WET DEPOSITION CONTRIBUTION TO URBAN RUNOFF QUALITY IN KHARTOUM - SUDAN

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ABSTRACT

Rain samples were collected by events from July to September 2007 using manual wet-only precipitation collectors at three sites in Khartoum-Sudan projecting good spatial coverage of the study area. Volume weighted average pH values of the rainfall samples were between 6.4 and 6.62, individual samples reaching as low as pH 5.84. Wet deposition concentrations were found to be 3.44, 37.5, 5.69, 5.76, 2.24, and 1.0 mg/l for BOD, COD, NH$_3$, SO$_4^{2-}$, NO$_3^-$, and TP respectively. The wet deposition pollutants concentrations were found to depend on the sampling elevation from the ground surface, time since start of rainfall event, and the time of day during which event take place. Wet deposition pollutant load in Khartoum was found to be primarily caused by activities on the lower troposphere such as transportation, waste resuspension, and may be agricultural and industrial activities to some extent. The presence of chlorine in the wet deposition samples further indicates that open burning is a major source of air pollution. Wet deposition was found to contribute 7.0, 5.0, 9.5, 45.5 and 40.3% of BOD, COD, NO$_3^-$, TP and NH$_3$ concentrations in storm water. And finally wet deposition contribution to Nile water quality during 2006 rainy season was found to be up to 0.87, 6.5, 0.77, and 66.9% of BOD, NO$_3^-$, TP and NH$_3$ respectively.

Keywords: Atmospheric Wet Deposition, Urban Runoff Quality, Air Pollution, Environmental Management, Nile Water Quality.

1. INTRODUCTION

The degradation of environmental quality in many regions of the world has accelerated during the past decades especially due to urban sprawl and industrial development, which has led to important changes in different compartments of the environment. Important atmospheric species are considered to be responsible for wide spread environmental effects including, changes in pH of wet deposition, corrosion of buildings material etc. Deposition of air pollutants is an important loss process for most of the species present in the atmosphere that can cause severe damage to ecosystems. Air pollutants are deposited to the earth’s surface especially through wet and dry processes.
Storm water pollution sources in urban areas include; atmospheric pollution, dry and wet fallouts (deposition), vehicle emissions, buildings and roads conditions, animals, urban debris and litter, spills and leaks but atmospheric pollution is considered a major source of pollution in storm water (Butler and Davies [1]).

In regions where the biogeochemical cycles are disturbed by human activities, atmospheric deposition can become an important of toxic substances or a source of nutrients for the ecosystems. Chemical deposition is an important factor of a global interdisciplinary approach to develop a predictive understanding of the main determinants of the functioning of the ecosystems.

Wet deposition and dry deposition have been and are being investigated in many parts of the world (Novotny and Chesters [2], Porter and Morris [3], Galy-Lacaux et al. [4]) and reported values of pollutants in rainfall in selected countries are shown in Table 1 (Novotny and Chesters [2]).

<table>
<thead>
<tr>
<th>Constituent</th>
<th>USA</th>
<th>England</th>
<th>Norway</th>
<th>USA</th>
<th>Norway</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>4.9-5.1</td>
<td>5.1-5.6</td>
<td>3.98</td>
<td>3.9-4.2</td>
<td>4.6</td>
</tr>
<tr>
<td>COD (TOC)</td>
<td>14.1-65</td>
<td></td>
<td></td>
<td></td>
<td>(1.31)</td>
</tr>
<tr>
<td>Org. N</td>
<td>2.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH₃-N</td>
<td>0.3-0.41</td>
<td>0.7</td>
<td>0.13-0.44</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>NOₓ-N</td>
<td>0.47-0.52</td>
<td>0.97</td>
<td>0.25-1.39</td>
<td>0.37</td>
<td></td>
</tr>
<tr>
<td>PO₄-P</td>
<td>0.012-1.1</td>
<td>0.002</td>
<td>0.025-0.12</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>0.03-0.05</td>
<td>0.024-1.04</td>
<td>0.056</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>Mercury</td>
<td>0.0009</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cadmium</td>
<td>0.001-0.1</td>
<td>0.004</td>
<td>0.0003</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Susp. solids</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In this paper, pollutants wet deposition rates are determined experimentally in order to estimate the impact of these pollutants on the urban runoff quality in Khartoum-Sudan, which in turn will affect the Nile water quality and hence other ecological systems as well.

2. EXPERIMENTAL PLAN AND ANALYTICAL PROCEDURE

Wet Deposition

Deposition of pollutants by wet processes is relatively easy to determine through analysis of precipitation samples. Rain waters have been collected at 1.5 m, 9.0 m and 13.5 m above the ground on event basis using a manual sampling setup for six rainfall events. The precipitation collector (minimum dimension 25 cm) was distant from any
obstacle that could disturb the sampling (Porter and Morris [3]). The sample collector was an inert polyethylene bucket. Samples were removed upon specified durations, upon fill up, or immediately after rainfall to avoid contamination. Samples were then analyzed for dissolved oxygen (DO), pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended particulates (SP), Nitrate, Ammonia, sulfate, carbonate, chlorine and total phosphorous (TP).

**Storm Water Runoff**

Random water samples were collected from at twenty seven 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 (Ahmed and Digna [5,6]). Samples were analyzed for biochemical oxygen demand (BOD) and chemical oxygen demand (COD), nitrate, total phosphorus (TP) and ammonia.

**Analysis**

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, ammonia, sulfate, carbonate, and chlorine using Hanna multi-parameter meter C200. Suspended particulates were filtered and weighted.

**3. RESULTS AND DISCUSSION**

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 [7]), 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 46.6% open rural, 34.1 agricultural, 17.8% residential, 1.5% commercial, and 0.1% industrial.

Major sources of urban runoff pollution include (as has been mentioned in Section 1) atmospheric washout or wet deposition which, in turn, is affected primarily by (Butler and Davies [1], Novotny and Chesters [2]):

1. Urban and industrial emissions including those from power generation, industrial processes, and open burning at waste dump sites
2. Agricultural and forest emissions resulting from human activities such as:
   i. open burning
ii. Fertilizer component reaching the atmosphere through wind erosion or volatilization
iii. Pesticides reaching the atmosphere from drift during application and through wind erosion or volatilization
iv. Decomposing farm wastes and animal operations releasing ammonia, hydrogen sulfide, methane and mercaptans to the atmosphere

3. Transportation
i. Emissions from motor vehicles
ii. Resuspension of waste/dirt accumulated on the surfaces by motor vehicles
iii. Volatilization of motor vehicle fluids upon repair and/or spills
iv. Volatile hydrocarbons emitted from spills or other transportation activities

Wet Deposition

Three wet deposition stations two in the middle of Khartoum (Alriadh and Nasir Areas) and one in a remote west side of Khartoum (West Umdurman-Umbaddah) were chosen for this study. The first two stations lie on a residential commercial area while the third is in the boundaries of a residential/commercial/industrial area. The third station was used to verify the uniform spatial distribution of wet deposition rates in the study area and to ascertain whether the type of land use and local effects are considerable in atmospheric pollution.

It is important to note that (while all sites are affected by local traffic emissions and waste resuspension) Alriadh is a first class residential area, Nasir is a second class residential area and both stations are west of many industrial establishments in Khartoum and are definitely affected by emissions since wind is mostly East and North during the sampling period. West Umdurman location is in a third class residential area affected by surrounding industrial areas and many animal markets. The average results from the three stations are listed in Table 2.

Table 2 reveals that there is a little variation (within the precision limits) between various areas of the Khartoum and the only observed variation was on the carbonate concentration at the West Umdurman sampling location and this was attributed to industrial sources in the area and was eliminated from the overall average. Also the observed values of monitored pollutants were found to fall close to the international values reported earlier in Table 1 except for the high values of ammonia and NO$_3^-$ encountered in Khartoum.
Table 2. Average and Standard Deviation of Pollutant Concentrations in Wet Deposition by Station

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Alriadh Average</th>
<th>Nasir Average</th>
<th>W. Umdurman Average</th>
<th>Overall Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DO (mg/l)</strong></td>
<td>5.53 1.36</td>
<td>3.94 0</td>
<td>5.63</td>
<td>5.0333333</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>6.62 0.46</td>
<td>6.58 0.19</td>
<td>6.4</td>
<td>6.5333333</td>
</tr>
<tr>
<td><strong>BOD (mg/l)</strong></td>
<td>2.39 2.39</td>
<td>6.1725 2.63</td>
<td>1.752</td>
<td>3.438167</td>
</tr>
<tr>
<td><strong>COD (mg/l)</strong></td>
<td>35 0</td>
<td>40.0 5.0</td>
<td>N/A</td>
<td>37.5</td>
</tr>
<tr>
<td><strong>NH₃ (mg/l)</strong></td>
<td>3.84 2.87</td>
<td>6.93 0</td>
<td>6.3056</td>
<td>5.691867</td>
</tr>
<tr>
<td><strong>SO₄²⁻ (mg/l)</strong></td>
<td>4.94 3.59</td>
<td>N/A N/A</td>
<td>6.5856</td>
<td>5.7628</td>
</tr>
<tr>
<td><strong>CO₃²⁻ (mg/l)</strong></td>
<td>2.4 2.90</td>
<td>3.1 1.34</td>
<td>17.0</td>
<td>2.75 ²</td>
</tr>
<tr>
<td><strong>NO₃⁻ (mg/l)</strong></td>
<td>2.24 0</td>
<td>N/A N/A</td>
<td>N/A</td>
<td>2.24</td>
</tr>
<tr>
<td><strong>TP (mg/l)</strong></td>
<td>1.0 0</td>
<td>N/A N/A</td>
<td>N/A</td>
<td>1.0</td>
</tr>
<tr>
<td><strong>CT (mg/l)</strong></td>
<td>N/A N/A</td>
<td>4.9 1.88</td>
<td>N/A</td>
<td>4.9</td>
</tr>
<tr>
<td><strong>SP (mg/l)</strong></td>
<td>5.2 5.02</td>
<td>N/A N/A</td>
<td>4.0</td>
<td>4.6</td>
</tr>
</tbody>
</table>

² W. Umdurman sample not included in average

Beside the variation of wet deposition pollutant concentrations with activity and pollution sources in the area, the BOD and NH₃ concentrations were found to decrease with elevation from the ground surface while SO₄²⁻ increase, all pollutants decrease with the time since the beginning of the rainfall event and follow a pattern with the time of day at which rainfall event take place. This variation is illustrated using BOD, SO₄²⁻, and NH₃ in Figures 1, 2, and 3 respectively.

Figure 1 indicates the strong lower troposphere contribution to wet deposition which is primarily due to transportation, waste resuspension, and probably some industrial and agricultural activities. It can also be observed from Figure 2 that there is a cyclic behavior of transportation emissions related pollutants (SO₄²⁻ and NH₃) where it is high at peak rush hours (4 to 9th hour, and 16 to 20th hour). This fact emphasizes the role of transportation in wet deposition pollutant concentrations.
Figure 1. Variation of Pollutants Concentration in Wet Deposition with Elevation

Figure 2. Variation of Pollutants Concentration in Wet Deposition with Time of Day
Storm Water Quality

Table 3 lists the results of event mean concentrations (EMC) weighted to the type of land use during August, September and Overall Khartoum state mean weighted concentrations. The calculations of EMC and Weighted mean concentrations were thoroughly covered by Ahmed and Digna [5]. The mean weighted concentration for each event for certain land use was determined using the following formula (Lee and Lin [8]):

\[
C_e = \frac{\sum_{i=1}^{n} C_i \times C_i}{C_T}
\]  

(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:

\[
C_a = \frac{\sum_{i=1}^{m} C_e \times V_i}{V_T}
\]  

(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

Table 3 also presents the total percentage contribution of storm water to the Nile pollutant loading based on the Gemstat average concentrations [9].

**Table 3. 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**

<table>
<thead>
<tr>
<th>Item</th>
<th>BOD</th>
<th>COD</th>
<th>NO\textsubscript{3}</th>
<th>TP</th>
<th>NH\textsubscript{3}</th>
</tr>
</thead>
<tbody>
<tr>
<td>August Mean Concentration (mg/l)</td>
<td>62.48</td>
<td>1576.54</td>
<td>20.45</td>
<td>1.23</td>
<td>11.49</td>
</tr>
<tr>
<td>September Mean Concentration (mg/l)</td>
<td>45.79</td>
<td>854.27</td>
<td>33.45</td>
<td>2.94</td>
<td>14.11</td>
</tr>
<tr>
<td>Weighted Mean Concentration (mg/l)</td>
<td>48.20</td>
<td>757.30</td>
<td>23.70</td>
<td>2.20</td>
<td>14.11</td>
</tr>
<tr>
<td>Gemstat* Mean Concentrations (mg/l)</td>
<td>3.09</td>
<td>N/A</td>
<td>0.40</td>
<td>1.42</td>
<td>0.07</td>
</tr>
<tr>
<td>Total Season Loading (tons)</td>
<td>7640</td>
<td>143301</td>
<td>5532</td>
<td>485</td>
<td>2339</td>
</tr>
<tr>
<td>September Storm water Pollutant Load to Gemstat Nile Loading (%)</td>
<td>12.2</td>
<td>-</td>
<td>68.8</td>
<td>1.7</td>
<td>166.0</td>
</tr>
</tbody>
</table>

* Based on Gemstat Averages (Gemstat [9])

**Contribution of Wet Deposition to Storm Water Quality**

The rainfall events duration in Khartoum usually do not exceed 3 hours and although there was a variation in pollutant concentrations with time as shown in Figure 3, this variation is not significant and wet deposition concentrations can be considered well represented by the average concentrations of Table 2. Values of wet deposition pollutant concentrations of Table 2 were divided by the Khartoum state weighted mean concentrations of Table 3 to estimate the contribution of air pollution and wet deposition to storm water quality and to the Nile water quality. The results of this calculation are shown in Table 4.

**Table 4. Wet Deposition Contribution to Storm Water and Nile water Quality at Khartoum (2006)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Wet Deposition Contribution %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BOD</td>
</tr>
<tr>
<td>Storm Water Quality</td>
<td>7.0</td>
</tr>
<tr>
<td>Nile Water Quality*</td>
<td>0.87</td>
</tr>
</tbody>
</table>

* Based on Gemstat Averages (Gemstat [9])
Table 4 reveals two important facts: the first is that storm water management extremely relies on managing air pollution sources and this leads to the conclusion that pollution sources are inseparable. The second fact is that, although direct atmospheric deposition effect on the Nile quality but atmospheric pollution has an indirect impact on the Nile water quality. Therefore the management of storm water using available technology and techniques should be given a priority and the air pollution and wet deposition dimension.

4. CONCLUSIONS

This paper gave preliminary investigation results of wet deposition and its effect on storm water quality in Khartoum-Sudan which is a typical urban community on the Nile system and the paper also presented estimates of impacts on water quality of the Nile at Khartoum. The results of this research are relevant to all other urban communities within the Nile basin. Specific conclusions from this paper are:

- Wet Deposition is an important contributor to storm water quality in Khartoum and therefore urban runoff management practices should include air pollution.
- Although the Nile water quality might not be affected by direct deposition of air pollutants but it is certainly affected by deposition on the watershed.
- Wet deposition pollutant load in Khartoum was found to be primarily caused by activities on the lower troposphere such as transportation, waste resuspension, and may be agricultural and industrial activities to some extent.
- The presence of chlorine in the wet deposition samples further indicates that open burning is a major source of air pollution.

REFERENCES


