Variations in Heavy Metal Concentrations Following the Dredging of an Oil Well Access Canal in the Niger Delta

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Abstract: In a study to assess the impact of dredging on heavy metal contamination, surface water was monitored for over one year, from December 1997 to December 1998. Samples were collected twice before dredging, in December 1997 and in June 1998, corresponding to dry and raining seasons respectively. Samples were also collected immediately after dredging in July 1998 and were monitored in August, September and December 1998. Samples were collected and analysed from five stations within the study area, station 1-5. Station 1 was in the dredged canal, which was originally a side branch of the Warri River tributary. In the Warri River tributary, Station 2 was 500m upstream and Station 3 was 1000m upstream of the mouth of the dredged canal, whilst Stations 4 and 5 were respectively 500m and 1000m downstream of it. Stations 3 and 5 represented the reference situation to which possible dredging effects could be compared. Prior to dredging, the concentration of heavy metals in the surface water samples of Warri River occurred in traces; lead (0.01-0.28 mg l⁻¹), zinc (0.04-1.02 mg l⁻¹), copper (0.00-0.17 mg l⁻¹), iron (0.22-0.88 mg l⁻¹), chromium (0.00-0.03 mg l⁻¹) and cadmium (0.03-0.14 mg l⁻¹). These values are comparable to values obtained elsewhere in the Niger Delta. But following the dredging of an oil well access canal, the concentration of heavy metals increased in several folds depending on the metal; lead (2.57 mg l⁻¹) zinc (9.56 mg l⁻¹), copper (15.36 mg l⁻¹), iron (229.50 mg l⁻¹), manganese (14.30 mg l⁻¹), chromium (0.27 mg l⁻¹) and cadmium (0.39). The results indicated a significant elevation of heavy metal concentrations over the background values. The percentage increase are as follows; 2333, 2130, 20,750, 51,113, 1960, 1266 and 703% for lead, zinc, copper, iron, chromium, manganese and cadmium respectively. However, 6 months after the dredging, the concentration of heavy metal reduced drastically to 533, 499, 4973, 6013, 480, 328 and 188% for lead, zinc, copper, iron, chromium, manganese and cadmium respectively over the background values. Notwithstanding the effect of tidal dilutions, the impact of dredging on heavy metals is medium to long term.

Key words: Dredging · Heavy metals · Niger Delta · Mangrove · Oil exploration · Warri River · Water quality

INTRODUCTION

Hydrocarbon exploration in the Niger Delta is often constrained by access difficulties due to the meandering wetland of the region. Dredging is often required to make oil exploration sites accessible for drilling and development. During dredging, waterway sediment, soil, creek banks and vegetation along the right of way are typically removed and deposited as dredge spoils at the bank of the newly dredged canal, resulting in a number of environmental impacts including alteration of topography and hydrology [1-3], acidification and water contamination [4-6], which has resulted in vegetation damage [7] and fish kills [6]. Turbidity plumes created as a result of dredging have been reported to cause alteration in the population and diversity of phytoplankton [8] and zooplankton [9, 10]. Benthic invertebrates are also impacted by dredging [6]. In a study carried out by Lewis et al. [11], dredging caused a reduction in numbers of benthic species, increased turbidity, reduction of primary productivity and mobilization and increased bioavailability of sediment trace metals. Dredging has been reported to cause the re-suspension of sediments, which is linked to the
re-mobilization of contaminants particularly heavy metals and increasing their bioavailability [12]. Re-suspension of sediment causes the oxidation of sediment leading to the mobilization of metals into the water body [13]. It has been variously reported that sediments are sinks for heavy metals and their disturbance through dredging could cause the re-mobilization of metals [14-21].

In Niger Delta, following the dredging of a tributary of the Warri River to enable the drilling of an oil well has led to a number of impacts including impairment of benthic invertebrates [6], algal bloom [8] and destruction of zooplankton [9]. Ohimain et al. [22] revealed that changes in the physico-chemical environment arising from the dredging may have contributed to the observed impacts. The study revealed that while some parameters decreased such as dissolved oxygen, others increased including turbidity, suspended solids, BOD, and sulphate following the dredging. The alteration of these water quality parameters were thought to contribute to the observed impacts, but the contribution of heavy metals have not been reported. Kwon and Lee [23] reported that heavy metals are toxic and exert chronic and lethal effects on aquatic animals and plants. Obiajuwa et al [24] reported heavy metal pollution around hydrocarbon production facilities elsewhere in the Niger Delta. Hence, this study is aimed at assessing the impact of dredging on the dynamics of heavy metals of the Warri River system over a year period.

MATERIALS AND METHODS

This study was carried out in and near a dredged canal (5°31"N, 5°31"E) leading off a tributary of the Warri River in the mangrove swamp of the Niger Delta about 20km from Warri in Delta State, Southern Nigeria (Figure 1). The vegetation here is typical of mangrove swamp dominated by Rhizophora species. The area is characterized by high relative humidity (80-92%) and annual average rainfall exceeding 2800mm. Although, there are two seasons (wet and dry), measurable precipitation occurs in all the months of the year. Notwithstanding, the period of April to October is often regarded as raining season, while November-March is regarded as dry season. Atmospheric temperature ranged between 27°C to 29°C [25].

Fig. 1: Map of Warri River showing the study area
The surface water of the study area was monitored for over one year, from December 1997 to December 1998. Samples were collected from five stations within the study area, station 1-5. Station 1 was in the dredged canal, which was originally a side branch of the Warri River tributary. In the Warri River tributary, Station 2 was 500m upstream and Station 3 was 1000m upstream of the mouth of the dredged canal, whilst Stations 4 and 5 were respectively 500m and 1000m downstream of it. Stations 3 and 5 represented the reference situation to which possible dredging effects was compared. From each station, samples were collected twice before dredging, in December 1997 and in June 1998, corresponding to dry and raining seasons respectively. Samples were also collected immediately after dredging in July 1998 and were monitored in August, September and December 1998.

During sampling, water samples were collected into 100ml bottles and preserved with concentrated sulphuric acid to pH <2. Buck Scientific Atomic Absorption Spectrophotometer model 200A was used for heavy metal analysis according to APHA [26]. A correlation study was carried out with the results of physicochemical parameters (temperature, pH, alkalinity, turbidity, chloride, conductivity, TDS, TSS, DO, BOD, COD, hydrocarbons, ammonia, nitrate and sulphate) obtained from a previous study in the same location and of the same samples [22] in order to explain the origin of the heavy metals.

RESULTS AND DISCUSSION

Prior to dredging, the concentration of heavy metals in the surface water samples of Warri River occurred in traces; lead (0.01-0.28 mg l\(^{-1}\)), zinc (0.04-1.02 mg l\(^{-1}\)), copper (0.00-0.17 mg l\(^{-1}\)), iron (0.22-0.88 mg l\(^{-1}\)), chromium (0.00-0.03 mg l\(^{-1}\)) and cadmium (0.03-0.14 mg l\(^{-1}\)) (Fig. 2). These values are comparable to values obtained elsewhere in the Niger Delta [27-29]. But following the dredging of an oil well access canal, the concentration of heavy metals increased in several folds depending on the metal; lead (2.57 mg l\(^{-1}\)) zinc (9.56 mg l\(^{-1}\)), copper (15.36 mg l\(^{-1}\)), iron (229.50 mg l\(^{-1}\)), manganese (14.30 mg l\(^{-1}\)), chromium (0.27 mg l\(^{-1}\)) and cadmium (0.39 mg l\(^{-1}\)). The results indicated a significant elevation of heavy metal concentrations over the background values. The percentage increase are as follows; 2333, 2130, 20,750, 51,113, 1960, 1266 and 703% for lead, zinc, copper, iron, chromium, manganese and cadmium respectively over the background values. Action of tidal dilution is partly responsible for the reduction in heavy concentrations, but the presence of the unconfined sulfidic dredged materials deposited adjacent to the canal that is leaching into the canal may have helped to sustain acidification and heavy metal mobilization through pyrite oxidation [30]. It has been variously reported that the reason for the prolonged effect of dredging was attributed to the washing of leachates into the river from unconfined spoil dumps [31-33]. Elevated levels of heavy metals have been variously reported to be associated with oil development activities in the Niger Delta [34-38] and there are indications of heavy metals bioaccumulation [27-42].

In an attempt to understand the source of the elevated metals, a correlation studies between the heavy metals and 15 physicochemical parameters [22] was carried out. Out of the 15 physicochemical parameters, only 10 exhibited significant relationships with the metals, these are presented in Table 1. From the results of the correlation studies, it appears that there are at least three factors/mechanisms contributing to the heavy metal re-mobilization, they include sulphate acidity/conductivity/TDS, turbidity and oxygen/organic carbon systems. From the correlation analysis, it appears that acidity play a major role in the elevation of the water heavy metal concentrations following the dredging operations. For instance, pH correlated negatively with all the metals with correlation coefficients > 9.3 except for iron where it is 0.828. Similarly, sulphate concentrations had a strong positive correlation with all the metals with correlation coefficients > 9.3. It has been previously reported that soils and sediments of the mangrove ecosystem of the Niger Delta is high in non-bioavailable forms of heavy that are bound to the sediments/ soils as metal sulphides [1, 30, 43-45]. The dredging may have caused the re-suspension of anoxic sediments leading to their oxidation, which resulted in the formation of sulphuric acid causing the lowering of the pH and the release of heavy metals. According to Peltola and Astrom [46], dredging results in the oxidation of the reduced sulphur in the sediments resulting in a lowering of pH, which in turn leaches metals. Conductivity and TDS showed similar strong positive relationship with all the metals, suggesting that the acidification following the oxidation of the sediments may have caused the mobilization of sediment bound metals into the water column.
Fig. 2: changes in heavy metal concentrations following dredging

Table 1: Correlation coefficients of heavy metals with physico-chemical parameters following the dredging of Warri River

<table>
<thead>
<tr>
<th>Physico-chemical parameters</th>
<th>PH</th>
<th>Turbidity</th>
<th>TDS</th>
<th>TSS</th>
<th>DO</th>
<th>BOD₅</th>
<th>COD</th>
<th>Organic carbon</th>
<th>Conductivity</th>
<th>Sulphate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td>-0.930</td>
<td>0.808</td>
<td>0.918</td>
<td>0.810</td>
<td>-0.897</td>
<td>0.978</td>
<td>0.954</td>
<td>0.965</td>
<td>0.927</td>
<td>0.973</td>
</tr>
<tr>
<td>Zinc</td>
<td>-0.933</td>
<td>0.803</td>
<td>0.911</td>
<td>0.804</td>
<td>-0.901</td>
<td>0.978</td>
<td>0.956</td>
<td>0.966</td>
<td>0.920</td>
<td>0.969</td>
</tr>
<tr>
<td>Copper</td>
<td>-0.954</td>
<td>0.789</td>
<td>0.882</td>
<td>0.791</td>
<td>-0.904</td>
<td>0.989</td>
<td>0.969</td>
<td>0.977</td>
<td>0.891</td>
<td>0.968</td>
</tr>
<tr>
<td>Iron</td>
<td>-0.828</td>
<td>0.944</td>
<td>0.921</td>
<td>0.945</td>
<td>-0.740</td>
<td>0.917</td>
<td>0.848</td>
<td>0.871</td>
<td>0.920</td>
<td>0.927</td>
</tr>
<tr>
<td>Chromium</td>
<td>-0.939</td>
<td>0.798</td>
<td>0.912</td>
<td>0.800</td>
<td>-0.903</td>
<td>0.982</td>
<td>0.962</td>
<td>0.972</td>
<td>0.921</td>
<td>0.977</td>
</tr>
<tr>
<td>Manganese</td>
<td>-0.942</td>
<td>0.801</td>
<td>0.904</td>
<td>0.803</td>
<td>-0.886</td>
<td>0.990</td>
<td>0.961</td>
<td>0.972</td>
<td>0.911</td>
<td>0.970</td>
</tr>
<tr>
<td>Cadmium</td>
<td>-0.944</td>
<td>0.802</td>
<td>0.902</td>
<td>0.804</td>
<td>-0.885</td>
<td>0.991</td>
<td>0.962</td>
<td>0.973</td>
<td>0.910</td>
<td>0.972</td>
</tr>
</tbody>
</table>
The second system affecting heavy metal mobilization is turbidity and suspended solids. Both parameters had a strong positive relationship with the studied heavy metals. This is plausible because the dredging may have caused the re-suspension of sediments, which increased water turbidity, suspended solids and the concentrations of the heavy metal associated with the sediment phase. It has been reported that heavy metals bounded to sediments, play a major role in the pollution of the river system [47, 48].

The third system affecting heavy metal mobilization is oxygen and carbon systems. Dissolved oxygen had a strong negative correlation with all the metals, while organic carbon, COD and BOD had a strong positive relationship with the metals (Table 1). The re-suspension of the sediment may have exerted an oxygen demand causing the depletion of oxygen, which is utilized for the oxidation of metal sulphides to their sulphate forms, thus mobilizing metals into solution.

CONCLUSION

In conclusion, the dredging of an oil well access canal caused the elevation of heavy metals in Warri River. The result of the six month post dredging monitoring shows that the concentration of heavy metals reduced considerably, however, the presence of unconfined spoil banks adjacent to the canal tends to prolong the impacts. It is therefore concluded that the impacts of dredging on heavy metal is medium to long term.

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REFERENCES


