Fuzzy logic modeling of bioaccumulation pattern of metals in coastal biota of Ondo State, Nigeria

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Abstract The accumulation patterns of ten metals in tissues of plant, Eichornia crassipes, and fishes, Hydrocynus forskahlii and Oreochromis mossambicus, were modeled with simple fuzzy classification (SFC) to assess toxic effects of anthropogenic activities on the coastal biota. The plant sample was separated into root, stem, and leaves and the fishes into bones, internal tissues, and muscles. They were analyzed for As, Cd, Cr, Cu, Ni, Pb, V, Fe, Mn, and Zn after wet oxidation of their dried samples. The results were converted into membership functions of five accumulation classes and aggregated with SFC. The classification results showed that there was no metal accumulation in the plant parts while the fishes were classified into low accumulation category. The internal tissues of the fishes had higher metal accumulation than the other parts. Generally, Fe and Mn had highest concentrations in the biota but are natural to the area and may not constitute significant risk. Cr had the highest transfer and accumulation from the coastal water into the aquatic lives and may be indicative of risk prone system being a toxic metal. Metal contaminations in the zone had not significantly accumulated in the biota making them less prone to risk associated with metal accumulation.

Keywords Fuzzy logic · Metals · Coastal area · Biological tissues

Introduction

The presence of high concentrations of metals in the tissues of plants and animals are undesirable (Yousuf and El-Shahawi 1999; Farkas et al. 2002; Ashraj 2005; Vutukuru 2005; Farombi et al. 2007). Metals like Cd, As, Cr(VI), and Pb have low toxicity threshold and possess the potential of disrupting the activities of enzymes and hormones through the formation of chemical bonds with active sites of enzymes and inhibition of the activities of metalloproteins among many other adverse reactions (Tort and Torres 1988; Canli 1995; Aucoin et al. 1999; Rasmussen and Anderson 2000; Adami et al. 2002; Basa and Rani 2003; Waqar 2006). These biochemical reactions of metals and their tendencies to generate free radicals responsible for malignant growths and oxidative stress in living tissues (Filipovic and Raspor 2003; Abou EL-Naga et al. 2005) have
made studies on their presence in the ecosystem important. These metals when discharged into the environmental media may be at trace level and may not cause immediate significant toxic effects. However, their persistency and non-biodegradability tendencies increase their bioaccumulation and biomagnifications capacities on long exposure and their concentration in the food chain and/or web as the tropic level increases. Some of the metals may not be toxic in their metallic form but can be bio-transformed through relevant biochemical reactions in living tissues thereby exhibiting increased toxicity (Chau and Wong 1977). Therefore, the regulation of metal discharge is a serious global concern regardless of the concentration at discharge points. Seafoods, particularly marine fishes, contribute substantially to human diet in several nations and screening of these against harmful substances is essential. Research works on monitoring of metal concentrations, their accumulation tendencies, and bioactivities in plants and animals found in the human diet and in some particular human tissues are therefore increasing especially in developed countries to indicate metal ecotoxicity and for environmental impact assessment purposes. However, data on biological monitoring of metals in developing countries, from crude-oil exploration areas and in some living tissues of plant and animal species useful to man, are limited and are needed because of the global interactions of the environment and its implications on human health.

Reported works in literature on metal contamination or accumulations in living tissues reported individual metal concentrations as part-per-million without information on the potential combined effects such metals can have on living tissues. The need for the use of modeling tools to understand extents of environmental problems in this regard, define solution objectives, develop promising alternatives, evaluate such alternatives potentials among other has been identified by Lund and Palmer (1998). Thus, the use of fuzzy logic modeling approach for the monitoring and understanding of bioaccumulation of metals based on expert knowledge or regulatory standards and to help in understanding the systemic trend in data is a novel approach. This new methodology of bio-monitoring will aid effective policy formulation through the identification of useful trends in field data and for appropriate environmental management. Fuzzy logic is an emerging disciplinary matrix introduced in 1965 from artificial intelligence (Zadeh 1965). Its potential in better modeling chaotic, biological, and other animate system has been reported in literature (Sadegh-Zadeh 2001). It is thus emerging as data mining methodology.

The coastal area of Ondo used as the site for this study is a crude oil exploration zone in Nigeria with some works published on metals in living tissues (Asaolu et al. 1997; Asaolu 2002; Asaolu and Olaofe 2005). Increase in tempo of crude oil exploration in the zone since April 1998 when exploration started has created negative impacts on the hosting community and the neighborhood (Adebowale et al. 2008). However, the prevailing biogeochemical reactions in the zone have potential of enhancing self-purification. The need to establish the impact of the industrial, domestic, and commercial activities on tissues of plant and fish species in the area especially beyond the conventional approach of individual metal concentration to the holistic use of fuzzy logic modeling tool is identified. This study, therefore, used fuzzy-based modeling tools to monitor contamination impacts of anthropogenic activities on different parts of a plant species: *Eichornia crassipes* (water hyacinth) and two fish species: *Hydrocynus forskahlii* (tiger fish) and *Oreochromis mossambicus* (Mozambique tilapia). The focus is to gain deeper insight on the potential of using fuzzy logic-based models as effective data mining tool and modeling approach for biological and animate systems and the degree of metal accumulation in biological tissues.

**Materials and methods**

**Study area and samples description**

Ondo coastline (latitude 5°50' N–6°09' N and longitude 4°45' E–5°05' E) is an estuarine coastal zone with an entry point at Awoye where there is exchange of water between the upland wetlands freshwater and the saline Atlantic Ocean.
The water close to this estuarine point is therefore brackish. A crude-oil prospecting platform on one of the sampling sites (latitude 5°54′ N, longitude 4°59′ E) classified the region as one of the crude-oil belt region of Nigeria (Niger-Delta region) with the claims of environmental degradation due to the prospecting activities. Crude oil prospecting started in the region about 10 years ago (April 1998) to the period of this study (August 2008). The total area covered by watershed is over 2,000 km². The climatic condition of the area involves a combination of wet and dry seasons with a temperature range of 28–32°C. A more detailed site description is in an earlier publication (Adebowale et al. 2008).

Two fish species and one plant sample were taken from the site and used for the study. Elongate tiger fish (*H. forskahlii*) belonging to the family *Alestiidae*—African tetras formerly a subfamily of *Characidae*; it is an open water predator often found near the water surface that feeds on fishes, preferring long-bodied fish as they are easier to swallow and also takes insects, grass, and snails. It breeds in freshwater environments. Reproductively, most members of this family are non-guarders. The second fish specie, Mozambique tilapia (*O. mossambicus*), has spread worldwide through introductions for aquaculture. Its populations in the wild resulted from the intentional release or escapes from fish farms. *O. mossambicus* is omnivorous and feeds on almost anything, from algae to insects. The two fishes are part of human consumption in the coastal area. The plant sample used is *E. crassipes* with the common name water hyacinth. Water hyacinth (*E. crassipes*) is a member of the pickerelweed family—Pontederiaceae (Center and Spencer 1981). It varies in sizes from a few centimeters to over a meter in height. The glossy green, leathery leaf blades are up to 20 cm long and 5–15 cm wide and are attached to petioles that are often spongy and inflated. It reproduces sexually by seeds (Agami and Reddy 1990). It is one of the most productive plants on earth and is considered the world’s worst aquatic plant (Charudattan 1986). Low oxygen conditions do develop beneath water hyacinth mats formed by the plant and the dense floating mats impede water flow and create good breeding conditions for mosquitoes.

**Sampling and preservation of samples**

Plant samples were randomly collected on the water course where they float at various sampling sites and were kept in air-tight polyethylene bags. It was observed that as the sampling sites get closer to the estuarine discharge point at Awoye the plant was not found which indicated the inability of the plant to survive in saline water habitat. Samples of the fish species were purchased from fishermen found on the water course and were preserved with 4% formalin. The preservation period was however short and the preserving solution was analyzed for metals study to avoid negative interference.

**Chemical analysis**

The plant samples (12 specimens of average weight 122 ± 9 g) were separated into roots, leaves, and stems to determine the accumulation trend from root to the shoot. They were each dried in oven at 60°C till well dried. The dried samples were grinded before digestion. Five hundred milligrams of dried weight of each fraction was digested with 10 mL of mixture of HClO₄ and 10 mL HNO₃ at about 80°C for 4 h. The resulting clear-colored solutions were made up to mark in volumetric flask (25 mL) with demineralized-distilled water. The reagents used were all of analytical grade and all vessels were well treated to avoid external contributions of metals. Sample and reagent blanks were analyzed to correct for possible external contributions. The blanks had less than 4% of the metals investigated. Replicate samples were also evaluated and all analyses were done in triplicate to ensure precision and reproducibility of results. The mean values and the standard error of mean at 95% confidence limit are presented. The quality assurance of the analysis was ensured by the spiking of the samples with known concentration of metal standards for recovery studies. The recoveries of metals were between the range of 84–102%. The digested samples were analyzed for ten trace elements (As, Cd, Cu, Cr, Fe, Mn, Ni, Pb, V, and Zn) using atomic absorption spectrophotometer (AAS) Buck Scientific Model 205A as reported in APHA (1995). All the metals were analyzed with the flame mode.
of the AAS (F-AAS). The detection limits range from 0.01–0.15 μg/g. The choice of the metals investigated was based on the earlier studies that reported the contamination of this coastal area with these metals (Adebowale et al. 2008, 2009).

Metal analysis in the different parts of fish species was carried out using similar approach to that of plant samples except that 10 mL of H₂O₂ was used instead of HClO₄ because the fish is rich in organic matter. The quality assurance step taken for the analysis of fish samples is the same with that of the plant sample and the recovery ranged from 87–98% of the metals studied. The fishes (ten specimens each) were oven dried at 60°C and separated, before digestion, into classifications of skeletal system comprising the bones, fins, and the bony part of the head; the muscle and scale which are the part found in human diet and the internal tissues which include the gill, kidney, liver etc. The average weights of the fishes were 276 ± 14 g for O. mossambicus and 213 ± 8 g for H. forskahlili. The digested samples were analyzed for the same ten elements as in plant samples. Water samples were likewise collected from the same coast and analyzed from the same metals for correlation with aquatic biota’s concentration. They were preserved with 2 mL concentrated HNO₃ per liter. The water samples were digested with concentrated HNO₃ by heating 50 mL water samples and 5 mL concentrated HNO₃ at 70°C for 2 h. The resulting clear solutions were made up to mark with demineralized–distilled water in 100 mL volumetric flasks and the metals quantified with F-AAS. All reagents used were of analytical grade and sample blank was analyzed to determine interference. The sample blank had less than 5% of metals investigated. The quality assurance of the water analysis was ensured with the spiking of water samples with known concentration of metal standards and the metal recovered for water analysis ranged between 91% and 104%.

Fuzzy synthetic evaluation principle

Fuzzy synthetic evaluation is based on fuzzy logic which deals with highly variable, linguistic, uncertain, and vague data or information and could extract logical, reliable, systemic, and transparent information from such data collection for practical applications. It expresses multiple level process between [0, 1] with a rule-based IF X AND Y THEN Z approach where the “IF” part is the antecedent and the “THEN” the consequence part. The antecedents input variables, X and Y are aggregated with operators like “AND” which is standard minimum (intersection) and/or with standard maximum (union operator) which is “OR” (Icaga 2007; Ocampo-Duque et al. 2006; Lu and Lo 2002).

The first step used in formulating fuzzy model for environmental purpose is the selection of the environmental media (i.e., soil, water, sediment, plant etc.) and the choice of relevant conventional parameters (e.g., DO, BOD, metals etc.) need for the modeling. Afterward is the determination of the concentration of the parameters by standard chemical analysis to obtain the observed values which serve as the antecedents in the modeling. Then, the parameters are classified into ith classes based on the observed values obtained from analysis and the relevant quality criteria set by regulatory bodies for the parameters and other related knowledge reported in literature (Table 1). The next step is to obtain membership function used to convert each parameter into fuzzy function. This involves that standardization of the natural measurement scale to the quality parameter based on the ith (which is five for this study) classifications earlier proposed using the Eqs. 1–5 below. The limits used in the membership formulations (a, b, c, d, and e) are based on the regulatory standard limits in relation to the degree of accumulation investigated (Table 1).

\[
\lambda_a = \begin{cases} 
1 & \text{when } 0 \leq x \leq a \\
\frac{(b - x)}{(b - a)} & \text{when } a < x < b \\
0 & \text{when } x \geq b 
\end{cases} \quad (1)
\]

\[
\lambda_b = \begin{cases} 
0 & \text{when } x \leq a \text{ or } x \geq c \\
\frac{(x - a)}{(b - a)} & \text{when } a < x < b \\
1 & \text{when } x = b \\
\frac{(c - x)}{(c - b)} & \text{when } b < x < c 
\end{cases} \quad (2)
\]
Table 1 Membership function limits for metals accumulation in biological tissues

<table>
<thead>
<tr>
<th>Metals</th>
<th>No accumulation (μg/g) (a)</th>
<th>Low accumulation (μg/g) (b)</th>
<th>Moderately high accumulation (μg/g) (c)</th>
<th>High accumulation (μg/g) (d)</th>
<th>Hyper accumulation (μg/g) (e)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plant</td>
<td>Fish</td>
<td>Plant</td>
<td>Fish</td>
<td>Plant</td>
</tr>
<tr>
<td>As</td>
<td>0.10</td>
<td>0.05</td>
<td>5.0</td>
<td>0.50</td>
<td>25.0</td>
</tr>
<tr>
<td>Cd</td>
<td>0.10</td>
<td>0.05</td>
<td>1.00</td>
<td>0.50</td>
<td>20.0</td>
</tr>
<tr>
<td>Cr</td>
<td>0.50</td>
<td>0.10</td>
<td>50.0</td>
<td>20.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Cu</td>
<td>1.00</td>
<td>0.10</td>
<td>500.0</td>
<td>250.0</td>
<td>1,000</td>
</tr>
<tr>
<td>Ni</td>
<td>1.00</td>
<td>0.10</td>
<td>100.0</td>
<td>50.0</td>
<td>1,000</td>
</tr>
<tr>
<td>Pb</td>
<td>0.10</td>
<td>0.05</td>
<td>50.0</td>
<td>2.50</td>
<td>1,000</td>
</tr>
<tr>
<td>V</td>
<td>1.00</td>
<td>0.10</td>
<td>100.0</td>
<td>10.0</td>
<td>5000</td>
</tr>
<tr>
<td>Fe</td>
<td>50.0</td>
<td>10.0</td>
<td>500.0</td>
<td>50.0</td>
<td>1,000</td>
</tr>
<tr>
<td>Mn</td>
<td>50.0</td>
<td>10.0</td>
<td>500.0</td>
<td>50.0</td>
<td>1,000</td>
</tr>
<tr>
<td>Zn</td>
<td>50.0</td>
<td>10.0</td>
<td>500.0</td>
<td>50.0</td>
<td>1,000</td>
</tr>
</tbody>
</table>

\[
\lambda_c = \begin{cases} 
0 & \text{when } x \leq b \text{ or } x \geq d \\
\frac{(x - b)}{(c - b)} & \text{when } b < x < c \\
1 & \text{when } x = c \\
\frac{(d - x)}{(d - c)} & \text{when } c < x < d 
\end{cases} 
\] 

(3)

\[
\lambda_d = \begin{cases} 
0 & \text{when } x \leq c \text{ or } x \geq e \\
\frac{(x - c)}{(d - c)} & \text{when } c < x < d \\
1 & \text{when } x = d \\
\frac{(e - x)}{(e - d)} & \text{when } d < x < e 
\end{cases} 
\] 

(4)

\[
\lambda_e = \begin{cases} 
0 & \text{when } x \leq d \\
\frac{(x - d)}{(e - d)} & \text{when } d < x < e \\
1 & \text{when } x \geq e 
\end{cases} 
\] 

(5)

where \(\lambda_a, \lambda_b, \lambda_c, \lambda_d, \) and \(\lambda_e\) represent the membership function for the group classifications a, b, c, d, and e, respectively; \(x\) represents the observed values from chemical analysis; and a, b, c, d, and e are the limits criteria for different classification (Table 1).

The next step involves the arrangement of the membership functions of the quality observed into evaluation matrix \(R\) and the application of fuzzy operators.

\[
R = \begin{bmatrix} 
\lambda_{11} & \lambda_{12} & \cdots & \lambda_{1m} \\
\lambda_{21} & \lambda_{22} & \cdots & \lambda_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
\lambda_{n1} & \lambda_{n2} & \cdots & \lambda_{nm} 
\end{bmatrix} 
\] 

(6)

The operators in FSE used for aggregating the membership functions (which is the antecedent part) are simple fuzzy classification (SFC), fuzzy similarity method, fuzzy comprehensive assessment, fuzzy information intensity, and defuzzification (details are in Chang et al. 2001; Lu and Lo 2002; Haiyan 2002; Onkal-Engin et al. 2004). Simple fuzzy classification is briefly described below for use as modeling methodology for metal accumulation monitoring in biological tissues.

**Simple fuzzy classification**

This operator aggregates membership functions obtained from environmental data using Eqs. 7–9. From the membership function the possible overlaps (fuzziness) in classification and field results are accounted for. The fuzzy membership function is used to form a relationship between the observed data and the degree of accumulation in living tissues through an evaluation matrix \(R\) (Eq. 6). \(R\) is subjected to any fuzzy reasoning method. The fuzzy reasoning used for this study is the distance operator expressed by Eqs. 7–9:

\[
k_j = \left( \frac{\sum_{i=1}^{n} (W_i \lambda_{ij})^2}{\sum_{i=1}^{n} \sum_{j=1}^{m} (W_i \lambda_{ij})^2} \right)^{1/2} 
\] 

(7)

\[
\sum_{i=1}^{n} W_i = 1 
\] 

(8)

\[
k_p = \max \{k_1\} 
\] 

(9)
where \( k_j \) is the resultant aggregate accumulation class of the pollutants for each classification, \( w_i \) is the weight allocated to each parameter monitored, \( k_p \) is the chosen class to which the environmental media belongs taken from the maximum value of \( k_j \). The choice of appropriate weight \((w_i)\) for the parameters which defines the importance of the parameter and its influence on the final output is made by varying methods. For this study, analytical hierarchy process–singular value decomposition as presented in Ocampo-Duque et al. (2006) was used based on the reported toxicity of the trace elements and the resulting weights are: \( w(\text{As}) = 0.13; \) \( w(\text{Cd}) = 0.11; \) \( w(\text{Cr}) = 0.20; \) \( w(\text{Cu}) = 0.07; \) \( w(\text{Ni}) = 0.10; \) \( w(\text{Pb}) = 0.11; \) \( w(\text{V}) = 0.08; \) \( w(\text{Fe}) = 0.06; \) \( w(\text{Mn}) = 0.06; \) and \( w(\text{Zn}) = 0.08. \)

**Results and discussion**

**Metals in plant tissues**

Metal concentrations in root, stem, and leaves of \( E. \ crassipes \) and the corresponding water samples from the coastal area are presented in Table 2. The concentrations of the metals in the coastal area are generally lower than what was obtained in previous study (Adebowale et al. 2008). This clearly depicts that atmospheric precipitation play a very significant role in the chemistry of the zone. There is high dilution of the metal concentrations by atmospheric precipitation at the time of the present study (August 2008) being the peak of wet season with high frequency of rainfall. The climatic conditions and the low salinity of the coastal water at this period however favor the growth of \( E. \ crassipes \) forming a dense mat cover on the water course. This allows for the interaction of the metals in the coastal habitat with the plant. The concentrations of the metals in the plant parts were also moderate but the transfer factors of the metals into the plant as a whole are high (Table 2). It is very evident therefore that the plant is extracting the metals from the coastal water despite the reduced level of contamination (Agunbiade et al. 2009). The comparative assessment of the accumulation and transfer of metals into the different plant parts are presented in Fig. 1. The stem has the highest transfer of As, Cd, Cr, V, Fe, and Mn while the root has the highest values for Cu, Ni, Pb, and Zn. This implies that \( E. \ crassipes \) can be useful in phytoextraction and/or rhizofiltration of the metals found high in their parts for phytoremediation technology (Agunbiade et al. 2009). Cr was distinctly the most transferred. The high transfer factors of the metals into the plant parts are also indications of the bioavailability of the metals which is higher in aquatic habitat than in soil since the plant habitat is aqueous compared to transfer factor observed in plants in soil habitat.

**Table 2** Metals concentration in separate plant parts compared with the concentrations in the water across the coast and transfer factor of the metals

<table>
<thead>
<tr>
<th>Metals</th>
<th>Water (µg/L)</th>
<th>Plant parts (µg/g)</th>
<th>Transfer factor a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Root</td>
<td>Stem</td>
</tr>
<tr>
<td>As</td>
<td>8.18 ± 0.53</td>
<td>0.16 ± 0.01</td>
<td>0.20 ± 0.02</td>
</tr>
<tr>
<td>Cd</td>
<td>11.21 ± 0.72</td>
<td>0.19 ± 0.01</td>
<td>0.29 ± 0.03</td>
</tr>
<tr>
<td>Cr</td>
<td>45.41 ± 1.12</td>
<td>5.05 ± 0.45</td>
<td>5.34 ± 0.87</td>
</tr>
<tr>
<td>Cu</td>
<td>1.33 ± 0.04 b</td>
<td>31.40 ± 0.96</td>
<td>28.99 ± 1.97</td>
</tr>
<tr>
<td>Ni</td>
<td>62.09 ± 0.98</td>
<td>0.72 ± 0.08</td>
<td>0.70 ± 0.13</td>
</tr>
<tr>
<td>Pb</td>
<td>18.16 ± 0.52</td>
<td>0.39 ± 0.02</td>
<td>0.37 ± 0.11</td>
</tr>
<tr>
<td>V</td>
<td>94.18 ± 2.36</td>
<td>1.49 ± 0.18</td>
<td>1.75 ± 0.31</td>
</tr>
<tr>
<td>Fe</td>
<td>5.78 ± 0.61 b</td>
<td>290 ± 8.5</td>
<td>339 ± 5.8</td>
</tr>
<tr>
<td>Mn</td>
<td>8.36 ± 0.43 b</td>
<td>364 ± 12.2</td>
<td>365 ± 11.9</td>
</tr>
<tr>
<td>Zn</td>
<td>3.28 ± 0.34 b</td>
<td>132 ± 4.8</td>
<td>123 ± 8.2</td>
</tr>
</tbody>
</table>

Results are mean ± SEM
aTransfer factor of metals into all the plant parts together
bThese values of metals were reported in milligrams per liter
Fig. 1 Graph of transfer factor of metals into the different parts of Eichornia crassipes

(Moreno-Jimenez et al. 2009). Bioavailability of metal is closely linked to their solubility in aqueous phase. Thus, in aquatic habitat transfer of metals is enhanced when the metals exist in soluble fractions. Low concentration of metals in the parts of E. crassipes is as a result of the degree of contamination of the habitat and the large biomass of the plant forming dense mat on the water course with each absorbing metals into its tissues.

Fuzzy logic modeling of metals in plant tissues

The simply fuzzy classification was used to model metal accumulation in the plant root, stem, and leaves. The accumulation class to which the result belongs is taken from the maximum value and is used to evaluate impact status, the affinity of the plant for metals, and the exposure risk to the environment by the accumulation of the metals. The outcomes of the membership functions in the plant root based on the five accumulation classifications are presented in the evaluation matrix shown in Fig. 2.

The results of the membership functions show that the metals are between no accumulation to moderately high accumulation classes which is relatively safe for the environment. Fe and Mn are the metals with membership function in the moderately high accumulation category. These two metals are abundant in Ondo coastal area (Adebowale et al. 2008). The non-existence of any of the membership function in the high and hyper accumulation category is an indication of low impact of the metal contamination on the plant root. The results of the algorithm of SFC aggregation of the membership function and the weight using for the plant root in the order of a, b, c, d, and e are presented in the matrix below:

<table>
<thead>
<tr>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>e</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.73</td>
<td>0.69</td>
<td>0.05</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

The plant root is classified as having no accumulation of metals with 0.73 membership function in this category. However, the membership function of the low accumulation is very close to the no accumulation category which indicates that the plant root has the capacity of accumulating metals but no significant accumulation was occurring because of the state of the habitat and the large quantity of the plant on the coastal area. Thus, the biomonitoring of metals into the root of the plant using fuzzy logic revealed that there is no accumulation of metals from the coastal water into the plant and no attendant risk to the environment.
Furthermore, the evaluation of the accumulation pattern of metals in the plant’s stem follows a similar pattern with that of the root. The evaluation matrix obtained from the membership function of the metals in the plant stem is given in Fig. 2. The classification of the metals were between no accumulation and low accumulation classes except Fe and Mn which has membership in moderately high category. Cr also exist at the boundary of the low and moderately high accumulation classes criteria for the stem samples. The ability of *E. crassipes* to accumulate and/or transfer the metals from the environment via the root into the plant stem is not clearly reflected in the modeling result (Fig. 2). However, the Cd membership function in low accumulation category for the stem was higher than its corresponding value in the roots indicating potential higher affinity of the stem for Cd metal.

The SFC algorithm of the plant stem is presented in the matrix below:

Finally, the evaluation matrix for plant leaves (Fig. 2) follows the same trend with the stem and the root. It therefore implies that the plant is safe and has not accumulated metals from the coastal water. The risk posed by metal exposure and accumulation in the biota is not likely to be experienced in this zone based on the results obtained in this study. The metals contamination reported in water and sediment of the coastal area by an earlier study (Adebowale et al. 2008) is not found accumulating into this plant from the coast but is being partitioned and demobilized into the sediment phase (Adebowale et al. 2009). This therefore suggests that the transfer of the metals into the food chain is minimized by the preference of the metals for the sediment phase than the biotic region making the ecosystem relatively safe from the impact of the metal contamination. The results of the algorithm of SFC for the plant leaves as presented in the matrix below confirm this finding.

The final algorithm aggregate for the leaves also classified the plant as having not accumulated metals into its tissues as depicted by membership function 0.75 in the no accumulation category. The plant is safe and free of metal accumulation in its present state.
Metals in tissues of fishes

The concentrations of metals obtained in the bones, internal tissues, and muscle of both species of fish from this coastal area are presented in Table 3. The table also presents the concentrations of metals in the water course within the coastal region and the transfer factors determined to assess the movement of metals from the water into the whole parts of the fishes. The internal tissues of *O. mossambicus* have the highest concentration of Cr, Cu, Pb, Ni, Fe, Mn, and Zn. The internal tissues studied consist of the liver, kidney, and gill. The liver is involved in the detoxification of the toxic metals and the kidney is a major site of attack for toxic materials. The higher concentrations of some metals in these internal tissues of fishes than in any other parts particularly the muscles have also been reported in literature (Jankong et al. 2007). Generally, the muscle of this fish has the lowest concentration of the metals except in few cases. This implies that the fish may be safe for consumption because the muscle is the part consumed. Consumption of the fish bone and internal tissues is not recommended as it may increase exposure to metals accumulation and toxicity in human. The bone concentrations of As, Cd, and V in the fishes were the highest. Cd and Ca have similar ionic radius which is 0.97 Å and 0.99 Å, respectively, which makes them to have a tendency of acting as camouflaged elements against each other (Reeder 1996; Ianni et al. 2000; Korfali and Davies 2004). Thus, there is likelihood that Cd is replacing Ca in the bone of the fishes. The transfer of metals into this fish evaluated by the total concentration of the metals in the fish compared with the mean metal concentration in the coastal water expressed that *O. mossambicus* transferred Pb, Fe, Mn, and Zn highly into its tissues. Generally, the transfer factors of the metals into the fish are high indicating biomagnification of the metals above the ambient value in the coastal region. It is also obvious that Cr is the most transferred metal as it was also observed in plant samples. This implies that Cr poses environmental risk to the biota in the coastal zone.

Moreover, the comparative assessment of transfer factor of the metals into the different parts of *O. mossambicus* is presented in Fig. 3. The transfer of As and Cd elements into the bones of the fishes was further confirmed. Arsenic is less reported as being higher in the bones as against the internal tissues in literature but was found in highest concentration in the bone compared to other part of *O. mossambicus* from this coast. The internal tissues of *O. mossambicus* have the highest transfer of the trace elements investigated except As, Cd, and V. This confirms the earlier result reported in this study on the metals concentration.

For the analysis of *H. forskahlil*, the trend of concentrations of metals in the bones, internal
tissues, and muscle of *H. forskahlii* is also presented in Table 3 and the transfer factors determined to assess the movement of metals from the water into the entire parts of the fish. The bones of *H. forskahlii* have the highest concentration of As, Cd, Ni, Fe, Mn, and Zn as against the internal tissues of *O. mossambicus* which have the highest concentrations of these toxic elements except As and Cd. The trend of As and Cd in the fish is the same with that of *O. mossambicus* and may be due to the same reasons. Likewise, the muscle of *H. forskahlii* has the lowest metal concentrations except Cr (Table 3). This implies also that the fish may be safe for consumption having less metal concentrations in the part used in human diet. The transfer of metals into the whole fish measured by metals’ transfer factors showed that Cr is the most transferred followed by the micronutrients; Mn, Fe, and Zn in that order. The transfer of Cd into this fish species was notably high while it was observed that the transfer factors of *H. forskahlii* are generally higher than for *O. mossambicus* except for the Pb and some micronutrients; Mn, Fe, and Zn. *H. forskahlii* therefore may have higher affinity for toxic metals than *O. mossambicus*. Moreover, the comparative assessments of transfer factors of the metals into the different parts of *H. forskahlii* are presented in Fig. 4. The generally high transfer factors of the metals into the fishes and the plant is a clear indication that some portion of the metals are biologically available to the biotic system despite the reduce concentration of the metals in the coastal water.

Fuzzy logic modeling of metals in tissues of fishes

The accumulation trends of the metals into the fishes are modeled with fuzzy-based model to assess the combine effects of metals and the potential risk of exposure metals may have on the food web/chain and on human dietary intake of the fish. Due to the human consumption of the fishes, the quality criteria used for the formulation of membership functions for the fish species were more stringent than for the plant samples (Table 1).

The metal concentrations in the different part of *O. mossambicus* formulated into membership functions and arranged into the evaluation matrix are presented in Fig. 5. The order of arrangements of the metals and their weight follows the pattern used for the plant sample. The classification categories are also the same with the plant classification. The outcomes of the membership functions of the metals in the bones of *O. mossambicus* (Fig. 5) ranged from no accumulation to high...
accumulation categories. Hyper accumulation was not witnessed for any metal. The high accumulation category occurred only for Fe and Mn which are micronutrients and are in high concentration in the coastal area.

The membership functions of the metals investigated are more towards the low accumulation class than the high accumulation. Cr, As, Ni, and Pb are classified between no accumulation and low accumulation classes. Overall, most of the metals have more degree of membership in low accumulation class. Hence, the result of the algorithm of SFC for the bones of *O. mossambicus* fish as presented in the matrix below classified the bone’s status as low accumulation since the maximum \( k_j \) of 0.73 belongs to this class of accumulation.

\[
\begin{array}{cccccc}
0.52 & 0.73 & 0.44 & 0.04 & 0.00 \\
\end{array}
\]

It is therefore evident that the accumulation of metals in the fish bone is low with minimal risk on its dietary intake. However, the membership function 0.52 for no accumulation and 0.44 for...
moderately high accumulation implies that the metal-accumulating pattern in the fish bones tends more towards the no accumulation than the moderately high accumulation. Thus, with regular control of contaminants’ sources, non-accumulation of the metals will be witnessed in the coastal biota.

The formulation of evaluation matrix for the accumulation of metals into the internal tissues of *O. mossambicus* is also presented in Fig. 5. The trend of the membership function is similar to that of the fish bones. Hyper accumulation is equally not witnessed in the fish internal tissues.

The results of SFC algorithm classified the fish internal tissues into the low accumulation category ($max k_j = 0.71$) as presented below.

The results of other categories however have higher value ($k_j = 0.51$) for the moderately high accumulation category than ($k_j = 0.47$) for the no accumulation class. This is different from the trend obtained for the fish bone. It implies that the fish internal tissues have more metals, higher risk, and higher capacity to bioaccumulate metals than the bones. The internal tissues may accumulate more if exposed to a more contaminated coastal region.

The last part of *O. mossambicus* that was monitored is the muscle which is used in human diet. The evaluation matrix of the metals is presented in Fig. 5. The membership functions follow similar pattern with other parts of the fish investigated. The fuzzy algorithm result for the fish muscle presented below has the max $k_j$ of 0.73 at the low accumulation category implying a low metal accumulation in the fish muscle while the next value of $k_j$ being 0.54 belongs to the no accumulation class.

![0.54 0.73 0.42 0.02 0.00](image)

The fuzzy logic modeling of *H. forskahlilii* based on earlier presented criteria produced an outcome of the membership functions formulated into matrix for the fish bone as presented in Fig. 6. The matrix is similar to the ones obtained for the bones of *O. mossambicus* (Fig. 5) indicating that the accumulation pattern of metals in the bones of the two fishes investigated in the coast is the same and that the extent of contamination and its resultant effects are minimized. The final classification outcome for the bone taken from the $k_p$ classified metal accumulation in the fish bone as also low accumulation with maximum aggregate $k_j = 0.79$. The maximum $k_j$ of this fish’s bone is higher than that of *O. mossambicus* but the classification is the same.

![0.47 0.79 0.44 0.06 0.00](image)

The no accumulation and moderately high accumulation categories have close $k_j$ values which ensure that the classification is clearly low accumulation category.

Furthermore, the internal tissues of *H. forskahlilii* have very similar accumulation pattern with the other parts thus far discussed (Fig. 6). The overall classification based on the

![0.78 0.22 0.00 0.00 0.00](image)

**Fig. 6** Fuzzy membership functions of metals in the tissues of *H. forskahlilii* in the order of As, Cd, Cr, Cu, Ni, Pb, V, Fe, Mn, and Zn per row and classification of the accumulation represented in the columns in the order of a, b, c, d, and e.
outcome of SFC algorithm also classified the fish internal tissues into the low accumulation category \( k_j = 0.74 \) as presented in the matrix below. The next \( k_j \) value \( k_j = 0.50 \) belong to the moderately high accumulation class similar to the result obtained for internal tissues of *O. mossambicus*. This result revealed further the capacity of the internal tissues to bioaccumulate more metals than other fish parts when exposed to higher concentration because they contain the parts involve in detoxification and other related biochemical reactions.

\[
\begin{array}{cccccc}
0.45 & 0.74 & 0.50 & 0.05 & 0.00 \\
\end{array}
\]

Finally, the presentation of the matrix for the muscle of *H. forskahlii* of membership function (Fig. 6) revealed consistencies in the data trend with earlier results discussed except that Fe has no membership function in the high accumulation category, only Mn has. The aggregate outcome of SFC for the fish’s muscle also belong to the low accumulation region \( k_j = 0.70 \) and the next value is for the no accumulation category \( k_j = 0.55 \).

\[
\begin{array}{cccccc}
0.55 & 0.70 & 0.46 & 0.03 & 0.00 \\
\end{array}
\]

**Conclusion**

The accumulation patterns of ten metals in the different parts of a plant sample, *E. crassipes*, and two fishes’ samples, *Hydrocynus forskahlii* and *Oreochromis mossambicus*, have been investigated and modeled with simple fuzzy classification. The values of the transfer factors of metals in the aquatic biota indicate their capacity to transfer metals from the coastal site into their tissues. However, the classification results showed that there is no metal accumulation in the different parts of the plant from the coast but the fishes are classified into low accumulation category. The internal tissues of the fish species have high metal accumulation than the other parts. Generally, the concentration of Fe and Mn ranked highest in the coastal biota but are micronutrients and are from the natural, geological structure of the area and may not constitute significant risk. Cr has the highest transfer and accumulation from the coastal water into the aquatic lives and may be indicative of risk prone system being a toxic metal. It is therefore concluded that the metal contamination in the coastal zone have not significantly accumulated nor affected the biota. The prevailing biogeochemistry of the coastal must have therefore favored the metals distribution into the sediment phase than the biota making the coastal biota more risk averse.

**References**


