Remediation of arsenic-concentrated waters in a highly urbanized Nigerian city

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Abstract

Arsenic is a toxic metal with adverse effect on health, hence the need for geochemical evaluation of water sources to determine the level of arsenic concentration, their sources and propose remediation method to stem the tide of pollution of water in Ibadan, a highly urbanized city in South west Nigeria. Thirty water samples were randomly taken in the study area at locations underlain by quartzite (8), banded-gneiss (14) and augen-gneiss (8). Furthermore, 14 samples of effluents and rocks samples (fresh and weathered) were also collected and analyzed to ascertain the source of arsenic. Remediation studies using the phytoremediation method were carried out. Phytoremediation was done by cultivation of matured water hyacinth (*Eichhornia crassipes)* in 10.0, 20.0, 50.0 and 100.0 mg/L of arsenic acid. Arsenic content in all the water samples were determined using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES). Plants were harvested, dried, pulverized and analysed for metal content using inductively coupled-ion chromatography. Mean concentration of arsenic in the water samples underlying rock units was 0.01 mg/L; however, high arsenic concentration was obtained in effluents (0.02 mg/L) and quartzite (0.8 ppm). This implied that water derived from areas underlain by quartzite and in close proximity to effluents could be susceptible to arsenic contamination. The calculated Pollution index for arsenic also revealed high levels of pollution in effluents. Highest arsenic bio-accumulation was found at 100 mg/l in matured water hyacinth. Water sources in Ibadan metropolis are susceptible to arsenic contamination from leaching of weathered quartzite

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bedrocks and effluents from markets and industries. Remediation of arsenic using water hyacinth proved to be a good method in case of future pollution.
Keywords: arsenic, effluents, contamination, toxic, remediation, urbanized, quartzite, pollution, water hyacinth, phytoremediation.

1 Introduction

The release of heavy metals such as Cu^{2+}, Zn^{2+}, Fe^{2+} and As^{2+} in biologically available forms into the environment by human activity may damage or alter both natural and man-made ecosystems (Adeniji [1], Cyle *et al.* [6], Kabata-Pendias *et al.* [14], Tyler *et al.* [28] and Williams *et al.* [33]). Arsenic (As) which has a harmful effects on both humans and environment at low concentration occurs naturally in soil and minerals and may get into water and land through water run-off, wind-blown dust and leaching by man (Chowhury *et al.* [4], Chwirka, *et al.* [5], DeMarco, *et al.* [8], Nriagu, [16], Patlolla, *et al.* [18], Seth, *et al.* [24] and Wasserman, *et al.* [32]). Plants based bioremediation technologies have received recent attention as strategies to clean-up contaminated soil and water from various heavy metals (Das *et al.* [7], Lenntech [15], Rogers *et al.* [19], Sadowsky [21], Salt *et al.* [22], and Zayed *et al.* [35]). The focus on water hyacinth (*Eichhornia crassipes)* as a key step in wastewater recycling is due to the fact that it forms the central unit of a recycling engine driven by photosynthesis and therefore the process is sustainable, energy efficient and cost efficient under a wide variety of rural and urban conditions (Gijzen *et al.* [11], Gupta [12]).

The aim of the present study was to evaluate the arsenic (As) content in the various water types in Ibadan metropolis and to demonstrate the phytoremediation potential of water hyacinth, *E. crassipes* for the removal of As.

1.1 The study area

Ibadan the site for this study is located in the southwestern part of Nigeria, and lies between latitude 7°15′N–7°30′N and longitude 3°45′E–4°00′E (Figure 1). The city is characterized by lack of proper sewage and waste disposal systems (Tijani *et al.* [26]).

2 Materials and method

2.1 Project Set-up

The study which was mainly experimental was designed by dividing it into three:

2.1.1 Water sampling

Water samples were collected from spring, stream, swamp, industrial and market effluent/drain and groundwater (Figure 2), during the dry season to avoid any form of dilution. Samples were collected into a two (2) liter polythene bottle

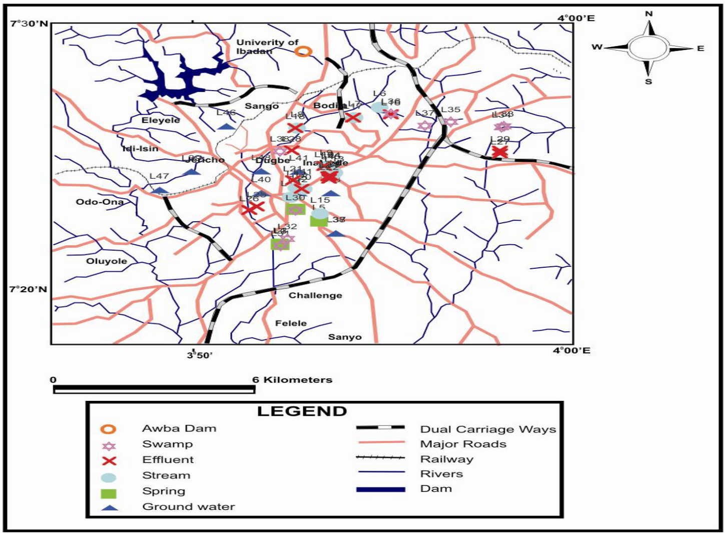

Figure 1: Location map of the study area showing sample sites.

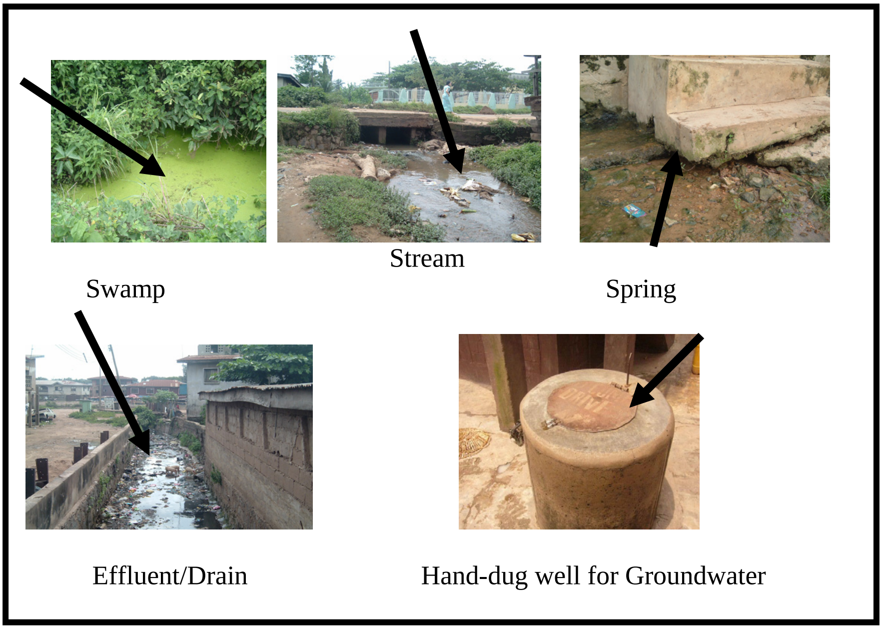

Figure 2: The various sources of water used in the study.

while measurements of pH, Electrical conductivity (EC) and Total dissolved solutes (TDS) were determined in-situ. The water was acidified with 0.2mg/L of concentrated Hydrochloric acid after the in-situ measurements.

2.1.2 Rock sampling

Three (3) rock samples were picked in all the areas where water samples were taken to assess the effect of weathering on the various water types.

2.1.3 Experimental remediation study

2.1.3.1 Preparation of As solution

Arsenic solution of 1.32 mg/L was prepared from 197.84g of As_2O_3 into 100mL bottle, and dissolved in de-ionized water. Different measurements of arsenic acid solution (0mg/l (that is de-ionized water), 10mg/l, 20mg/l, 50mg/l, and 100mg/l) were measured into 100ml plastic buckets.

2.1.3.2 Phytoremediation method

Water Hyacinth (*Eichhornia crassipes*) was harvested, rinsed with de-ionized water to remove any epiphytes and insect larvae grown on plants, and stored in the constructed green house (170 x 246 x 246 cm^3) used for the phytoremediation experiment. It is believed that the uptake of metals is greater in plants grown in pots of water in the green house than from the same water in the field (De Vries *et al.* [9], Page *et al.* [17]).

The experiment examines the effect of increased concentrations of As on the water hyacinth growth and the degree of uptake of the As into the different tissues of the plants within fifteen days. In this experiment five 10litre plastic buckets arranged in the green house were filled with groundwater to its 10litre level before pipetting different concentrations of arsenic acid solution in the order - 0mg/l (No arsenic acid solution added), 20mg/l, 50mg/l, and 100mg/l into the buckets. The water hyacinth was then cultivated in the different arsenic concentrations in the buckets. However, the As concentrations in both the solution and the different tissues of the plant were determined using the ICP-OES methods.

3 Results and discussion

3.1 Geochemistry of rock

Geochemical results revealed high level of arsenic (Table 1) in the fresh quartzite which has become very low in the weathered quartzite. This shows that areas underlain by quartzite can be polluted by arsenic and can get into the various water sources through mobilization of the metal from the weathered bedrocks
Various water sources of the study area were then evaluated to deduce whether the weathered bedrock has any adverse effect on the environment.

3.1.1 Physico-chemical results of the various water types

The average pH (Table 1) value of effluent is acidic (5.89), while that of the other water sources (spring, swamp, stream, and groundwater) are found to be alkaline (7.23). The acidic nature of effluents could be linked to the various dissolved metal ions in the solution. Electrical conductivity (EC) (µs/cm) and Total dissolved solids (TDS) (mg/l) were found to be within the WHO (2006) standard (1400 µs/cm) for all the water sources with values ranging from 0.17-112.4 and 0.169-73.06 respectively.

The heavy metal concentrations in the water sources were compared with the WHO (2006) standard while the mean concentration of world rivers (MCWR, Hem [13]) was compared with those obtained for swamp and effluent waters (Kabata-Pendias *et al.* [14]) (Table 1). Mean concentration values for all the water sources analysed were generally less than 1.5mg/l. The mean concentration of Cu, and Zn, in swamp and effluents is in the order one thousand (1000) times more than MCWR. The increase in these water types could be linked to their enriched content in the dissolved metal ions probably due to effect of solid and liquid waste discharged into them. However, it was noticed that arsenic is about ten times lower in the swamp and effluent waters than the MCWR value; this

Table 1: Mean physico-chemical results of trace metals of rocks and water sources.

Rock Types; Water sources	As	Pb	Zn	Cu	Ba	pH	TDS (mg/l)	EC (µs/cm).
Quartzite Rock (F)	0.8	19.6	48	0.3	445	-	-	-
Quartzite Rock (W)	0.01	11.2	91	0.7	573	-	-	-
Augen gneiss Rock (F)	0.01	9.8	11	0.7	688	-	-	-
Augen gneiss Rock (W)	0.01	11.3	13	0.5	1021	-	-	-
Banded gneiss Rock (F)	0.01	5.1	32	6.4	1188	-	-	-
Banded gneiss Rock (W)	0.01	4.1	32	2.6	921	-	-	-
Spring	0.01	0.01	0.02	0.01	0.02	7.1	49.36	75.94
Swamp	0.01	0.68	1.09	0.22	0.18	7.2	36.26	55.79
Stream	0.01	0.01	0.15	0.01	0.36	7.3	0.37	0.58
Ground water	0.01	0.01	1.2505	0.041	0.405	7.0	0.85	1.31
Effluents	0.07	0.03	0.28	0.01	0.47	5.89	0.62	0.95
WHO 2006	0.01	0.01	3	2	0.3	6.5-8.5	500	1400.00
World River (MCWR); Hem, 1985	0.001	0.5	0.015	0.003	0	-	-	variable

Notes: W. H. O – World Health Organization; EC – Electrical Conductivity. TDS – Total dissolved solid, F – Fresh rock, W – Weathered rock reveals no contamination of the metal As in these water types. The order of concentration of the micro-nutrients in all the water sources is therefore Cu>Zn>Ba>As.

3.1.2 Pollution index

Pollution index (PI) was used to quantify the pollution risk in various water types and to identify the contaminated water. The result showed (Table 2) that spring, stream and groundwater of the city are safe while the effluents and swamp are polluted. Pollution Index reveals considerable high Pb in the various water sources, however high arsenic was observed only in the effluents (Figure 3).

Table 2: Pollution Index values for the various water sources.

Elements (mg/l)	Spring	Stream	effluents	swamp	groundwater
As	1.00	1.00	6.57	1.00	1.00
Cu	0.00	0.00	0.00	0.01	0.03
Zn	0.01	0.05	0.09	0.04	0.09
Pb	1.20	1.10	3.29	7.56	4.77
Ba	0.03	0.52	0.67	0.03	0.53

3.1.3 Experimental remediation method

Results of Water hyacinth (*Eichhornia crassipes*) cultivated showed an increase of As uptake in the different parts of the plant as the days progresses especially in the 50mg/l solution. The same progressive increase in As was observed in all the various parts of the plant for 100mg/l (Table 3). The rate of absorption was highest in the roots and leaf of the plant with the highest As concentration in the 50mg/l and 100mg/l solutions, while the rate of adsorption was observed to be low with the lower As solutions (10mg/l and 20mg/l).

Table 3: Geochemical results of water as the arsenic concentration increases.

Sampling_l	As concentration (mg/l)	Pb(mg/l)	Cu(mg/l)	Zn(mg/l)	Ba(mg/l)	As(mg/l)
W1	0	0.01	0.009667	0.019	0.36333333	0.01
W2	10	0.01	0.002667	0.034333	0.39	0.01
W3	20	0.01	0.002333	0.037	0.38	0.01
W4	50	0.01	0.008667	0.026	0.36333333	0.03
W5	100	0.01	0.002	0.089667	0.36333333	0.066667

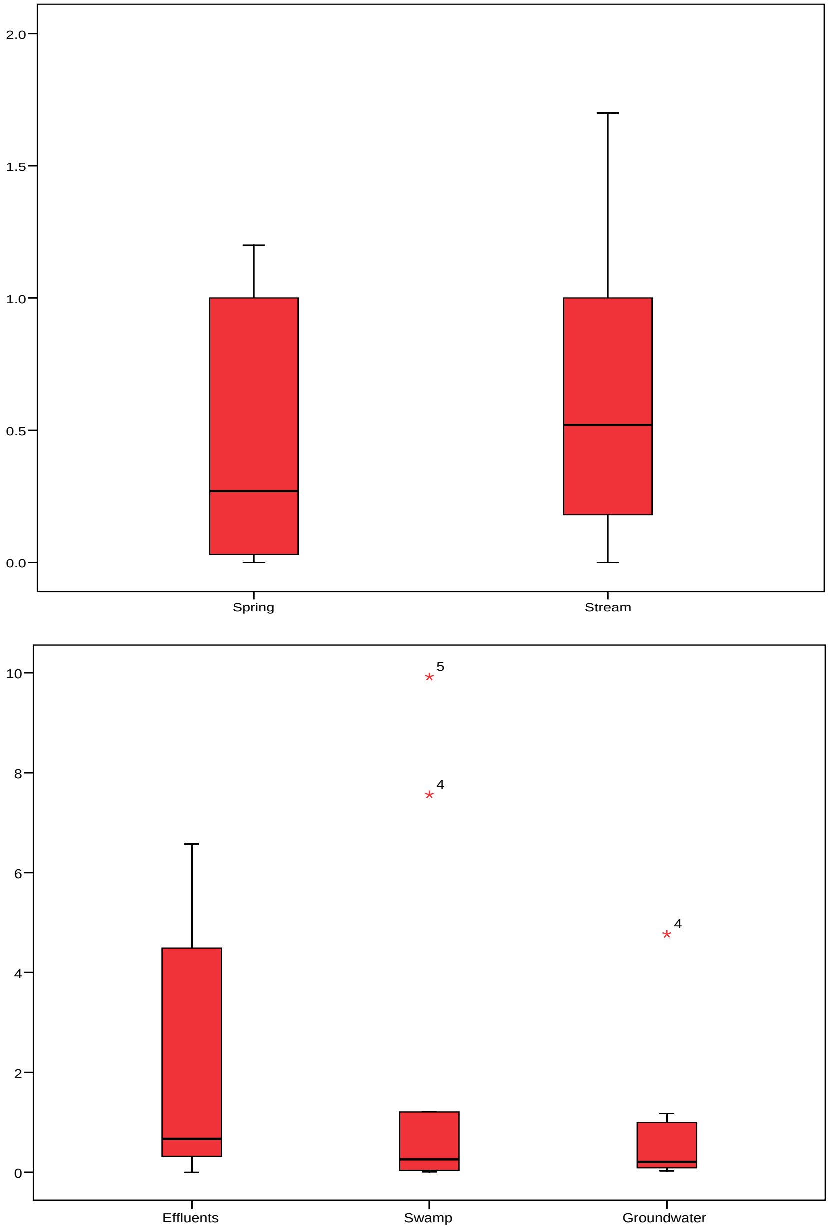

Figure 3: Box plot showing pollution index of spring, stream effluents, swamp and groundwater.

4 Conclusions

In conclusion, future pollution by arsenic of the various water sources are eminent in areas close to industrial and market wastes and also from weathered rocks of in the study area. The study also shows that Water Hyacinth can serve as a good remedial material in case of pollution. The water-hyacinth provides a means of purification and of trapping vast amounts of fertile elements which are normally lost.

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