not to reduced pollution at DR1.

**Table 1 Statistical characteristic of the data sets**

| | pH | | Ammonia | | Nitrate | | Phosphate | |
|---|---|---|---|---|---|---|---|---|
| | DR1 | DR2 | DR1 | DR2 | DR1 | DR2 | DR1 | DR2 |
| | | | | *1995* | | | | |
| Standard Error | 0.09 | 0.067 | 0.353 | 0.033 | 0.02 | 0.004 | 0.644 | 0.535 |
| Count | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| | | | | *1996* | | | | |
| Standard Error | 0.191 | 0.050 | 3.851 | 0.069 | 0.023 | 0.004 | 2.333 | 0.788 |
| Count | 9 | 8 | 9 | 8 | 9 | 8 | 9 | 8 |
| | | | | *1997* | | | | |
| Standard Error | 0.118 | 0.097 | 7.729 | 0.073 | 0.019 | 0.013 | 3.254 | 0.472 |
| Count | 12 | 13 | 12 | 13 | 12 | 13 | 12 | 13 |
| | | | | *1998* | | | | |
| Standard Error | 0.153 | 0.271 | 1.955 | 0.814 | 0.022 | 0.145 | 0.242 | 0.230 |
| Count | 10 | 11 | 10 | 11 | 10 | 11 | 10 | 11 |
| | | | | *1999-2000* | | | | |
| Standard Error | 0.271 | 0.130 | 0.284 | 0.931 | 0.521 | 0.448 | 0.574 | 0.369 |
| Count | 5 | 7 | 5 | 7 | 5 | 7 | 5 | 7 |

During 1998 -2000 the median values at DR1 are closer to the mean values, suggesting that the process of pollution has a constant nature. However, the reduced frequency of sampling during 1999-2000 might have resulted in data, which does not reflect the real status of the water quality. The significant difference in the level of phosphate concentrations between DR1 and DR2 could be associated with the difference in the land use pattern of the drained area. DR1 drains 3 different types of areas – residential, industrial and open undeveloped grounds. The residential part consist of medium density one story housing units, where the roof runoff is discharged and infiltrated to gardens, therefore its contribution in terms of quantity and quality of the total runoff could not be significant. The industrial area has much higher level of impermeability, thus in terms of runoff quantity its contribution is expected to be much higher than the contribution from the rest of the area. Possible sources of phosphate pollution to DR1 could be associated with informal discharges form the industrial enterprises or with the use of fertilizers by informal small-scale farmers in the open ground area. However, the constant nature of the flow and the pollution variations suggest that the source is most likely associated with regular informal discharges than with pollution from agricultural runoff.

***Regulatory and control aspects***

The evident difficulty to monitor and control diffuse pollution requires an objective orientated approach, where the main goal should be to control and maintain natural water quality in a sustainable manner. In order to prevent environmental pollution, the development of specific guidelines, based on local data about the background water quality in the area is very important. These documents should be enough specific to allow comparison with actual measurements and detection and assessment of pollution levels. The Zimbabwean regulations (WWEDR, 2000) are discharge - orientated and are aiming at enforcing in practice the “polluter pays” principle. They focus on effluent discharges to surface water, effluent and sludge disposal on land, and solid waste disposal. Runoff quality is included in the different classifications only for specific cases as sludge, effluent and solid waste disposal sites. Possible pollution from agricultural or urban runoff is not envisaged, most probably because of the difficulty to identify these types of sources of pollution and corresponding polluters.

A sustainable approach to the control and regulation of diffuse pollution would require the following points to be considered:

*The Water quality objective approach* should be implemented in order to provide a wider range of protection of the water resources and to specify the natural (surface and groundwater) background quality for each specific region. The implementation of this approach does not necessarily mean that it should lead to a conflict for cases where the effluent discharge regulations are in place, as in Zimbabwe. It should be viewed as a broader approach to the regulation of water quality, which could include guidelines/criteria for natural water quality and incorporate the acting regulations for effluent discharges in order to achieve the prescribed objectives. The formulation of sustainable and practically sound objectives require:

- A sound estimation of the present status of the natural water quality;
- A good knowledge of effluent treatment and disposal Best Practice (BP) - local and international;
- Consideration of the conditions for implementation of BP in the light of the economic status of the region and availability of financial, technical and human resources.

*The water quality monitoring aspects* are closely linked to the regulatory instruments in place and should form an integrated part of such documents. The following aspects should be considered:

- The design of a sustainable and practically implement able monitoring program - it would require a good understanding of local conditions, possible sources of discrete and diffuse pollution, the pollution nature and should be based on historical information collected. The implementation of a monitoring program to match the water quality objective approach could become a serious challenge. In some cases it could result in an oversized monitoring program, with the inclusion of numerous sampling points (end of pipe and natural water quality) and numerous parameters tested, which could jeopardize its implementation. In other cases the locations and parameters tested could be not enough to provide the necessary information. The design of a suitable monitoring program is region specific and requires expert knowledge in the field. The frequency of sampling is another aspect to be considered during the design of the program. Monitoring of diffuse pollution, which is closely related to runoff, requires an event-orientated approach. Specifically for the case of tropical countries with distinctive wet and dry seasons, the major pollution loads are expected during the beginning of the rains season, therefore frequency of sampling during this period should be higher. Intensity of rainfall events is also an important factor, because of its erosive effect and the increased risk of transport of pollutants. Regular monthly monitoring of urban drainage, as in the case of City of Harare program, would not provide reliable information. Proper determination of the annual frequency of sampling should be done based on detailed examination of the rainfall patterns specific for the region and should provide enough data for statistically reliable results. It is important to be noted also, that the design of a monitoring program is not a "once for ever" exercise but should be viewed as a processes, where regular periodical assessments of its effectiveness and consequent improvements are mandatory.

- The data quality assurance aspect should be mentioned as pivotal for the success in the implementation of any monitoring program. It is directly connected to the available financial, technical and human resources potential and if these resources are not provided the basic objectives of the monitoring program would be jeopardized. Proper data validation and storage procedures (UN/ECE Task Force on Monitoring & Assessment, 1996) should be executed on regular basis to minimize errors occurrence. The quality assurance measures are even more important in the cases of diffuse pollution control, because they would allow eliminating gross measurement errors and would reduce the natural high variability of the data sets, due to the uncertainty of rainfall occasions and runoff quality.

*Tools for identification and estimation of diffuse pollution sources* – considering the nature of diffuse pollution and urban drainage specifically, pollution loads magnitude would be determined by the land use and rainfall patterns. Therefore, its correct estimation would depend heavily on the proper evaluation of the characteristics of the drained area, reliable methods for runoff estimation and reliable rainfall data sets. These factors, presented in the form of an information database, together with the information provided by the corresponding water quality monitoring programs, result in a massive information block, which is difficult to be handled and interpreted manually. For this reason, the estimation and control of diffuse pollution requires the development and implementation of models, based on GIS systems, which could provide the necessary means for data handling, storage and retrieval. Also, the application of such tools would improve the reliability of results obtained and their level of accuracy. Their implementation is even more relevant for the cases of urban drainage pollution, where the variability of land use practices per unit area is much higher compared to cases of agricultural diffuse pollution. The need for development of such type of models is also important in view of the introduction of an integrated approach to the water resources management practice, which require consideration of different and numerous factors affecting water quantity and water quality, based on catchment principles.

*Pollution abatement measures* – diffuse pollution is difficult to identify and its remediation could be extremely complex and costly. Therefore, pollution prevention measures should have high priority. Public awareness programs are one important measure. Proper maintenance of road structures and drainage channels, together with a sound solid waste management practice would lead to prevention of urban drainage pollution. A previous study on the urban drainage in high-density areas in Harare (Mvungi et al., 2002) shows that one of the most important sources of urban drainage pollution is related to poor solid waste collection practice. New development of urban areas should consider the implementation of measures to reduce urban drainage pollution such as: reduction of impervious surfaces, provision of more green areas and proper drainage and sanitation facilities. In cases where pollution is already identified, abatement measures should include improved control of informal discharges. In places where land is available, the provision of natural treatment systems as provision of wetlands before the discharge of drainage channels into surface watercourses could be an appropriate measure for retention of suspended particles and reduction of nutrients (Kao and Wu, 2001).

## CONCLUSIONS

- Nutrient variations in two drainage channels of the City of Harare show that phosphates are a serious source of pollution to surface waters, especially at Coventry rd. drainage channel (DR1) and could be associated with informal discharges from the industrial area drained. This finding points out to the need of controlling not only industrial discharges to the sewer system but to the drainage system as well, which should be executed by local authorities.
- The present water quality regulations in Zimbabwe need to be viewed as a step in the development of the country's water resources legislation and could be incorporated in a broader document, which should be "objective orientated" and should provide the means for regulation of diffuse pollution sources.
- A sustainable approach towards the implementation of diffuse pollution control practice requires that it should be viewed as a system of mutually interrelated activities – the monitoring, the data processing, the decision-making process and the pollution abatement measures, where the quality of the management and implementation of each one of them separately, would reflect on the system outputs as a whole. The multifactoral nature of the problems associated with diffuse pollution control and abatement requires the implementation of models, based on GIS, in order to support and improve the quality of the decision-making process.

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## REFERENCES

AQUASTAT (2003). FAO's information System on Water and Agriculture at http://www.fao.org/ag/AGL/aglw/aquastat/countries/zimbabwe/index.stm

*Balinger B.R. and Thornton J.A. (1982) The hydrology of the lake McIlwaine catchment . In*: Lake Mcllwaine – the Eutrophication and Recovery of a Tropical African Man-made Lake. *Edited by Thornton J.A., Nduku W.K., Dr W. Junk Publishers, The Hague-Boston-London, pp. 34-43*

Hranova R., Gumbo, B., Klein, J. and van der Zaag, P. (2002). Aspects of the water resources management practice with emphasis on nutrients control in the Chivero basin, Zimbabwe, *Physics and Chemistry of the Earth*, 27, p.875-885

Jarawaza M. (1997). Water Quality Monitoring in Harare. In: *Lake Chivero: A Polluted Lake,* University of Zimbabwe Publications, Harare, pp. 27-34

JICA/MLGRUD (1996). *A study on water pollution control in the Upper Manyame River Basin in the Republic of Zimbabwe,* Main Report by Japan International Cooperation Agency & Ministry of Local Government, Rural and Urban Development, Harare City Council, Harare, Zimbabwe

Kao C.M., Wu M.J. (2001). Control of non-point source pollution by a natural wetland. Wat. Sci. Tech. **43** (5), pp169-174

Mathuthu, A.S., Zaranyika, M.F. and Jonnalagadda, S.B. (1993). Monitoring of water quality in upper Mukuvisi River in Harare, Zimbabwe. *Environment International* 19, pp. 51-61

Moyo N.A.G. (1997). Causes of massive fish deaths in Lake Chivero. *Lake Chivero – a polluted lake.* Edited by N.A.G.Moyo, University of Zimbabwe Publications, pp.98 – 104

Mvungi A., Hranova R. and Love D. (2002) Impact of home industries on water quality in a tributary of the Marimba River, Harare: implications for urban water management" *Proceeding of the 3rd WaterNet/WARFSA Symposium, Water Demand Management for Sustainable Development,30th and 31st October 2002, Tanzania*. http://www.waternetonline.ihe.nl/aboutWN/3rdProceedings.htm

*APHA/AWWA (1989) Standard methods for the examination of water and wastewater*, 17th edition, American Public Health Association/ American Water Works Association/ Water Environment federation, Washington DC, USA

UN/ECE Task Force on Monitoring & Assessment (1996). *State of the art on monitoring and assessment of rivers* Volume 5, RIZA report No 95.068, p.60-71

WWEDR (2000). Water (Waste and Effluent Disposal) Regulations, Statutory Instrument 274 of 2000, Republic of Zimbabwe.