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Urban Runoff in Khartoum and its Effect on the Nile Water Quality

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ABSTRACT: This paper infers upon the quality of urban runoff from Khartoum-Sudan (a typical urbanized community that lies on the banks of the Nile-system) and its effect on the Nile water quality. In addition, the correlation of storm water runoff contaminant load with the environmental management practices in the Khartoum area is discussed. Water quality parameters were measured at residential, commercial, agricultural, industrial and rural areas sampling points and mean concentrations were calculated for the rainy season August–October 2006. Weighted mean concentrations of BOD, COD, NO^-_3, TP, NH_3 were found to be in the order of 45.8, 854.3, 33.5, 2.9, 14.1 mg/l respectively. The BOD and COD weighted mean concentrations for residential and commercial land uses in Khartoum 46.8, 511.9 and 1368.8 mg/l far exceeded the U.S. National Urban Runoff Program (NURP) mean EMC values of 10.0, 73.0 and 9.3, 57.0 mg/l respectively indicating poor environmental management of the urban Khartoum area. The average pollutants concentrations were found to decrease with the order of rainfall event during the year, decrease with increased rainfall amount, and increase with increased duration between events. During the month of Sep. the Khartoum state has contributed 164 Mm^3/month of runoff to the main Nile constituting 0.824% of the total main Nile flow estimated using SCS method for dry conditions. The corresponding total loading rates of pollutants were found to be 12.2, 68.8, 1.7, 166.0% of the total main Nile average pollutant loading for BOD, NO^-_3, TP, NH_3 based on the Global Environmental Monitoring System (Gemstat) average water quality data of the Blue Nile at Khartoum.

INTRODUCTION

Receiving waters near urban and suburban areas are often adversely affected by urban storm water runoff which, in turn, is greatly influenced by catchment characteristics such as the geographical location, road and traffic characteristics, buildings and roofing types, weather, particularly rainfall, land use distribution, environmental management practices and many other factors. The degree and type of impact varies from location to location, but it is often significant relative to other sources of pollution and environmental degradation (Novotny *et al.*, 1981).

Upon development of an urban area the artificial surfaces increase the amount of surface runoff in relation to infiltration, and therefore increasing the total volume of water reaching the river during or after the rainfall and it reaches the river faster (Butler *et al.*, 2004). This obviously strong implications on water quality and it is important that the full effects are understood.

A huge urban growth occurred in Khartoum state during the last 10 years and this urbanization has a significant impact in the water quality. The purpose of this paper is to study the effect of the runoff from Khartoum state (a typical urbanized community that lies on the banks of the Nile-system among many others) in the quality of the Nile water and to correlate environmental management practices to the degree of pollution encountered in storm water. This work is critical since all urbanized communities within the ten Nile basin countries and within the Nile catchment area are built on the Nile system banks, and controlling their pollution load is extremely important in managing the Nile system water quality and environment.

STUDY AREA

Khartoum state which is currently undergoing a 25 years planning process lies entirely within the Nile system catchment area and contribute directly to the Nile system flow and water quality. Other seasonal streams coming from outside the Nile system catchment area penetrate the state and deliver considerable quantities of water to the White Nile, the Blue Nile and the main Nile.

Khartoum, the capital of Sudan and Khartoum State, lies at the Blue Nile and White Nile confluence where the river Nile is formed (Figure 1). The current population of Khartoum is estimated to be eight millions currently compared to three and half millions back in 1993 (Ahmed, 2006) composing more than 45% of the urban population in the Sudan. The total

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Khartoum area has increased 10 folds during the previous twenty years. Khartoum has a short cool winter and a long hot dry season, which is intercepted by a hot humid season (July–September), during which most of the annual rainfall (167 mm) occurs.

The Khartoum metropolitan area is rapidly expanding and urban sprawl is continuing. Land has become a commodity and green areas are turning into apartments, commercial districts, and industrial areas. The management practices of urbanization activities are not keeping pace with the fast urbanization rate.

The Khartoum state, with an area of 22,000 km^2 approximately is divided into residential, commercial, industrial (almost 70% of the countries' industrial production is manufactured in the Khartoum state (Unido, 2001), agricultural and open rural areas where nomadic pastoralism life patterns are dominant. The expansion and allocation of areas among these various types of uses is unplanned and is taking place, sometimes, due to other factors such as displacements due to war and other crisis which is bringing Internally Displaced Persons (IDPs) in fat numbers to reside in camps around and inside the urban Khartoum area. The current division the total state area among various land uses is shown in Figure 2.

Khartoum is generating about 7,000 tons of waste per day (0.8 kg/d/capita) in households, of which 51% soil, 35% food, 9% paper and cardboards, 2% plastic, and 2% wood and 2.2% metals (SECS, 2006). Poor collection services and improper disposal at open dump sites characterize solid waste management practices. All types of waste hospital, industrial, hazardous and household are collected together and disposed off similarly. Commercial areas are crowded with street sellers and sometimes storm water drains are used to display their merchandise leading to accumulation of dirt in these drains and eventually storm water contamination. Agricultural activity uses many chemicals unavoidably and it drains directly into the Nile system and industrial areas are sumps of smelly liquid waste in many cases since no proper drainage/treatment is provided for industrial wastewater. The number of automobiles has risen dramatically over few years from few thousands to 66,000 currently and are mostly hand cleaned all over the state and without appropriate drainage for their waste and lubricants. All of these practices affect the quality of storm water significantly.

During the wet season 2006 (Figure 3), usually the Nile system witness flooding together with a dramatic deterioration in its water quality. For example while the turbidity of the White Nile rise from 20 in February to 160 mg/l in August the nitrate rise from 2 to 7 mg/l in the same months (Abbo, 2007). A more significant change in water quality takes place in the Blue Nile where the turbidity rise from 10 in February to 4605 mg/l in August (and some times up to 22,000) and the nitrate rise from 3.9 to 9 mg/l in the same months (Abbo, 2007).

Fig. 1: The Greater Khartoum Metropolitan Area, the Nile Confluence

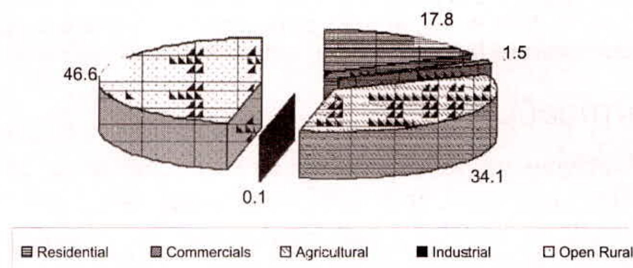

Fig. 2: Land Use in Khartoum State (2006)

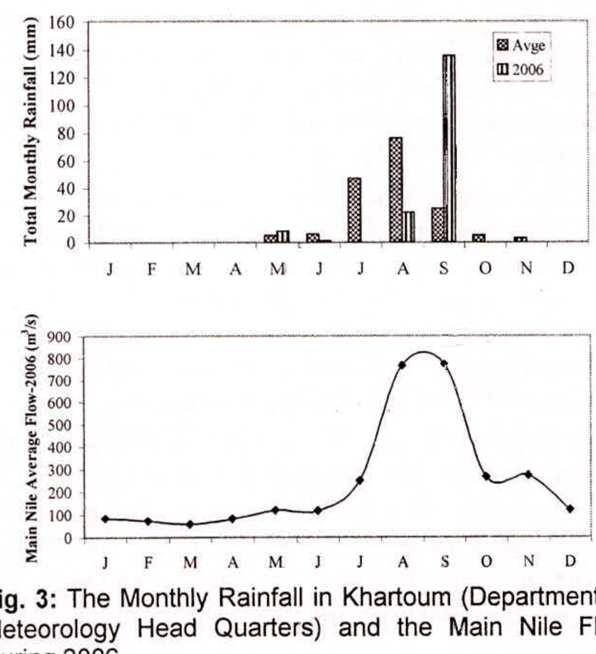

Fig. 3: The Monthly Rainfall in Khartoum (Department of Meteorology Head Quarters) and the Main Nile Flow During 2006

EXPERIMENTAL PLAN AND APPROACH

The pollutants associated with the storm runoff in the Khartoum state were selected according to the land use and the respective pollution sources within the state. These pollutants were described thoroughly by Ahmed, (Ahmed, 2006), and can be summarized as Oxygen demanding substances (Biochemical Oxygen Demand and Chemical Oxygen Demand (BOD, COD)), nitrate, phosphorus and ammonia. Nitrogen and phosphorus are important constituents of storm runoff from agricultural areas. Organic material could be found in residential lawns and gardens, roadsides, commercial and industrial landscaped areas and COD represent appropriately the industrial waste and automotive pollutants build up on street surfaces.

Random water samples were collected from at 27 sampling locations representing different land uses; residential, commercial, agricultural, industrial and open rural area, upon four rainfall events during the rainy season from August to October of 2006. The samples were analyzed for BOD using standard 5 days BOD test, COD using the open reflux apparatus, nitrate using Hanna nitrate test kit, total phosphorus and ammonia using Hanna multi-parameter meter C200.

Khartoum state main seasonal streams are ungauged and only estimates of their runoff can be made based on meteorological data. In this paper the Soil Conservation Services (SCS) method (Chow, 1988 and Wilson, 1990) was used to predict the total amount of flow contributed by the Khartoum state to the Nile flow. The calculated total flow contribution is compared to estimates made by others.

RESULTS AND DISCUSSION

Event Mean Concentrations (EMC)

Since the data records consist of only few events; weighting the individual storm concentration by the runoff volume for the storm event can achieve greater accuracy. The mean weighted concentration for each event for certain land use can be determined using the following formula (Lee *et al.*, 1999),

$$C_e = \sum_{i=1}^{n} \frac{C_i \times C_i}{C_T} \qquad \dots (1)$$

Where,

C_e = Mean weighted concentration in a storm event for certain land use

C_i = Concentration of the sample (i) in the storm event

C_T = Total concentration of the samples for the land use in the storm event

n = The total number of the samples took from the same land use

The mean concentration for the whole season for the same land use is then can be calculated using the following formula,

$$C_a = \sum_{i=1}^{m} \frac{C_e \times V_i}{V_T} \qquad \dots (2)$$

Where,

C_a = The mean concentration for certain land use

V_i = Runoff of the storm (i) in the rainy season

V_T = The total Runoff in the rainy season

m = Number of significant storm events in the rainy season

The weighted mean concentrations from different land uses and for different pollutants calculated using Eqn. (1) are shown in Figure 4. The variation of mean weighted COD concentrations with total rainfall depth and duration between events is shown in Figure 5.

Figure 4 indicates that the most polluting land uses are the commercial and industrial where they contribute much more than the other land uses in terms of concentration. The least polluting land uses are the open rural and agricultural land uses with the residential land use contributing high BOD concentrations almost as much as the industrial land use. Nitrate and phosphorous are found primarily in agricultural lands, but it is also important to know that main contribution of nitrate is coming from industrial and residential areas indicating poor wastewater drainage and management. Overall the BOD and COD weighted mean concentrations for residential and commercial land uses in Khartoum 46.8, 511.9 and 58.8, 1368.8 mg/l far exceeded the U.S. National Urban Runoff Program (NURP) mean EMC values of 10.0, 73.0 and 9.3, 57.0 mg/l respectively indicating poor environmental management of the urban Khartoum area.

The COD mean weighted concentrations for the whole state were calculated and correlated with the order of storm in the season and it was found out that earlier storms contain the highest COD as will be discussed later. In addition Figure 5 clearly indicates the exponential decrease of COD with amount of rainfall where the wash volume decrease the concentration and the exponential increase of COD with duration of events due to increased COD surface accumulation periods.

Surface Runoff Calculations

As has been mentioned all of the main streams in Khartoum state with the exception of the Nile system are ungauged, and therefore an estimate has to be made to estimate the effects of storm water quality on the Nile system water quality. The Soil Conservation Service (SCS) method is appropriate for heavy rain events, and for dry climate conditions, and can be used in the Sudan and Khartoum state specifically. Using $K = 0.2$ and appropriate CN number with respect to land use and soil classification, the excess rainfall P_e is determined in mm/month as (Chow, 1988),

$$P_e = \frac{(P - KS)^2}{(P + (1 - K)S)} \qquad \ldots (3)$$

Where P is the total (cumulative) precipitation and S is land use parameter related to the Curve Number (CN) which is a function of land use and soil classification.

This method produced a runoff of 1.89 and 164 Mm^3 for the months of August and September of 2006 respectively. To get an idea of how accurate this estimate a typical ungauged stream was selected and its runoff was estimated using two other methods the SCS method yielded 3.71 compared to 16 using Hydrocad software (HydroCAD, 2006) and 9.99 Mm^3 using the design hydrograph method (Chow, 1988). Obviously the SCS is a very conservative estimate.

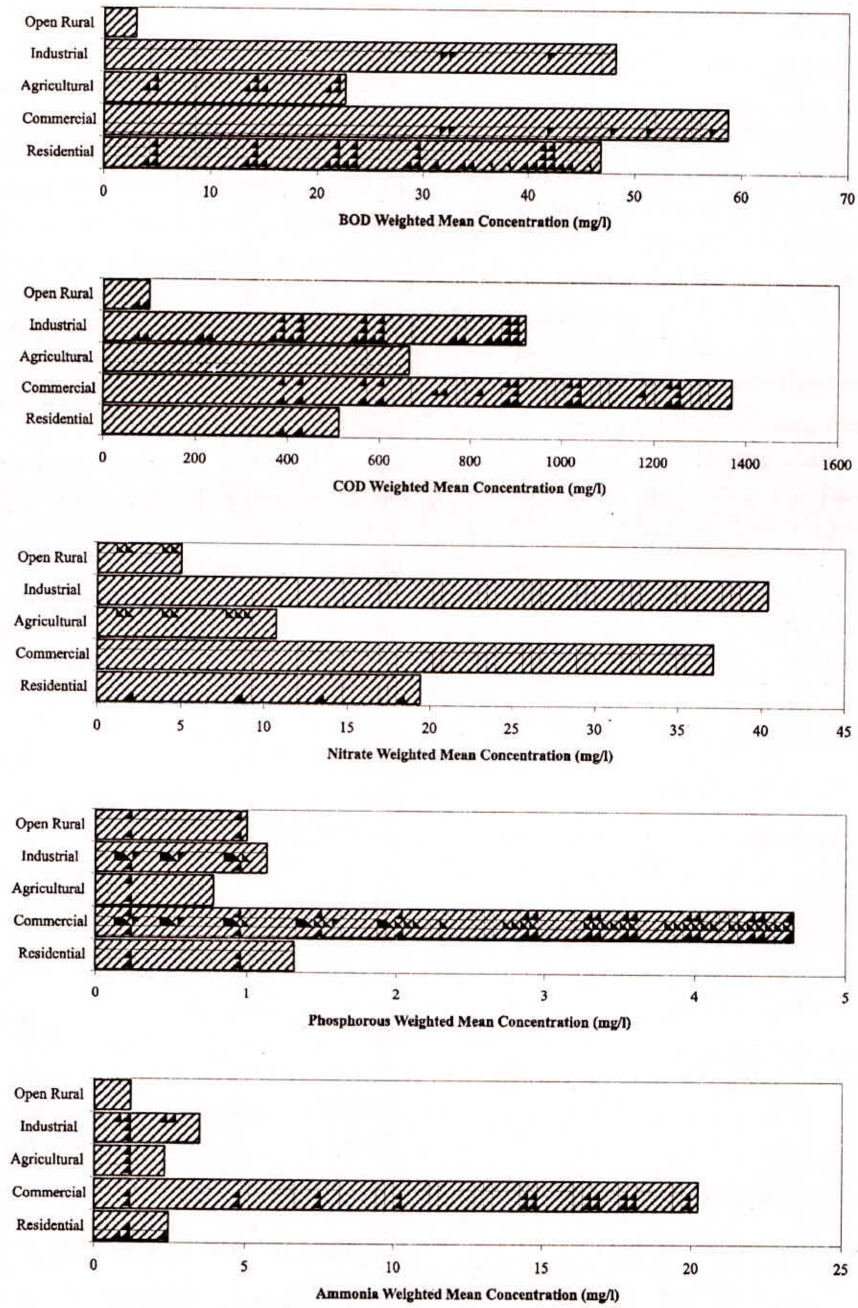

Fig. 4: Weighted Event Mean Concentrations of Various Pollutants from Different Land Uses

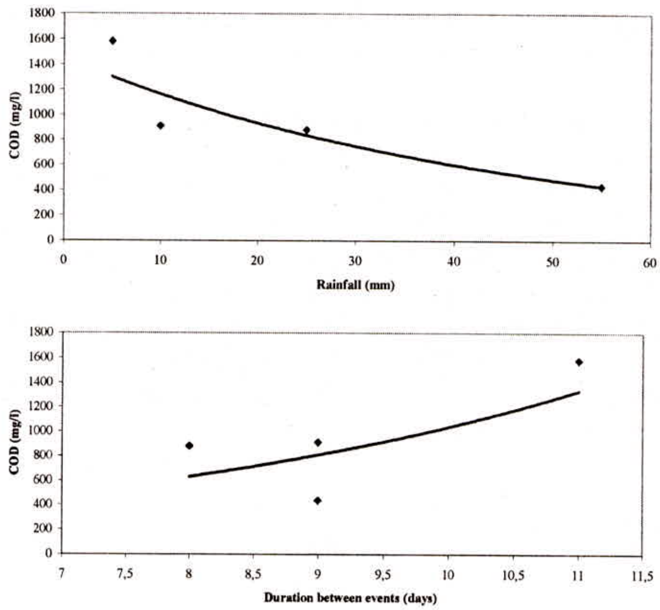

Fig. 5: The variation of mean weighted COD concentrations with total rainfall depth and duration between events

Storm Water Pollution Load and its Effects on Nile Water Quality

All receiving water can assimilate wastes to some extent depending on their natural self purification capacity but when pollutant loads exceeds this capacity problems arise such as harming the aquatic ecology and restricting the potential use of water (water supply, recreation, fisheries) (Butler *et al.*, 2004). The storm water pollutants loading rates on the Nile are calculated and related to the total Nile load using the Global Environmental Monitoring System Statistics (Gemstat) water quality data (Gemstat, 2007). This was done since no other sources of Nile water quality data were available. The results are shown in Table 1. The corresponding total loading rates of pollutants were found to be 12.2, 68.8, 1.7, 166.0% of the total main Nile average pollutant loading for BOD, NO^-_3, TP, NH_3 based on the Global Environmental Monitoring System (Gemstat) average water quality data of the Blue Nile at Khartoum.

Table 1 clearly shows that early storms make the greatest pollutant concentrations due to absence of surface cleaning during the dry period. In addition it shows the stunning facts of the percentages of loads contributed by storm runoff to the Nile load. Although the Nile loads were calculated based on averages dating to the eighties and nineties but it illustrates the effect of urbanization clearly specially when considering nitrate and ammonia.

Table 2 shows the percent contribution of each land use in the state to the total load. Obviously residential and agricultural are contributing most of the BOD, COD, Nitrate while phosphorous, nitrate and ammonia are manly contributed to from agricultural and open rural areas due to animal breeding and agricultural activities.

The insignificant contribution to total loading from industrial areas is due to its small area but not to reduced pollutant concentration. This fact leads to the conclusion that the environmental management of Khartoum state should focus now on residential and agricultural areas and take into consideration the future expansion of industrial areas.

Table 1: Monthly Storm Water Quality Average Concentrations and Weighted Mean Concentration, Gemstat Mean Concentrations, Total 2006 Season Loading, and September Storm water Pollutant Loading to Gemstat Nile Load

Item	*BOD*	*COD*	*Nitrate*	*Phosphorus*	*Ammonia*
August Mean Concentration (mg/l)	62.48	1576.54	20.45	1.23	11.49
September Mean Concentration (mg/l)	45.79	854.27	33.45	2.94	14.11
Weighted Mean Concentration (mg/l)	48.20	757.30	23.70	2.20	14.11
Gemstat Mean Concentrations (mg/l)	3.09	N/A	0.40	1.42	0.07
Total Season Loading (tons)	7640	143301	5532	485	2339
September Storm water Pollutant Load to Gemstat Nile Loading (%)	12.2	–	68.8	1.7	166.0

Table 2: Percent Contribution of Each Land Use in the State to the Total Storm Water Pollutant *Loading (2006)*

Land Use	*% Area*	*% Contribution to Total Loading*				
		BOD	*COD*	*Nitrate*	*Phosphorus*	*Ammonia*
Residential	17.8	0.45	0.24	0.35	0.23	0.21
Commertial	1.5	0.05	0.05	0.05	0.07	0.14
Agricultural	34.1	0.42	0.59	0.37	0.26	0.38
Industerial	0.1	0.00	0.00	0.00	0.00	0.00
Open Rural	46.6	0.08	0.12	0.23	0.45	0.27

CONCLUSIONS

Although the work done in this research is carried out for one season (2006) but its result are strongly conclusive of the following:

- The current environmental management practices of waste collection and land use designation in the Khartoum state are not keeping pace with the urban sprawl needs and are leading to a major contribution to the Nile water quality deterioration.
- Major attention should be to the current environmental practices in residential and agricultural areas and meanwhile pay attention to unplanned expansion in industrial areas.
- There have to be a storm water management unit to reduce the impacts of the Nile system water quality.
- More investigation and long term studies are needed to add accuracy and precision to this work and to create Decision Support Tools (DST) to reasonably foresee the corrective actions control measures needed to mitigate the impacts of storm runoff from urbanized areas along the Nile system banks.

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