Impact of agro-industrial activities on the water quality of River Nyando, Lake Victoria Basin, Kenya

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Abstract

The impact of agro-industrial activities on the water quality within River Nyando, Lake Victoria Basin was studied at different hierarchical levels between August 1997 and June 1999. Triplicate water samples were collected on a monthly basis from various stations ranging from the source to the mouth of the river and analyzed for selected physical and chemical water quality parameters using standard analytical methods. Statistical analysis was performed using MINITAB and STATISTICA computer packages.

Agricultural land use was found to be the major factor contributing to changes in water quality. Salinity and pH varied at river basin scale, turbidity, TDS and conductivity at catchment scale, while DO, alkalinity and pH at sub-catchment and river reach scale. The nutrient loads increased downstream. Anthropogenic sources contribute to high levels of nutrients within the basin. The changes recorded in water quality along the river were comparable to the modified Index of Biotic Integrity (IBI) and Nyando Habitat Evaluation Index (NHEI) derived for the river during the same period of study.

Findings of this study can be used to design measures for mitigating and monitoring environmental impacts arising from agro-industrial activities within the Lake Victoria Basin. The study recommends a comprehensive Nyando River Basin Management Programme to address the multiple issues environmental within the basin.

Key words: water quality, agro-industrial activities, land use

Introduction

Rivers play a significant role within a landscape as they are at the receiving end of all the human activities within their catchments. To get a true reflection of what happens within the catchment of a river basin either through point- or non-point sources of pollution, studies of spatial and temporal changes in water quality are very important. Non-point source pollution arises from sources that are normally associated with agricultural and silvicultural, and human activities within the catchment. Non point sources such as nutrients, pesticides, heavy metals and sediments are transported from land by atmospheric, surface water and ground water pathways (Nikolaidis *et. al.,* 1998).

The character of streams and rivers reflect an integration of physical and biological processes occurring in the catchment. Landscape properties that contribute most directly to the structure and function of adequate systems include prevailing climate, catchment and riparian landuse or cover patterns, channel slope and aspect, quartenary and bedrock geology, and hydrography (Richards *et. al.,* 1977; Townsend *et. al.,* 1977). Catchment processes operate at different hierarchical levels and therefore analysis of catchment attributes should be studied at different hierarchical scales. The appropriate focal level or scale of observation is defined by boundaries of the system under study, where scale represents either temporal or spatial dimension (Johnson and Gage, 1977).

Landscape form and composition play a major role in regulating stream chemistry. Landscape-level processes define the overall supply of elements to a stream and provide the framework within which other processes operate on smaller spatial scales and shorter temporal scales to regulate supply and availability (Meyer *et. al*., 1988). The availability and cycling of nutrients within a riverine environment is very important in the functioning of the ecosystems. Analysis of the changes in river water quality often reveals the impact of different activities taking place within a river basin. The landscape influences its water bodies through multiple pathways and mechanisms, operating at different spatial scales. A spatial conceptualization of aquatic ecosystems suggests a hierarchical organization of physical units, perhaps most clearly captured for rivers in hierarchy: habitat - reach, - segment – sub-catchment - basin (Hawkins *et. al.,* 1993) and in the nested classification of stream order (Strahler, 1964).

Human activities are responsible for fundamental changes to riparian vegetation of stream catchments around the world. For instance conversion of natural forest to agriculture may influence stream water chemistry (Maasdam and Smith, 1994), discharge (Gustard and Wesselink, 1993), water temperature (Hanchet, 1990), characteristics of the channel (Sweeney, 1993) and inputs of radiant energy and organic matter. Deforestation can increase light levels, and thus enhance algal productivity (Ulrich *et. al.,* 1993) but decrease inputs of woody debris, leaves and other coarse particulate organic matter (Evans *et. al.,* 1993). Changes in land use that affect riparian vegetation can, therefore, be expected to have important consequences for the abundance of invertebrates and fish as a result of changes in physico-chemistry of stream water.

Studies within the Saginaw River Basin revealed that nitrogen concentrations, alkalinity and TDS were more sensitive to agricultural land use during the summer and to underlying geology during autumn (Johnson *et. al*., 1997). In the same catchment, land use within the riparian region and throughout the catchment was equally effective predictors of total nitrogen, nitrate, orthophosphate and alkalinity. However, total phosphorus and TSS were better explained by land use within the riparian region than by catchment-wide variables, indicating the dominance of local controlling mechanisms while Ammonia and TDS exhibited the opposite pattern indicating regional control. Strong relationships between land use and nutrient concentration or export have also been observed for phosphorus and nitrogen (Omernick, 1976; Peterjohn and Correll, 1984; Osborn and Wiley, 1988). Increased export of nitrite-nitrate and orthophosphate was observed in predominantly agricultural and urban catchments as compared to forested catchments. According to Osborn and Wiley (1988), soluble reactive phosphorus concentrations were elevated downstream of urban centers, particularly during low flow periods unlike nitrate concentrations which were elevated during late winter and early spring in response to agricultural activities and during summer and autumn as a result of urban runoff.

Nyando River is 153 Km long and its basin covers a catchment area of 3,450 Km^2 and drains into the Winam Gulf of Lake Victoria which lies between longitude 34^o 13’ and 34^o 52’ East and latitude 0^o 4’ and 0^o 32’ South of the equator. The river originates in the highlands at an altitude of 1,700 m.a.s.l and terminates at the lakeshore swamps at an elevation of 1,135 m.a.s.l. Studies on the impact of land use on the water quality of riverine environments within the Lake Victoria Basin are scarce. A knowledge gap exists, as water quality managers do not have adequate data on which to base their management practices. The paper describes a study carried out to determine the changes in the water quality of Nyando River in relation to different agro-industrial activities within the Basin.

Materials and methods

The study was carried out from August 1997 to June 1999. Changes in water quality were examined at various hierarchical levels The highest hierarchy, the river basin scale compared impact of environmental variables on water quality 40 kilometers from the river mouth along River Nyando and the lower reaches of Sondu-Miriu Basins.. This involved stations NRU, NRW, NRX and NRY within the Nyando and stations SMR, SMS and SMT within the Sondu- Miriu River Basins. Changes at the river catchment scale were examined in all sampling stations along River Nyando from the source (Station NRR) to the river mouth (Station NRY). The impact of non-point pollution sources was examined at the sub-catchment scale by comparing the water quality above and below coffee, tea and sugarcane land use practices within the basin. Point source pollution was investigated at the river reach level by sampling above and below effluent discharge points at stations NRS, NRT, NRU and NRK (Figure 1).

Three replicate measurements and water samples were collected on a monthly basis at every sampling station. The physical water parameters temperature, conductivity, total dissolved solids (TDS), turbidity, salinity and pH were measured *in situ* using conductivity / TDS meter, turbidimeter and pH meter respectively.

Standard water quality handling and analytical methods (APHA, 1994) were used to determine the chemical water quality parameters and nutrients. The nutrients determined included phosphate-phosphorus PO_4^{3-}-P, nitrate-nitrogen NO_3^--N, Ammonium-nitrogen NH_4^+-N and Silicates. Physico-chemical parameters determined include Dissolved oxygen (DO), alkalinity, hardness, pH, temperature, conductivity, total dissolved solids (TDS), turbidity and salinity.

Data analysis

Statistical data analysis was done using MINITAB release12.1 and Microsoft EXEL computer packages. In all the analyses, 95% level of significance was used as the critical point. General Linear Model Analysis of Variance (ANOVA) and two-way ANOVA was used to test for similarity of water quality between the river basins, different land use practices and above and below sources of pollution both at the catchment and sub-catchment levels. For temporal and spatial variation, Tukey’s Multiple Range Test was performed to delineate which particular observations were significantly different from the others.

Figure 1. Map of Nyando and Sondu-Miriu Basins showing the location of sampling stations along the rivers.

Results

River basin scale

A comparison of conductivity shows that all stations in Sondu-Miriu are similar but differs significantly (F=124.44, df(11,518), p<0.0001) from all the other sampling stations in River Nyando except for station NRD. The concentration of $PO_4{}^{3-}$-P in all stations along River Nyando and the loads entering the lake were significantly higher in the Sondu – Miriu River (F=9.48, df(11,497), p<0.0001). Apart from stations NRR (5.07 $\pm$ 0.45 mgL^{-1}) and NRY (3.53 $\pm$ 0.29 mgL^{-1}), the mean concentration of nitrate-nitrogen along River Nyando was significantly higher than stations in the lower reaches of Sondu-Miriu (F=11.27, df(11,467), p<0.0001) but the load entering the lake was higher from Sondu-Miriu. No significant difference was noticed in the mean concentration of ammonium-nitrogen between Nyando and Sondu-Miriu River. The two river basins however differed in their silicate concentrations (F=6.34, df(11,434), p<0.0001).

River catchmnet scale

Figure 2 shows the spatial variation of water quality along River Nyando.

Conductivity (F = 124.44; df = 11,518; P<0.0001), TDS (F = 95.82, df =14,470), P<0.0001) and turbidity (F=21.55, df=(11,461), P<0.0001) of the water varied significantly at different sites along the river. Whereas TDS decreased, turbidity increased downstream. The variation in the concentration of nutrients during the study period at stations NRR, NRT, NRW and NRY (Figures 3 to 6) indicates that the amount of nutrients increases downstream.

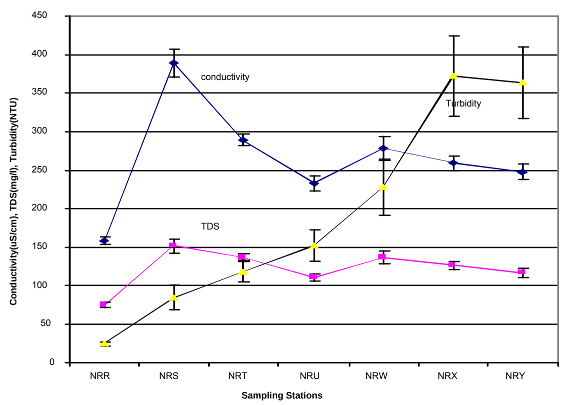

Figure 2. Variation in conductivity, turbidity and TDS in River Nyando from the source to the mouth.

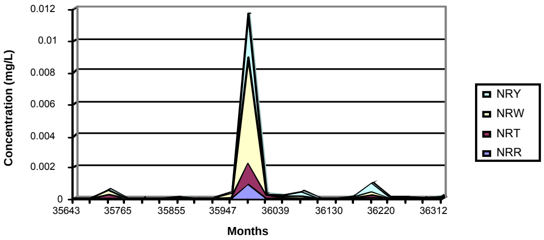

Figure 3. Variation in the concentration of NH_3-N along River Nyando.

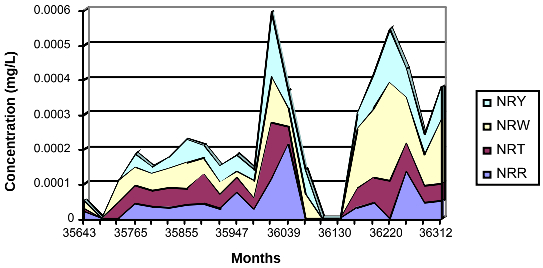

Figure 4. Variation in the concentration of NO_3-N along River Nyando.

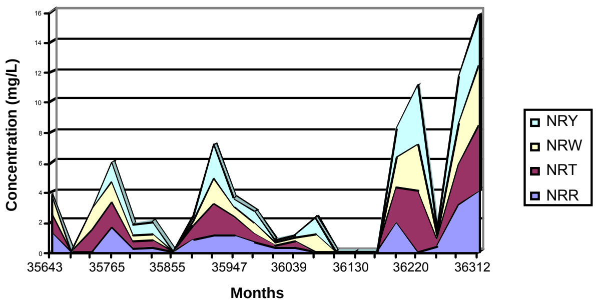

Figure 5: Variation in the concentration of Silicates along River Nyando.

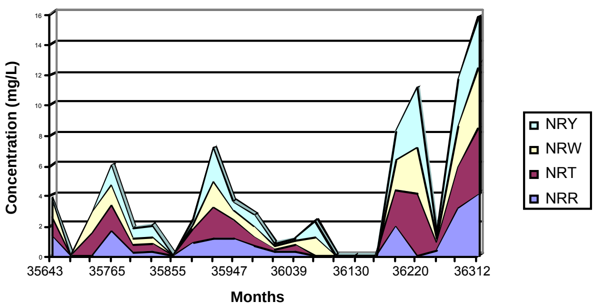

Figure 6. Variation in the concentration of PO_4-P along River Nyando.

River sub-catchmnet scale.

(i) Coffee Zone

Significantly poorer water quality occurred below the coffee-growing zone as compared to sites above. Phosphate-phosphorous concentration which showed no variation between the two sites, significantly varied with time ($F = 74.67$.df (15.95), $P<0.001$). The same was true with silicates ($F = 52.74$, df (13,83), $P<0.001$). The concentration of ammonium-nitrogen ($F=153.33$, df (14,89): $P<0.001$) and nitrate-nitrogen ($F = 16.18$, df (14,89); $P<0.001$) also showed a strong seasonal variation during the study period.

(ii) Tea Zone

Significant variation in alkalinity ($F = 8253.47$, df (1,29), $P<0.001$), turbidity ($F = 9.21$, df (1,17), $P<0.01$), conductivity ($F = 15936.23$, df (1,29), $P<0.001$), pH ($F = 28.51$, df (1,29), $P<0.001$) and BOD ($F = 5.14$, df (1,23), $P<0.03$) was recorded between the sub-catchments with and without tea plantations. It is important to note that most water quality parameters like conductivity, TDS, pH, turbidity and Ammonium-nitrogen were higher in the reference sites that in sub-catchments with tea plantations. The nutrients phosphate-phosphorous ($F = 26.17$, df (1,23), $P<0.001$), silicates ($F = 56.72$, df (1,17), $P< 0.001$) and nitrate-nitrogen ($F = 32.18$, df (1,17), $P<0.001$) were significantly higher in the tea zone..

(iii) The Sugarcane Zone

The values of water quality parameters below the sugarcane zone were significantly higher than areas without sugarcane except for the nitrates ($F=112.73$, df(1,35), $p<0.0001$) which was significantly higher in the latter station. There was however no significant difference in the pH between the two sites.

Impact of Industrial effluent

Table 1 gives the changes in water quality above and below Muhoroni Sugar Company (MSC) and Agro–Chemical and Foods Company (ACFC) The water quality was poorer below than above the factories. Of the variables analyzed only the alkalinity, nitrate-nitrogen and silicates had significantly higher concentrations in the station above the factories. Apart from phosphate-phosphorus the water quality variables varied significantly with time during the study period.

A comparison of the water quality below Chemelil Sugar Company (CSC) and MSC / ACFC (Table 2) revealed that the impact of the effluents on water quality was significantly different. All the nutrients had higher concentrations below Muhoroni than Chemelil Factory except for the silicates and all the water quality parameters analyzed varied significantly with time.

Table 1. Mean values of physico-chemical parameters above and below Muhoroni Sugar Company and Agrochemicals and Food Company

PARAMETER	Mean Above MSC/ACFC	Mean Below MSC/ACFC	P-Value
Conductivity (u/cm)	232.54	278.26	<0.0000
Alkalinity (mg/L)	136.02	130.23	<0.0000
Turbidity (NTU)	152.61	227.92	<0.0000

TDS (mg/L)	110.07	136.61	<0.0000
Salinity	0.11	0.14	<0.0000
DO (mg/L)	6.32	6.61	<0.01
BOD (mg/L)	3.12	2.60	<0.0000
Silicates (mg/L)	1.48	1.27	<0.0004
NH4- N (mg/L)	0.0003	0.0005	>0.42
NO3-N (mg/L)	6.06	5.17	<0.0002
PO4-P (mg/L)	0.000005	0.000005	>0.05

Table 2: Comparison of mean values of Physico-chemical parameters below Chemelil Sugar Company and MSC / ACFC during the study period

PARAMETER	Mean Below	Mean Below	P-Value
	CSC	MSC/ACFC	
Conductivity (u/cm)	276.85	285.08	<0.0000
Alkalinity (mg/L)	156.21	140.96	<0.0000
Turbidity (NTU)	213.79	190.35	>0.1
TDS (mg/L)	132	140	<0.0000
Salinity	0.12	0.14	<0.0000
DO (mg/L)	7.11	6.47	<0.0000
PH	7.55	7.43	<0.0000
Silicates (mg/L)	1.61	1.27	<0.0000
NH4-N (mg/L)	0.00014	0.0005	>0.1
NO3-N (mg/L)	4.66	5.08	<0.0000
PO4- P (mg/L)	0.00007	0.00009	<0.0000

Discussion

River basin scale

Most of the physico-chemical parameters were higher in the Nyando as compared to the Sondu-Miriu River Basin. High levels of salinity, alkalinity, TDS, conductivity and turbidity in Nyando could be attributed to poor agricultural practices and high use of agro-chemicals. The similarity of the water quality parameter at station SMR on the Sondu-Miriu to those of the upper reaches of River Nyando shows that the former is not as degraded as the latter.

The amount of nutrients in Nyando was also found to be higher than in Sondu-Miriu except for NO^{3-} -N. This could be attributed to several point and non -point agro-industrial activities in the Nyando Basin which pollute the river. However, higher concentrations of nitrates in Sondu-Miriu as compared to Nyando could be attributed to the high amounts of nitrate- based fertilizers used in maize plantations in the former catchment. Considering the nutrient loads, it emerges that Apart from PO_4-P, the nutrient loads of all the other nutrients are higher at the Sondu-Miriu Rivermouth than Nyando. This is due to a greater discharge as compared to Nyando. The higher concentration of nitrate could however be attributed to speciation of the nitrogen species that has been found to differ according to agricultural land use. Cooke and Prepas (1998) found nitrate-nitrogen to be the dominant nitrogen species in runoff from cropland while ammonium-nitrogen predominated in runoffs from mixed agricultural catchments. The situation in the study area is therefore not unique as the sugarcane zone in the Nyando catchment is an area with mixed agricultural practices as opposed to the Sondu-Miriu that is predominantly maize crop.

River catchment level

The variations of water quality within the Nyando River at the catchment level are closely related to the land use practices within the catchment. Conductivity and TDS for instance were lowest in the reference station at the source of the river. These parameters differed quite significantly in sub-catchments with intense agro-industrial activities along the river. Stations in less impacted sub-catchments had lower concentrations as compared to stations located in areas with high human population, agricultural and industrial activities. The waters of the river were also more turbid at stations in the middle reaches of the river and stations in the lower reaches. The land use within this steep valley is located in areas dominated by intensive large scale and subsistence agriculture where both cash and food crops are grown in the riparian zones to the riverbanks without a buffer zone. The same areas occur in the floodplains with very high human and livestock population density and a rather drier climate. This coupled with unstable riverbanks characteristic of this area exposes the soils to erosive forces thus heavy siltation.

The amount of dissolved oxygen was lowest in stations located downstream of industrial and municipal effluent discharge points. The decomposition of organic substances from the industries and urban centers contributes to the low levels of dissolved oxygen in the water. Low dissolved oxygen levels at station NRY, however could be attributed to reduced water speed or lack of turbulent water movements that could increase the oxygenation at this floodplain station.

The pH, salinity and alkalinity of the river water did not vary much throughout the catchment. This could be explained by the fact that the basement rocks within the entire catchment are basically the same contributing to similar acidity-alkalinity levels. Changes seen at the sub-catchment and river reach levels however are due to anthropogenic sources.

The concentration of nutrients within the catchment of the river basin originates more from diffuse as opposed to point sources. Although the levels of phosphates and nitrates are higher at stations, associated with industrial effluents, the land use upstream these stations is also composed of large and small-scale agricultural farms with huge inputs of agro-chemicals. Minimal levels in reference station and the general increase in the amount of nutrients downstream supports the argument on the predominant contribution of diffuse nutrient sources within the catchment.

River sub-catchment scale

Changes in water quality at the sub-catchment scale in the Nyando Basin are influenced by land use. Poorer water quality was recorded below the coffee-growing zone both temporally and spatially. It is important to note that whereas pH showed no variation at the catchment level, at sub-catchment the parameter was significantly higher. The concentration of phosphate- phosphorus and Silicates did not vary above and below the coffee zone but temporally the variation was significant. Nitrate- and Ammonium-nitrogen however differed both in space and time. This could be attributed to the predominant use of nitrogen-based agro-chemicals in coffee farms and organic wastes generated from the coffee industries within this sub-catchment. Temporal variation of all the nutrients within the sub-catchment indicates that these nutrients are continually generated from this zone throughout the year. Apart from agricultural activities, this is a transition zone between the upper and middle catchment with good vegetation cover. However deforestation rate is increasing and will enhance degradation in this area. The high level of nitrate-nitrogen concentration in this zone is comparable to the findings of Havel *et al.,* (1999) who recorded highest stream water nitrate concentrations in recently manipulated areas of the catchment. He attributed this to nitrification and decomposition of organic matter in deforested and transitional zones, a reason that could well apply to the study area.

Of all the land use practices in the basin tea growing appears to have minimal impacts in the river water quality. The occurrence of low TDS, conductivity and turbidity below the tea-growing zone could be ascribed to the provision of adequate vegetation cover around the farms that reduces the soil erosion within these sub-catchments. High levels of nitrate nitrogen and silicates can however be attributed to the use of agro-chemicals with nitrates and silicates as the major constituents. Silicates could also arise from non anthropogenic sources.

The high conductivity, TDS, turbidity and alkalinity in sub-catchments where sugarcane is grown is a direct consequence of high population density, poor agricultural practices and lack of buffer zone along the river. It is common in this sub-catchment to find farms cultivated right up to the riverbanks. This coupled with multiple tillage and huge input of agro-chemicals in the sugarcane farms contributes largely to elevated levels of these parameters. The high levels of nutrients in this sub-catchment can also be attributed to the same reasons above. However, high levels of nitrate- nitrogen in sub-catchments without sugarcane can be explained by the use of fertilizers where there is large-scale growing of maize.

Several spatial and temporal patterns observed in streamwater chemistry in most catchments are controlled by land use history and hydrology which controls the storage and transport of constituents (Havel *et al.*, 1999). The relative contribution of point or non-point sources depends on the source of the nutrients in respective catchments. Some studies have reported the predominance of point sources (Sundblad *et al.,* 1994) but in Nyando the situation appears different. The high contribution of nutrients from diffuse as opposed to point sources in the Nyando Basin however, parallels several other studies that have linked nutrient loadings to catchment land use, and particularly agriculture (Omernick *et al.*, 1991, Jaworski *et al.*, 1992, Johnson *et al.*, 1997, Moreau *et al.*, 1998). Agricultural land use within the Nyando River Basin is therefore a major contributing factor to the variation in the water chemistry and quality.

River reach scale

Industrial wastewater discharged into River Nyando has varied impacts on the river's water quality at the river reach level. Elevated levels of conductivity, TDS, and turbidity below ACFC / MSC can be closely linked to the industrial effluent from the factories, particularly to ACFC whose effluent has a characteristic persistent brown color. These changes can not wholly be ascribed to point sources as the area is within the sugarcane growing zone with potential diffuse pollution sources. Whereas pH, salinity, alkalinity and dissolved oxygen did not vary significantly at catchment scale, their variation seems to be more significant at the river reach level as can be seen in reaches below the industries.

The contribution of nutrients from ACFC/ MSC to the river system does not seem to be significant at this river reach possibly due to high contribution of nutrients from Muhoroni Township in the vicinity of the factories upstream. However, poor water quality between this reach and below Chemelil Sugar Company could be attributed to the efficiency of the treatment facility at Chemelil. During the study period, the treatment facility at ACFC was prone to frequent breakdowns and that of Muhoroni Sugar Factory was non-functional. The treatment facility at Chemelil was however well maintained with a provision of wetlands within the system, which was more efficient in the uptake of nutrients.

Pollution of inland water bodies by industrial and municipal wastewaters is a common phenomenon in developing countries (Gosh and MCbean, 1996). Whereas the effect of industries was not significant at catchment scale, it was however very significant at river reach scale. Point sources of pollution affect water quality due to high organic and nutrient pollution. High levels are generally recorded below effluent discharge points and reduces downstream due to the rivers self cleansing capacity (Markantonatos *et al.*, 1995). In the Nyando Basin, there are several point pollution sources spread along the river, particularly at Lelu, Fort Ternan, Muhoroni, Chemelil, and Ahero. These do not allow the river to recover adequately from industrial effluents. Reduction of pollutants from River Nyando to Lake Victoria therefore relies greatly on the effectiveness of the rivermouth wetlands.

Seasonality

The water chemistry in the Nyando basin varied temporally even in cases where no significant variation was noticed among sub-catchments or river reaches. Seasonal variation is however not a universal phenomenon. Reporting lack of distinct seasonal variation in the water chemistry, Topalian *et al.*, (1999) ascribed this to regular and intermittent pollution pulses. Seasonality in the concentration of nutrients, particularly in agricultural areas is however common with peaks being recorded during high flow periods (Probst, 1995, Sundblad *et al.*, 1994, Markantonatos *et a.l*, 1995, Moreau *et al.*, 1998). High flows usually occur when fields lack vegetation cover and nitrate-nitrogen for instance easily leached from the soil. Inorganic nitrogen forms are subject to biological transformations that increase with increasing temperature (Davies and Keller, 1983). Seasonality in nutrient levels can be attributed to the deposition in the sediments during low flow periods and resuspension and transportation during high flow periods.

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