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# Assessment of Public Health Risks of Heavy Metals Pollution in River Sosiani Catchment

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**Abstract** The objective of the study was to assess public health risks of heavy metals pollution in river Sosiani Catchment. This study was a multiple design approach whereby both experimental and socio-economic survey was done to obtain data. The units of analysis used in the socio-economic phase of the study were a random sample size of 402 WRUA members while the scientific phase of the study included two species of fish and water. Water was sampled from eleven sampling locations ($SR_0 - SR_{10}$) and fish from ten sampling points ($SR_1 - SR_{10}$) along river Sosiani. Data for the WRUA members was obtained through weighing and questionnaire analysis. Data for water and fish was obtained using AAS. Data analysis was done using the statistical program for social sciences (SPSS) version 23. The inherent public health risks from heavy metal exposure were determined using THQs for the respective heavy metals and HI which summed up the individual THQs. During the wet season, THQs for water revealed that all sites showed no potential risk for lead, only one site; Naiber exhibited the high risk values for cadmium and three sites, registered very high THQs way beyond the threshold of 1 for chromium. Two sites (Nairobi bridge and Kisumu bridge) had HI values above the limit of 3. During the dry season,both lead and cadmium showed very low THQ values for water, indicating no risk potential. Only chromium had high THQ values in five sites indicating high health risks. The trend was similar for the wet season for HI. An analysis of the risks from fish consumption of Barbus and catfish for both seasons showed that within the entire catchment and based on the received responses, the public health risk from fish consumption is very low with THQs being way below the threshold value of 1 for all the heavy metals (Pb, Cd and Cr). An evaluation of risks as exhibited by manifestation of symptoms within the catchment indicated that most of the inhabitants were symptomatic. Basically, it is concluded that water from river Sosiani had higher THQ and HI values and hence higher risk values than both the fish species. This rendered water from this location unfit for human consumption. The study recommends that urgent measures like pollution control through enforcement of the Kenyan regulations and proper engineering guidance for drainages and wastewater treatment plants will reverse and eventually stop this trend. The communities are also supposed to be sensitised and encouraged not to use river water for domestic use.

***Keywords***: *lead, chromium. Cadmium, heavy metals, river Sosiani*

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## 1. Background

Man's technological activities are varied and are mostly aimed at improving his living conditions. Most of these activities involve exploitation of the world's mineral resources, thus have unearthed, dislodged, and dispersed large quantities and concentrations of heavy metals into the environment [1]. Heavy metals refer to a group of metals and metalloids with specific weight greater than 5 $gcm^{-3}$ [2,3,4] or atomic number greater than 20 [5]. They have become an issue of concern due to their widespread distribution and multiple effects on the ecosystem [6], and the fact that a number of them are toxic or poisonous, thus adversely affect the quality of life [7]. Main sources of heavy metals are; paints and pigments, plastic stabilizers, mining operations, smelting operations, electroplating, reprocessing of cadmium scrap, incineration of plastics, fossil fuel use, fertilizer application, and sewage sludge disposal [8,9]. Heavy metal pollution is of public concern due to the fact that heavy metals are absorbed and accumulate in humans [10], with drastic effects that include undermined intelligence and introduction of debasing behavior [11]. Very little information has been available particularly within developing countries, about the effects of mining contamination on human populations that live beside, and rely on rivers for food and livelihood [12]. The same scenario was also observed by [13], whereby a lacuna was observed when it came to developing consumer patterns for fish. Additionally, it has been observed that public perception of water pollution has not been in line with the scientific realities [14]. A number of studies have been performed to address these deficiencies and include; contextualized risk perception analysis [15], development of integrated mitigation propositions and evaluation of gaps between consumer perception and scientific evidence. Generally, it has been accepted that public awareness of pollution is an important indicator of civilization as it reflects the dynamic of the populace with respect to pollution problems [16]. The awareness of the link between fish consumption and pollution is another aspect that has undergone a number of investigations. In their research, [17] saw that in the Tisza river basin of the Danube river, despite low fish consumption, the average population in the basin was at risk of heavy metal pollution. Conversely, [18] found that in Ghana's coastal areas, a per capita fish consumption of 0.0685kg/day would be of no risk to the human population. In Kenya, [6] conducted a study on the knowledge, attitude and perceptions of health risks from consumption of vegetables from dumpsites along Nairobi River. To date however, no similar study has been conducted on fish consumed from rivers.

Several methods have been proposed for estimation of the potential risks to human health from heavy metals in fish, water and soil. This is due to the fact that human exposure to heavy metals can occur through contact to these agents dermally, through inhalation or ingestion of water and food [19]. Thus, any determination of the risks associated with heavy metal should take into account the causative vector [20]. According to [21] and [22], risk assessment for heavy metals in public health involves field collection and compilation of data, followed by data incorporation into appropriate mathematical models to derive a value for risk. These factors obtained from data and used in these mathematical models include; daily intake value, exposure period, the age, body weight, consumption rate of the people exposed, $R_fD$ and specific bio data from the people exposed (e.g. age, body weight, consumption rate, etc.) [23]. Risk assessment is one of the fastest methods used to evaluate the impact of heavy metal hazards on human health and also determines the level of treatments that can be used to solve prevalent environmental problems. The methods are applicable to water, sediments [24], soil and foods [23]. These methods include Target Hazard Quotients (THQ) [19], Estimated Daily Intake (EDI) [18], Ecological Risk Indices [24], Heavy Metal Pollution Index (HPI) [25]; Nemerrow Pollution Index [26]

**Target Hazard Quotient (THQ)**

The Target Hazard Quotient (THQ) is used for the assessment of health risks through consumption by the local inhabitants and is calculated basing on the equation (1) [27,28]

$$\mathrm{THQ} = \left[ \frac{\mathrm{EF_r} \times \mathrm{ED_{tot}} \times \mathrm{SFI} \times \mathrm{MCS}}{\mathrm{R_f D} \times \mathrm{BW_a} \times \mathrm{AT_n}} \right] \times 10^{-3}. \qquad (1)$$

The method assesses the potential for developing non-carcinogenic effects and is expressed as a ratio of time weighted exposure level and a reference dose or concentration [27]. Despite the fact that THQ-based risk assessment methods do not provide quantitative estimates on the probability of a population experiencing adverse health effects from heavy metal exposure, they provide reliable indications on the risk levels associated with pollutant exposure [29]. After the THQ had been calculated, the hazard quotient for the risk posed by the exposure to two or more pollutants may result in additive and/or interactive effects [27]. Further, [30] suggest that the assessment of the overall potential health risk posed by more than one metal, THQ of every metal is summed up and is known as hazard index (HI) ad shown in equation (2)

$$\mathrm{HI} = \textstyle\sum_{i=1}^{n} \mathrm{THQ_i}. \qquad (2)$$

Despite the extensive use of THQ worldwide in the assessment of health risks associated with pollution [18,31], no study using the index has been documented in Kenya.

## 2. Methods

The study was conducted in Sosiani River catchment which is defined by Longitude 035° 00' 00''E, 035° 35'.00''E and also latitude 00°18'00''N, 00°37' 00''N within the Altitude range of 2,819m above sea level and 1,644m.above sea level. The upper limits of the catchment are in the Keiyo escarpment while the lowest part of the catchment is Turbo forest at the confluence of Sergoit and Sosiani rivers. The middle part of the area is constituted of the Eldoret Municipality. The entire river system is approximately 67 km long and 654 $km^2$basin area. It is one of the major tributaries of the Kipkaren river system. It traverses two counties i.e. Keiyo/Marakwet and Uasin Gishu [32,33]. Upper Sosiani is characterized by the Keiyo escarpment which is part of the Great Rift Valley and Kerio Valley basin. The coordinates of sampling stations in the different zones were recorded using Global Positioning System (GPS).

### 2.1. Research Design

This study was a multiple design approach in which the research.A socio-economic survey to obtain pertinent data (age or respondents, weights of respondents, type of fish eaten and frequency of eating fish) which would be useful in the determination of the risks to the human health involved.

### 2.2. Study Setting

The main land use in the Sosiani basin can be classified into five categories; indigenous and exotic forest; [35], urban and rural settlements, large scale commercial farming [36], subsistence farming [37,38] and isolated cases of quarry mining. Crops mainly cultivated in the catchment through conventional agriculture or irrigation includes maize, beans, passion fruits, vegetables, and potatoes. The catchment also has intensive floriculture, mainly through irrigation in green houses. Livestock rearing is another major land use activity in Sosiani sub catchment and is mainly in the upper and lower sub-catchments. Quarrying is also undertaken in the area at minor scale and it affects the drainage system of the area by acting as pools for stagnant water. The hydrology of the sub catchment is influenced by the topography of the area. The main Sosiani river flows from the Keiyo escarpment at the far South East through Uasin Gishu plateau to Turbo which is in the North west; The main tributaries to Sosiani river are-: Nundoroto, Kipsenende, Ellegirine and Lemook(Chepkorio). The groundwater flow direction is influenced by the topographical expression which is equally defined by the direction of the surface water flow. Monitoring of river flows are carried out at three regular gauging stations namely: - 1CB05 Sosiani, 1CB08 Nundoroto and 1CB09 Ellegirine rivers [39].

## 2.3. Unit of Analysis

Stratified random sampling method was used to obtain data from community members in the catchment, in the socioeconomic phase of the study; a random sample size of 402 WRUA members was selected. Two species of fish, catfish (*Clariusgariupinus*) and barbus (*Barbusbarbus*) and water were scientifically sampled.

## 2.4. Data Collection

The data obtained from the WRUA members, water and the two species of fish (Table 1) was used in the computation of THQ using equation (3).

$$THQ = \left[\frac{EF_r \times ED_{tot} \times SFI \times MCS}{R_f D \times BW_a \times AT_n}\right] \times 10^{-3} \quad (3)$$

Where Table 1 shows the criteria used for determination of the variable used in the computation of THQ; the computed Pb, Cd and Cr THQ values were then used in the computation of HI using equation (4).

$$HI = THQ_{Pb} + THQ_{Cr} + THQ_{Cd} \quad (4)$$

THQ and HI values were determined for both species of fish (Barbus and catfish) and water for each of the 10 sampling stations within the WRUAs. These indices were then used as a measure of the public health risks associated with metal pollution in the Sosiani catchment.

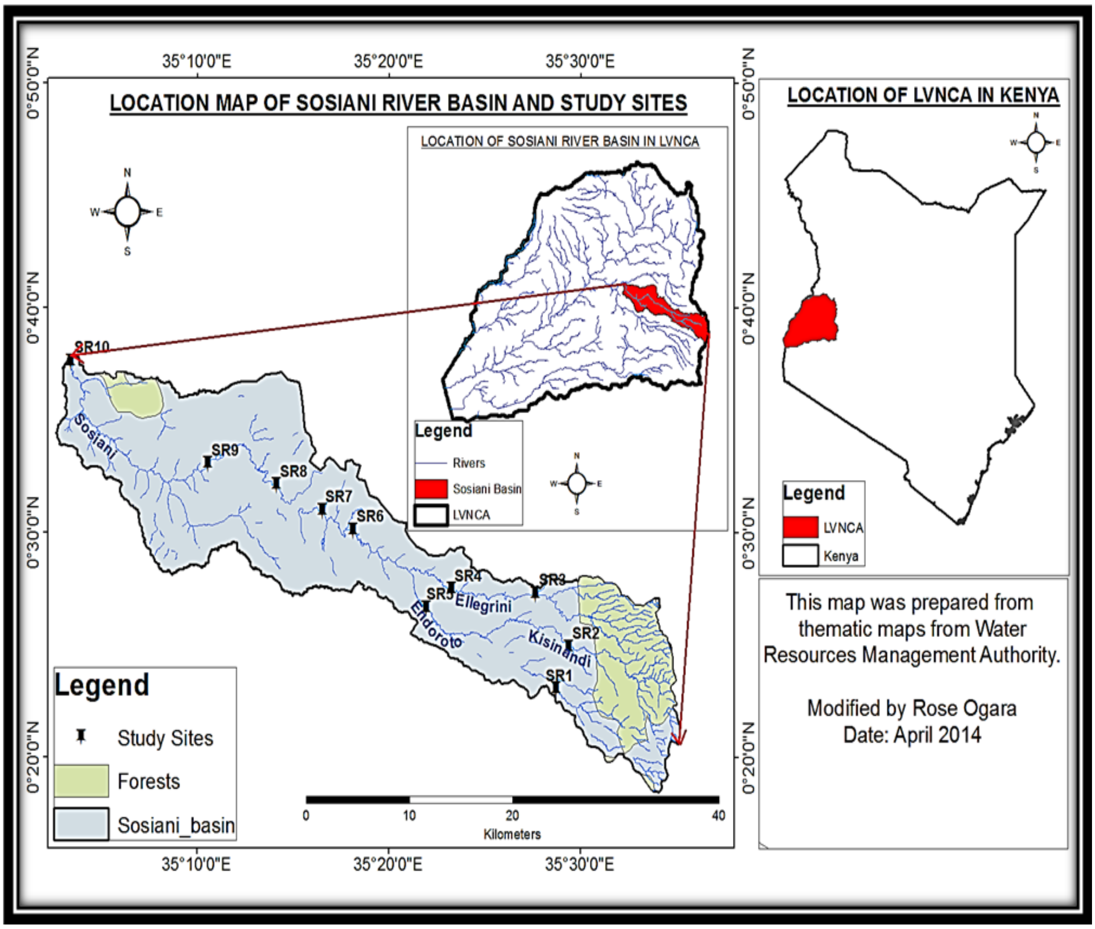


**Figure 1.** Map of River Sosiani showing the sampling sites (Source: [34])

**Table 1. Criteria for determination of variables used in the computation of THQ**

| Variable | Criteria for determination |
|---|---|
| $EF_r$ | Number of days a person in the catchment is exposed to the heavy metal agent. This was based on data from interviews, i.e. the number of days the respondent has lived in the catchment |
| $ED_{tot}$ | Total exposure duration: This was based on the mean life expectancy of the people in the vicinity of the polluted sampling site |
| SFI | Mass of dietary water or fish ingested by the respondents. This was based on the average consumption of the respondents in the vicinity of |
| MCs | the sampling site Heavy metal concentration in the ingested dietary material (mg $g^{-1}$); |
| $R_fD$ | Oral reference dose for the respective heavy metal. |
| $BW_a$ | Average body weight of the respondents in the vicinity of the sampling site |
| $AT_n$ | Average exposure time for non-carcinogenic agents |

## 2.5. Questionnaires

The content validity of the questionnaires was examined through discussions and consultations with experienced colleagues in the faculty to assess the relevance of research tools against the objectives of the study. This was to ensure that the questionnaires adhered to validity as elucidated by [40]. Reliability is an indication of the stability and consistency with which the instrument measures the concept and helps to assess the goodness of a measure [41] and it indicates the extent to which it is without bias (error free) and hence ensures consistent measurement across time and across the various items. For questionnaires, the study used an inter-item consistency reliability which is a test of the consistency of respondents' answers to all the items in a measure. The most popular test of inter-item consistency reliability is Cronbach's coefficient alpha (Cronbach's alpha).

The test retest technique of evaluating reliability of the questionnaire was employed. The instrument was administered to 8 sampled members twice in average of one month to test whether similar responses would be realised. The Cronbach's coefficient alpha was employed to compute the reliability coefficient of the two sets of data. The higher the coefficients, the better the measuring instrument. Cronbach's alpha is commonly used to establish internal consistency construct validity, with 0.60 considered acceptable for explanatory purposes while 0.70 considered adequate for confirmatory purposes and 0.80 considered good for confirmatory purposes [41]. Zone one was taken to be the control area where there are no sources of point pollution of heavy metals.

## 2.6. Data Analysis

Data analysis was done using the statistical program for social sciences (SPSS) version 23. Inferential and descriptive statistics were used to analyze data. Descriptive analysis of data was done using the mean, frequencies and percentages. In this study association between the study variables was assessed by a two-tailed probability value of $p<0.05$ for significance. The researcher conducted analyses of normality, for the outcome variable, prior to hypothesis testing by examining kurtosis and skewness of the data. In order to test and identify possible outliers in the data, graphical assessment visuals, including scatter and box plots were used. Elimination of observed outliers was based on a case by case basis, dependent on standard deviations, and on normality and homogeneity of variance assessments. Normality was assessed using examination of the histograms by seeing how they related or deviate against a normal bell curve distribution and observing the levels of kurtosis and skewness present. Univariate analysis was used to describe the distribution of each of the variables in the study objective. One-way analysis of variance (ANOVA) at 0.05 level of significance was used in the analysis.

# 3. Results & Discussion

## 3.1. Variables Used in Risk Evaluation Indices

Table 2, reveals the constants used in the computation of THQ using equation 3.2: it indicates an $EF_r$ of 365 days for water consumption, a choice based on the reality that dwellers in the river's vicinity suffer water exposure for a whole year (365 days). Conversely, the $EF_r$ for fish is 104 days, based on the respondents' twice per week fish consumption frequency. Additionally, $ED_{tot}$is 30 years (the average number of years respondents had lived within the catchment), while $BW_a$ and $AT_n$ are 70kg.

The $R_fD$ for lead, Cadmium and Chromium were 0.004, 0.001 and 0.003mgkg$^{-1}$ respectively, while the SFI was 1.2 and 0.077 for water and Fish respectively. The computed Pb, Cd and Cr THQ values were then used in the computation of HI using equation (3.3). THQ and HI values were determined for both species of fish (*Barbus barbus* and catfish) and water for each of the 10 sampling stations within the WRUAs. These indices were then used as a measure of the public health risks associated with metal pollution in the Sosiani catchment.

**Table 2. Constants used in the computation of THQ**

| Metal | $EF_r$(days) | | $ED_{tot}$(years) | SFI (kg) | | $R_fD$ (mgkg$^{-1}$) | $BW_a$(kg) | $AT_n$(years) |
|---|---|---|---|---|---|---|---|---|
| | **Water** | **Fish** | | **Water** | **Fish** | | | |
| Lead | 365 | 104 | 30 | 1.2 | 0.077 | 0.004 | 70 | 70 |
| Chromium | 365 | 104 | 30 | 1.2 | 0.077 | 0.003 | 70 | 70 |
| Cadmium | 365 | 104 | 30 | 1.2 | 0.077 | 0.001 | 70 | 70 |

**Table 3. Wet season Target Hazard Quotients (THQ) and Hazard Index (HI) associated with water consumption within the Sosiani catchment**

| **Sampling site location and name** | **THQ* and HI** | | | |
|---|---|---|---|---|
| | **$THQ_{Pb}$** | **$THQ_{Cd}$** | **$THQ_{Cr}$** | **HI** |
| $SR_1$: Kipsenende | 0.100 (0.001) $^{de}$ | 0.103(0.002) $^{de}$ | 0.286(0.000) $^{f}$ | 0.489 |
| $SR_2$: Ellegerine | 0.067 (0.005) $^{h}$ | 0.103(0.000) $^{cd}$ | 0.516(0.001) $^{de}$ | 0.686 |
| $SR_3$: Chepkorio | 0.072 (0.010) $^{g}$ | 0.034(0.000) $^{e}$ | 0.229(0.002) $^{g}$ | 0.335 |
| $SR_4$: Naiber | 0.077 (0.002) $^{g}$ | 1.714(0.002) $^{a}$ | 0.680(0.002) $^{c}$ | 2.471 |
| $SR_5$: Nundoroto | 0.069 (0.003)$^{gh}$ | 0.137(0.002) $^{cd}$ | 0.457(0.002) $^{e}$ | 0.663 |
| $SR_6$: Nairobi bridge | 0.109 (0.002) $^{d}$ | 0.069(0.000) $^{de}$ | 5.200(0.017) $^{a}$ | 5.377 |
| $SR_7$: Kisumu bridge | 0.124 (0.002) $^{c}$ | 0.171(0.002)$^{bc}$ | 5.162(0.026) $^{a}$ | 5.457 |
| $SR_8$: Eldowas WW | 0.143 (0.001) $^{b}$ | 0.206(0.000)$^{bc}$ | 1.752(0.020) $^{b}$ | 2.102 |
| $SR_9$: Kengen power | 0.087 (0.003) $^{f}$ | 0.103(0.000) $^{cd}$ | 0.648(0.020) $^{c}$ | 0.837 |
| $SR_{10}$: Sosianisergoit | 0.098 (0.002) $^{e}$ | 0.069(0.000) $^{de}$ | 0.571(0.000) $^{cd}$ | 0.738 |
| Threshold values† | 1.000 | 1.000 | 1.000 | 3.000 |

†Threshold values of THQ and HI for Pb, Cd and Cr [28]
* Numbers in parentheses indicate Standard deviations (N=3).

**Table 4. Dry season Target Hazard Quotients (THQ) and Hazard Index (HI) associated with water consumption within the Sosiani catchment**

| Sampling site location and name | THQ* and HI | | | |
|---|---|---|---|---|
| | $THQ_{Pb}$ | $THQ_{Cd}$ | $THQ_{Cr}$ | HI |
| $SR_1$: Kipsenende | $THQ_{Pb}$ | $THQ_{Cd}$ | $THQ_{Cr}$ | HI |
| $SR_2$: Ellegerine | $0.058(0.002)^{ef}$ | $0.034(0.000)^{c}$ | $0.895(0.010)^{f}$ | 0.987 |
| $SR_3$: Chepkorio | $0.039(0.002)^{h}$ | $0.011(0.001)^{de}$ | $0.571(0.000)^{de}$ | 0.622 |
| $SR_4$: Naiber | $0.079(0.002)^{c}$ | $0.000(0.000)^{e}$ | $2.343(0.017)^{g}$ | 2.422 |
| $SR_5$: Nundoroto | $0.050(0.006)^{g}$ | $0.034(0.000)^{c}$ | $1.257(0.034)^{c}$ | 1.341 |
| $SR_6$: Nairobi bridge | $0.066(0.003)^{d}$ | $0.000(0.000)^{de}$ | $0.667(0.026)^{e}$ | 0.732 |
| $SR_7$: Kisumu bridge | $0.062(0.003)^{de}$ | $0.000(0.000)^{de}$ | $7.943(0.017)^{a}$ | 8.005 |
| $SR_8$: Eldowas WW | $0.088(0.004)^{b}$ | $0.069(0.000)^{a}$ | $5.200(0.017)^{a}$ | 5.357 |
| $SR_9$: Kengen power | $0.053(0.002)^{fg}$ | $0.034(0.000)^{c}$ | $1.790(0.020)^{b}$ | 1.878 |
| $SR_{10}$: Sosianisergoit | $0.039(0.002)^{h}$ | $0.069(0.000)^{a}$ | $0.057(0.000)^{c}$ | 0.165 |
| Critical values$^{\dagger}$ | $0.106(0.003)^{a}$ | $0.034(0.000)^{bc}$ | $1.714(0.000)^{cd}$ | 1.854 |

$^{\dagger}$ Threshold values of THQ and HI for Pb, Cd and Cr [28]

* Numbers in parentheses indicate Standard deviations (N=3).

## 3.2. Public Health Risks Associated with Water Consumption within River Sosiani

Table 3 and Table 4 show the Target Hazard Quotient (THQ) and the Hazard Index (HI) associated with water consumption within the Sosiani catchment during the wet and dry seasons, respectively. THQ is an estimation of human health risk level (non-carcinogenic) which is caused by pollutant exposure. These indices are indicative of the risks associated with heavy metals within the catchment. The data indicates that the site downstream of Eldowas wastewater treatment plant ($SR_8$) had the highest $THQ_{Pb}$ at 0.143 (Table 3) implying that inhabitants of this location are at the highest risk from lead pollution.

It was followed by Kisumu bridge ($SR_7$) with 0.124 and Nairobi bridge ($SR_6$) with 0.109, whereby $SR_8$ and $SR_7$ were significantly higher ($F (9, 20) = 157.20$, $p = 0.00$) at $p< 0.05$ compared to $SR_6$ . All these locations are found within the mid catchment of the Sosiani river, which suggests a high risk of lead pollution. A curious figure of 0.100 was noted at Kaptagat forest ($SR_1$) denoting that despite the location of this site in the upper catchment, the lead pollution risks are high, warranting investigation. All other sampling sites ($SR_2$, $SR_3$, $SR_3$, $SR_4$, $SR_5$, $SR_9$ and $SR_{10}$) registered $THQ_{Pb}$ ranging from 0.067 to 0.098, with $SR_8$ and $SR_7$ being significantly higher at $p < 0.05$ compared to $SR_6$ ($F (9, 20) = 157.20$, $p = 0.00$), which in turn was higher than $SR_1$ and $SR_{10}$, and the remaining sites of $SR_2$, $SR_3$, $SR_4$ and $SR_5$ being in the same statistical range.

Similar observations are made for $THQ_{Pb}$ during the dry season with Kisumu bridge ($SR_7$) and Nairobi bridge ($SR_6$) registering comparatively lower $THQ_{Pb}$ values of 0.088 and 0.062 (Table 4) where $SR_7$ was significantly higher at $p < 0.05$ ($F (9, 20) = 409.76$, $p = 0.00$) than $SR_6$. The Sosiani Sergoit site ($SR_{10}$) however, had the highest $THQ_{Pb}$ within the basin in the dry season at 0.106, a value higher than that for the same location during the wet season, which means that the site is located within a heavily pollutant lead facility. A similar result is observed for Chepkorio ($SR_3$) with 0.079, while all remaining sampling locations had lower $THQ_{Pb}$ comparatively in the dry season compared to the wet season.

In respect to $THQ_{Cd}$, Naiber ($SR_4$) had a wet season $THQ_{Cd}$ of 1.714, way above all the recommended cadmium $THQ_{Cd}$ levels (Table 3). It implies that the high cadmium concentration within the water at Naiber and coupled with other demographic data, causes a high cadmium risk. The other sites had significantly lower THQs at $p <0.05$($F (9, 20) = 64.37$, $p = 0.00$), for instance Eldowas ($SR_8$) had 0.206 while all the other sites e.g. Nundoroto had $THQ_{Cd}$ below 0.137. In the dry season, a number of sites ($SR_5$, $SR_6$ and $SR_3$) reported no risk from cadmium contamination ($THQ_{Cd} = 0.000$). However, the other sites had indications of risks from $THQ_{Cd}$ with $SR_2$ having a THQ of 0.011, while $SR_1$, $SR_4$, $SR_8$ and $SR_7$ had $THQ_{Cd}$ of 0.034, 0.034, 0.034 and 0.069, respectively, with $SR_7$ being significantly higher at $p <0.05$ ($F (9, 20) = 51.67$, $p = 0.00$) compared to the other sites.The risks from pollution due to chromium as reported in Table 3 showed Nairobi bridge ($SR_6$) and Kisumu bridge ($SR_7$) having, $THQ_{Cr}$ of 5.200 and 5.162, respectively, during the wet season, which at $p < 0.05$ were significantly higher ($F (9, 20) = 5845.11$, $p = 0.00$) compared to the other sites.

This underscores the pollution risk from these sites, which are found in the mid Sosiani catchment. These were followed by Eldowas WW ($SR_8$) with 1.752, further emphasizing the Cr pollution risk within the urban areas of Eldoret during the wet season. The lower catchment had Kengen Power ($SR_9$) and Sosiani Sergoit junction ($SR_{10}$) with $THQ_{Cr}$ of 0.648 and 0.571, respectively, adducing a lower Cr pollution risk compared to the mid catchment. All the sites within the upper catchment i.e. $SR_1$, $SR_2$, $SR_3$, $SR_4$ and $SR_5$had $THQ_{Cr}$ of 0.286, 0.516, 0.229, 0.680 and 0.457, showing that Naiber ($SR_4$) and Kaptagat forest ($SR_2$) had higher risks from Cr pollution compared to the other sites.

The dry season saw the highest THQs registered in the catchment. For instance at $SR_6$ and $SR_7THQ_{Cr}$ of 7.943 and 5.200 were observed. These are THQ well beyond the critical levels of 1.00, emphasizing the severe health risks from Cr pollution at these sampling locations. These two locations had at $p < 0.05$ significantly different ($F (9, 20) = 5064.43$, $p = 0.00$) $THQ_{Cr}$ compared to the other sampling locations, since SR3, SR4 and SR10 had $THQ_{Cr}$ of 2.343. 1.257 and 1.714, respectively. These results indicate that all these five sampling locations are at risks beyond the threshold $THQ_{Cr}$, denoting severe risks. Conversely, the remainder sites have comparatively no potential risk.

An analysis of the Hazard Index (HI) from pollution due to heavy metals within the Sosiani catchment from water consumption shows that during the wet season, Kisumu bridge ($SR_7$), Nairobi bridge ($SR_6$) and Eldowas ($SR_8$) had in descending order, the highest risks from heavy metals; Kisumu bridge ($SR_7$) had HI of 5.457, Nairobi bridge ($SR_6$) 5.377 while Eldowas WW ($SR_8$) had 2.102. It stresses the fact that with regard to river water consumption, and especially during the wet season, the mid catchment dwellers are at a higher risk of heavy metal contamination. A similar deduction can be made within the upper catchment, for instance at Naiberi ($SR_4$) the HI was 2.471. However, within the same catchment, sampling locations $SR_1$, $SR_2$, $SR_3$ and $SR_5$ had comparatively lower HI values of 0.489, 0.686, 0.335 and 0.663, respectively, indicating lower heavy metal risk. The lower catchment sites of Kengen power ($SR_9$) and Sosiani Sergoit ($SR_{10}$) reported HI of 0.837 and 0.738, respectively inferring a similar heavy metal risks as those in the upper catchment. During the dry season, Nairobi bridge ($SR_6$) had the highest HI at 8.005, which was followed by Kisumu bridge ($SR_7$) with 5.357, it implies that despite the seasons, these two sites had high risks from heavy metal Cr and are higher compared to the other $SR_8$ (HI = 1.878) within the same catchment. In the upper catchment, a deviation is observed with Chepkorio ($SR_3$) having the highest HI (2.422) and Naiber ($SR_4$) having 1.341, while the other three sites have comparatively lower values ($SR_1$ = 0.987; $SR_2$ = 0.622 and $SR_5$ = 0.732). The lower catchment had the Sosiani Sergoit site ($SR_{10}$) reporting HI of 1.854 which was above the $SR_9$ value of 0.165.

## 3.3. Public Health Risks Associated with Consumption of *Barbus barbus* Fish from River Sosiani

The Table 5 and Table 6 show the THQ and HI associated with consumption of *Barbusbarbus* fish within the Sosiani catchment during the wet and dry seasons, parameters indicative of health risks from heavy metals within the catchment. The data obtained shows that during the wet season, fish obtained from Kengen power ($SR_9$) had the highest $THQ_{Pb}$ at 0.096 (5), which was at $p < 0.05$ significantly higher ($F$ (9, 20) = 40.42, $p = 0.00$) compared to 0.081 at Sosiani Sergoit ($SR_{10}$), within the same catchment. The data from $SR_{10}$ is in the same range as $THQ_{Pb}$ figures from stations within the mid catchment i.e. $SR_7$ (Kisumu bridge) and $SR_8$(Eldowas WW), of 0.081 and 0.080, respectively, indicative of high risks from lead pollution from *Barbusbarbus* fish, regardless of the sub catchment. However, this is contradicted by Nairobi bridge ($SR_6$) with $THQ_{Pb}$ of 0.017, warranting closer inspection. In the upper catchment, Chepkorio ($SR_3$), Nundoroto ($SR_5$) and Naiber ($SR_4$) had in descending order $THQ_{Pb}$ of 0.077, 0.065 and 0.064 suggesting a comparatively lower Pb risk in the upper catchment as opposed to the mid-catchment. This fact is further confirmed $SR_1$ and $SR_2$ with $THQ_{Pb}$ of 0.005 and 0.021, respectively. During the wet season, comparatively lower $THQ_{Pb}$ were observed in the lower catchment with $SR_9$ and $SR_{10}$ having $THQ_{Pb}$ of 0.024 and 0.048, showing that the Pb risk is lower in these sub-catchments during the dry season as opposed to the wet season. A similar trend is observed in the mid catchment with $SR_6$, $SR_7$ and $SR_8$ having $THQ_{Pb}$ of 0.010, 0.022 and 0.004, respectively, drawing similar deductions for the mid zone as that for the lower zone. In the upper Sosiani however, an outlying $THQ_{Pb}$ of 0.039 was observed at Ellegerin ($SR_2$) which was at $p < 0.05$ significantly higher ($F$ (9, 20) = 9.32, $p = 0.00$) than all the other sampling locations within the upper zone ($THQ_{Pb}SR_1$ = 0.001; $THQ_{Pb}$ $SR_3$ = 0.008; $THQ_{Pb}$ $SR_4$ = 0.011 and $THQ_{Pb}SR_5$ = 0.007). This means that there is a point source of pollution at $SR_2$ which warrants further investigation as the risk from Pb pollution here could arise.

In respect to risks from pollution due to Cd, the wet season had the lower zone having high $THQ_{Cd}$ values of 0.284 and 0.226, at $SR_9$ and $SR_{10}$ respectively. It implies that this region is the accumulation zone of Cd pollution, and thus *Barbusbarbus* fish consume a lot of material containing Cd. This inference is further reinforced by observations at $SR_7$ and $SR_8$ within the mid zone with $THQ_{Cd}$ of 0.227 and 0.224, respectively. The $SR_7$ and $SR_8$ Cd risk figures are significantly different ($F$ (9, 20) = 4292.21, $p = 0.00$) from those at $SR_5$ (0.099) and $SR_6$ (0.000), a phenomenon that is attributable to the riverine morphology within this zone, hence there is higher transfer of Cd from the water into *Barbusbarbus* fish, hence potential risk. In the upper catchment, Chepkorio ($SR_3$) had the highest $THQ_{Cd}$ at 0.283, comparatively higher compared to $SR_1$, $SR_2$, $SR_4$ and $SR_5$ (0.000, 0.026, 0.097 and 0.099, respectively) values within the same zone. The THQs a bove 0.2 pose a potential risk. In the dry season, a totally different trend is observed for risks from Cd; It is only the fish from $SR_1$ (Kipsenende) that had at $p < 0.05$ a sgnificantly higher ($F$ (9, 20) = 1006.79, $p = 0.00$) figure of 0.018.All fish from the other sampling locations had $THQ_{Cd}$ values lower than 0.005, showing that there is no potential risk in eating the fish in the upper zone which was registered at $SR_9$. The trend could imply that during the dry season there is less river matter containing cadmium, thus the cadmium levels in fish are comparatively lower.

**Table 5. Wet season Target Hazard Quotients (THQ) and Hazard Index (HI) for *Barbusbarbus* fish consumption within the Sosiani catchment**

| Sampling site location and name | THQ* and HI | | | |
|---|---|---|---|---|
| | $THQ_{Pb}$ | $THQ_{Cd}$ | $THQ_{Cr}$ | HI |
| $SR_1$: Kipsenende | 0.005(0.000)$^e$ | 0.000(0.000)$^f$ | 0.035(0.000)$^a$ | 0.040 |
| $SR_2$: Ellegerine | 0.021(0.003)$^d$ | 0.026(0.000)$^e$ | 0.033(0.001)$^a$ | 0.080 |
| $SR_3$: Chepkorio | 0.077(0.000)$^b$ | 0.283(0.000)$^a$ | 0.035(0.001)$^a$ | 0.394 |
| $SR_4$: Naiber | 0.064(0.001)$^c$ | 0.097(0.001)$^d$ | 0.035(0.000)$^a$ | 0.196 |
| $SR_5$: Nundoroto | 0.065(0.002)$^c$ | 0.099(0.001)$^d$ | 0.034(0.001)$^a$ | 0.199 |
| $SR_6$: Nairobi bridge | 0.017(0.002)$^d$ | 0.000(0.000)$^f$ | 0.031(0.000)$^b$ | 0.048 |
| $SR_7$: Kisumu bridge | 0.081(0.001)$^b$ | 0.227(0.000)$^b$ | 0.026(0.001)$^c$ | 0.334 |
| $SR_8$: Eldowas WW | 0.080(0.002)$^b$ | 0.224(0.001)$^c$ | 0.024(0.000)$^c$ | 0.328 |
| $SR_9$: Kengen power | 0.096(0.001)$^a$ | 0.284(0.000)$^a$ | 0.022(0.001)$^c$ | 0.403 |
| $SR_{10}$: Sosiani sergoit | 0.079(0.002)$^b$ | 0.226(0.002)$^{bc}$ | 0.031(0.001)$^b$ | 0.336 |
| Critical values$^†$ | 1.000 | 1.000 | 1.000 | 3.000 |

† Threshold values of THQ and HI for Pb, Cd and Cr [29]
* Numbers in parentheses indicate Standard deviations (N=3).

**Table 6. Dry season Target Hazard Quotients (THQ) and Hazard Index (HI) for *Barbusbarbus* fish consumption within the Sosiani catchment**

| Sampling site location and name | THQ* | | | |
|---|---|---|---|---|
| | $THQ_{Pb}$ | $THQ_{Cd}$ | $THQ_{Cr}$ | HI |
| $SR_1$: Kipsenende | 0.001(0.000) $^{g}$ | 0.018(0.000) $^{c}$ | 0.023(0.000) $^{c}$ | 0.041 |
| $SR_2$: Ellegerine | 0.039(0.000) $^{b}$ | 0.000(0.000) $^{e}$ | 0.035(0.000) $^{b}$ | 0.074 |
| $SR_3$: Chepkorio | 0.008(0.000) $^{e}$ | 0.001(0.000) $^{d}$ | 0.055(0.000) $^{a}$ | 0.064 |
| $SR_4$: Naiber | 0.011(0.000) $^{d}$ | 0.004(0.000) $^{b}$ | 0.000(0.000) $^{g}$ | 0.015 |
| $SR_5$: Nundoroto | 0.007(0.000) $^{e}$ | 0.000(0.000) $^{e}$ | 0.010(0.000) $^{e}$ | 0.017 |
| $SR_6$: Nairobi bridge | 0.010(0.000) $^{d}$ | 0.004(0.000) $^{b}$ | 0.009(0.000) $^{e}$ | 0.023 |
| $SR_7$: Kisumu bridge | 0.022(0.008) $^{cd}$ | 0.004(0.000) $^{b}$ | 0.015(0.000) $^{d}$ | 0.040 |
| $SR_8$: Eldowas WW | 0.004(0.000) $^{f}$ | 0.005(0.000) $^{a}$ | 0.007(0.000) $^{f}$ | 0.016 |
| $SR_9$: Kengen power | 0.024(0.000) $^{c}$ | 0.001(0.000) $^{d}$ | 0.013(0.000) $^{d}$ | 0.038 |
| $SR_{10}$: Sosianisergoit | 0.048(0.001) $^{a}$ | 0.003(0.001) $^{b}$ | 0.009(0.000) $^{e}$ | 0.060 |
| Critical values† | 1.000 | 1.000 | 1.000 | 3.000 |

† Threshold values of THQ and HI for Pb, Cd and Cr [29]

* Numbers in parentheses indicate Standard deviations (N=3).

The data for health risks associated with pollution from Cr within the Sosiani basin (Table 6) indicates a mixed trend in $THQ_{Cr}$ in the zones within the Sosiani catchment, for instance in the upper catchment $SR_1$, $SR_3$ and $SR_5$ registered $THQ_{Cr}$ of 0.035 which were marginally higher compared to $SR_2$ and $SR_5$ at 0.033 and 0.034, respectively but posing no potential risk. The lower zone had slightly lower $THQ_{Cr}$values compared to the upper zone with the mid zone having $SR_6$, $SR_7$ and $SR_8$ with $THQ_{Cr}$ of 0.031, 0.026 and 0.024, respectively. Similarly, the lower zone had $THQ_{Cr}$ of 0.022 and 0.031 for $SR_9$ and $SR_{10}$, respectively. This mixed trend implies an almost constant variation in the level of risk associated with Cr pollution within the Sosiani catchment during the wet season, despite the THQs showing significant differences ($F (9, 20) = 74.72$, $p = 0.00$) at $p < 0.05$. The dry season however had a different trend; for instance in the upper zone, there was no risk whatsoever associated with Cr pollution at $SR_4$ (Naiber) since the $THQ_{Cr}$ was 0.000; additionally the Cr risk at $SR_5$ (Nundoroto) was marginally higher at $THQ_{Cr}$ of 0.010. However, the risks associated with Cr at $SR_1$, $SR_2$ and $SR_3$ were at p< 0.05 significantly different ($F (9, 20) = 74.72$, $p = 0.00$), having 0.023, 0.035 and 0.055, respectively but of no potential risk. This trend terminated at $SR_6$ (Nairobi bridge) where the $THQ_{Cr}$ was 0.009, since all the sampling locations downstream registered a mixed trend with $SR_7$, $SR_8$ $SR_9$ and $SR_{10}$ having $THQ_{Cr}$ of 0.015, 0.007, 0.013 and 0.009, respectively. The observations indicate that regardless of the season a mixed trend in Cr accumulation downstream the Sosiani River is observed; consequently a mixed trend in Cr risk is observable.

HI data for *Barbusbarbus* fish consumption from the sampling locations indicated generally lower values in the dry season, as opposed to the wet season. This observation is true for all sampling stations except $SR_1$ ($HI_{wet} = 0.040$; $HI_{dry} = 0.041$). As indicated earlier, beyond this station ($SR_2$ to $SR_{10}$) there is a reversal in the relationship between $HI_{wet}$ and $HI_{dry}$ and also an increase in the difference between the HI values. For instance, at $SR_2$ the difference between $HI_{wet}$ and $HI_{dry}$ is 0.006 while at $SR_{10}$ the difference is 0.276. It means that the overall risk from heavy metals associated with *Barbusbarbus* fish consumption was much higher during the wet season compared to the dry season. Additionally, $SR_{10}$ had the highest HI during the wet season at 0.403, followed by $SR_3$ (0.394) and $SR_8$ (0.334) making these locations the most risky with respect to heavy metal pollution. It is worth noting that these locations are found in each of the three catchments within the Sosiani basin, underscoring the fact that regardless of the level of urbanisation, the inherent risk from heavy metals is high. However, the high figure at $SR_{10}$ is a pointer to this area being an accumulation zone for heavy metals within fish species, especially during the wet season. This could be attributed to the presence of a reservoir (Kengen power), the garages in Turbo town, the bridge and the old water supply piping. It is worth noting that in the dry season, a departure from the phenomenon observed in the wet season is seen with the upper zonehaving higher values of HI compared to the lower catchment.

## 3.4. Public Health Risks Associated with Consumption of Catfish (*Clariusgariepinus*) from River Sosiani

Table 7 and Table 8 present the THQ and HI values associated with heavy metals from consuming catfish within the river Sosiani catchment during the wet and dry seasons, respectively. From the data it is observable that during the wet season, the Sosiani Sergoit junction ($SR_{10}$) sampling site within the lower catchment of the Sosiani basin had the highest $THQ_{Pb}$ (0.025), which was at $p < 0.05$ significantly higher ($F (9, 20) = 77.93$, $p = 0.00$) compared to all the other sampling sites within the basin, with the closest $THQ_{Pb}$ associated with catfish consumption observed at Nundoroto ($SR_5$) at 0.007. It implies that the material consumed by fish within this zone of the catchment has high lead concentration, making it a lead accumulation zone. All other sampling sites ($SR_1$, $SR_2$, $SR_3$, $SR_4$, $SR_6$, $SR_7$, $SR_8$ and $SR_9$) registered $THQ_{Pb}$ below 0.005. During the dry season, all sites except $SR_6$ (Nairobi bridge) had lower $THQ_{Pb}$ compared to the wet season, with the $THQ_{Pb}$ figure ranging from 0.003 at Chepkorio ($SR_3$) to 0.005 at $SR_5$, $SR_6$ and $SR_{10}$,whose values at $p < 0.05$ showed no significant difference ($F (9, 20) = 1.33$, $p = 0.285$) from the other $THQ_{Pb}$. Such low figures indicate a lower risk from lead pollution due to catfish consumption. This phenomenon is attributable to changes in feeding patterns within the populace, especially during the dry season.

The results for Cd pollution risks due to catfish consumption (Table 7) indicate that during the wet season, Kaptagat forest ($SR_1$) had the highest $THQ_{Cd}$ at 0.019. This figure is lower than the recommended THQ of 1.000 indicative of a minimal risk from Cd pollution at this location, though at $p < 0.05$, it is significantly higher (F (9,

20) = 842.16, p = 0.00) compared to other sampling locations. These other sampling locations within the catchment had $THQ_{Cd}$ below 0.006, for instance a value observed at Eldowas WW was 0.007 and Nairobi Bridge was 0.006. It implies that apart from $SR_1$, $SR_4$ and $SR_8$, all catfish from sampling locations within Sosiani catchment have low Cd health risk. The dry season exhibits a different result since $SR_7$ and $SR_1$ display high $THQ_{Cd}$ figures (0.019 and 0.018, respectively), followed by $SR_6$ (Nairobi bridge) at 0.010. These values are below the recommended THQ thresholds of 1.000 [28] indicative of a low Cd risk from catfish consumption during the dry season, but are at $p < 0.05$ significantly higher ($F$ (9, 20) = 1261.31, p = 0.00) compared to other sampling sites. The fact that these other sampling sites i.e. $SR_2$, $SR_3$, $SR_4$, $SR_5$, $SR_8$, $SR_9$ and $SR_{10}$ had $THQ_{Cd}$ below 0.004 shows that consumption of catfish from these locations has an even lower risk, comparatively from Cd pollution. The low THQs could be attributed to the fact that most people in the urban area reported low fish consumption frequency, fish being a non-predominant source of protein within the catchment.

The results for health risks associated with Cr due to catfish consumption (Table 8) show that in the wet season, $SR_8$ and $SR_9$ had $THQ_{Cr}$ of 0.106 and 0.107, respectively, indicative of high Cr concentrations within catfish at these locations though these figures are just as those for Pb and Cd below the recommended threshold of 1.000 [28], though at $p < 0.05$ being significantly different ($F$ (9, 20) = 1707.29, p = 0.00) from $THQ_{Cr}$ at other sites. These were closely followed by $SR_6$ and $SR_{10}$, having 0.096 and 0.088, respectively, indicative of comparatively lower Cr poisoning risk from catfish consumption. The remaining locations ($SR_1$, $SR_2$, $SR_3$, $SR_5$, $SR_6$and $SR_7$) had $THQ_{Cr}$ lower than 0.064. It should however be noted that $SR_7$ (Kisumu bridge) had a very low $THQ_{Cr}$ of 0.005, implying that there was no risk from catfish at this location. The most likely reason for this could be that people seldom eat fish from this location. A similar trend is observed in the dry season since $SR_5$, $SR_8$, $SR_6$ and $SR_{10}$ had in ascending order $THQ_{Cr}$ of 0.085, 0.104. 0.117 and 0.145, respectively, with $SR_{10}$ being at $p < 0.05$ significantly higher ($F$ (9, 20) = 30.03, p = 0.00) than $SR_5$, $SR_8$, and $SR_6$. This shows that comparative to the other sampling locations ($SR_1$, $SR_2$, $SR_3$, $SR_4$, $SR_7$ and $SR_9$), catfish obtained from these sites had high Cr content. Nevertheless, the $THQ_{Cr}$ indicate mild risk low Cr poisoning since they are below 1.000. A glance at the HI figures during the wet season (Table 8) indicates that the catfish consumption within the lower and mid catchments had comparatively higher overall risks from heavy metal pollution to those in the upper catchment. For instance, $SR_9$ and $SR_{10}$ in the lower catchment had HI of 0.115, while $SR_6$ and $SR_8$ had 0.106 and 0.117, respectively which were higher than HI in the upper catchment (0.076, 0.057, 0.037, 0.034, 0.071 and 0.012 for $SR_1$, $SR_2$, $SR_3$, $SR_4$, $SR_5$and $SR_7$, respectively). This trend shows that during the wet season, the health risk of Cr poisoning from catfish consumption increases downstream.

A similar trend is observed during the dry season since $SR_6$, $SR_8$ and $SR_{10}$ have HI of 0.132, 0.112 and 0.152, respectively, which are higher than figures observed at $SR_1$, $SR_2$, $SR_3$, $SR_4$ and $SR_5$. Generally, there were no potential risks from cat fish. This could be due to age of the fish that is the cat fish that had the same weight with the barbus fish could have been of a younger age.

### 3.5. Public Health Risk Analysis Based on Symptoms of Heavy Metal Toxicity

The symptoms observed from the respondents within the catchment gave indications of their possible health disorders. By determination of the medical disorders associated with these symptoms and by extension the heavy metals associated with these medical disorders, it is possible with a degree of certainty, to quantify the public health risk from heavy metals within River Sosiani, and this information is presented in Table 7. As can be discerned, the most significant medical disorders afflicting the study respondents included; rashes and itches (64.76%), stomach related disorders (30.72%), joint pains (13.55%), while other less significant disorders include: abnormal heart beat (12.05%), abnormal blood pressure (9.34%) and heart burn (9.04%). Other significant physiological disorders are: irritability (32.23%), tiredness (14.16%) and chronic fatigue (8.13%).Use of water from the rivers within industrial sites or urban centres, coupled with the consumption of fish from the polluted rivers is the major sources of transmission of heavy metals into the human body. Due to these activities, anyone can be exposed to toxic chemicals that accumulate in fish from contaminated waters [42]. Since the effects of these heavy metals take time to become evident, most people would not be aware of the effects of heavy metal accumulation in their bodies.

**Table 7. Wet season Target Hazard Quotients (THQ) and Hazard Index (HI) for Catfish consumption within the Sosiani catchment**

| Sampling site location and name | THQ* and HI | | | |
|---|---|---|---|---|
| | $THQ_{Pb}$ | $THQ_{Cd}$ | $THQ_{Cr}$ | HI |
| $SR_1$: Kipsenende | 0.004(0.001) $^{b}$ | 0.019(0.000) $^{c}$ | 0.053(0.001) $^{d}$ | 0.076 |
| $SR_2$: Ellegerine | 0.003(0.001) $^{bc}$ | 0.000(0.000) $^{e}$ | 0.054(0.001) $^{d}$ | 0.057 |
| $SR_3$: Chepkorio | 0.001(0.000) $^{d}$ | 0.003(0.000) $^{b}$ | 0.033(0.001) $^{e}$ | 0.037 |
| $SR_4$: Naiber | 0.004(0.001) $^{b}$ | 0.003(0.000) $^{b}$ | 0.026(0.000) $^{f}$ | 0.034 |
| $SR_5$: Nundoroto | 0.007(0.000) $^{a}$ | 0.000(0.000) $^{e}$ | 0.064(0.001) $^{c}$ | 0.071 |
| $SR_6$: Nairobi bridge | 0.003(0.000) $^{c}$ | 0.006(0.000) $^{a}$ | 0.096(0.001) $^{b}$ | 0.106 |
| $SR_7$: Kisumu bridge | 0.005(0.000) $^{b}$ | 0.002(0.000) $^{c}$ | 0.005(0.000) $^{g}$ | 0.012 |
| $SR_8$: Eldowas WW | 0.004(0.000) $^{b}$ | 0.007(0.000) $^{a}$ | 0.106(0.001) $^{a}$ | 0.117 |
| $SR_9$: Kengen power | 0.005(0.000) $^{b}$ | 0.003(0.000) $^{b}$ | 0.107(0.001) $^{a}$ | 0.115 |
| $SR_{10}$: Sosianisergoit | 0.025(0.003) $^{c}$ | 0.001(0.000) $^{d}$ | 0.088(0.001) $^{b}$ | 0.115 |
| Threshold values† | 1.000 | 1.000 | 1.000 | 3.000 |

† Threshold values of THQ and HI for Pb, Cd and Cr [29]

* Numbers in parentheses indicate Standard deviations (N=3).

**Table 8. Dry season Target Hazard Quotients (THQ) and Hazard Index (HI) for Catfish consumption within the Sosiani catchment**

| Sampling site location and name | Dry season | | | |
|---|---|---|---|---|
| | $THQ_{Pb}$ | $THQ_{Cd}$ | $THQ_{Cr}$ | HI |
| $SR_1$: Kipsenende | 0.002(0.000) [d] | 0.018(0.000) [c] | 0.022(0.001) [g] | 0.041 |
| $SR_2$: Ellegerine | 0.002(0.000) [d] | 0.000(0.000) [e] | 0.053(0.001) [e] | 0.056 |
| $SR_3$: Chepkorio | 0.001(0.000) [e] | 0.003(0.000) [b] | 0.021(0.009) [g] | 0.024 |
| $SR_4$: Naiber | 0.002(0.000) [d] | 0.002(0.000) [c] | 0.000(0.000) [h] | 0.004 |
| $SR_5$: Nundoroto | 0.005(0.001) [ab] | 0.001(0.000) [e] | 0.085(0.001) [d] | 0.091 |
| $SR_6$: Nairobi bridge | 0.005(0.000) [a] | 0.010(0.000) [d] | 0.117(0.001) [b] | 0.132 |
| $SR_7$: Kisumu bridge | 0.003(0.000) [c] | 0.019(0.000) [c] | 0.037(0.003) [f] | 0.059 |
| $SR_8$: Eldowas WW | 0.004(0.000) [b] | 0.004(0.000) [a] | 0.104(0.001) [c] | 0.112 |
| $SR_9$: Kengen power | 0.002(0.000) [d] | 0.004(0.000) [a] | 0.021(0.002) [g] | 0.027 |
| $SR_{10}$: Sosianisergoit | 0.005(0.000) [a] | 0.002(0.000) [c] | 0.145(0.001) [a] | 0.152 |
| Critical values* | 1.000 | 1.000 | 1.000 | 3.000 |

† Threshold values of THQ and HI for Pb, Cd and Cr [29]
* Numbers in parentheses indicate Standard deviations (N=3).

**Table 9. Symptoms observed from the respondents from the catchment, associated medical disorders associated with the symptoms and the heavy metals associated with the disorders**

| Symptoms observed | % of population with symptoms† | | Heavy metal medical disorder associated with symptoms | Heavy metal(s) associated with medical disorder |
|---|---|---|---|---|
| | **Yes** | **No** | | |
| Rashes and itches | 64.76 | 35.24 | Skin allergy | Cr |
| Chronic heartburn | 9.04 | 90.95 | Gastrointestinal | None studied |
| Tiredness | 14.16 | 85.84 | Vertigo<br>Anaemia | Cd [43]<br>Pb*** |
| Persistent joint pains | 13.55 | 86.45 | Involuntary contractions | Cd [43] |
| Increased Irritability | 32.23 | 67.77 | Lead encelopathy | Pb*** |
| Stomach pains | 8.13 | 91.97 | Gastrointestinal | None studied |
| Chronic fatigue | 30.72 | 62.98 | Insomnia<br>Anaemia | Cd [43]<br>Pb*** |
| Chest pains/abnormal heartbeat | 9.34 | 90.66 | Respiratory insufficiency<br>Respiratory irritation<br>Bronchospasm | Cd [43]<br>Cr<br>Cr |
| High blood pressure | 12.05 | 87.95 | Hypertension<br>Hypertension | Pb***<br>Cd |

† Population n = 332
* As sourced from EHC 134 for cadmium
** As sourced from EHC 134 for chromium
*** As sourced from EHC 134 for lead.

# 4. Conclusion& Recommendation

The inherent public health risks from heavy metal exposure were determined using THQs for the respective heavy metals and HI which summed up the individual THQs. The data obtained showed that during the wet season, the inherent risk from lead contamination was low, the THQ being less than 1 for all the sites in the entire catchment. However, regarding risk from cadmium exposure in the wet season, Naiber exhibited the highest risk, as manifested by its high $THQ_{Cd}$. Analysis of risk from chromium contact during the wet season showed a drastic changes since in the mid catchment, Nairobi bridge, Kisumu bridge and Eldowas waste water registered very high THQs way beyond the threshold of 1 which basically rendered waters from this location unfit for human consumption during the wet season.

An analysis of the inherent risks from fish consumption of *Barbusbarbus* and catfish showed that within the entire catchment and based on the received responses, the public health risk from fish consumption is very low with THQs being way below the threshold value of 1 for all the heavy metals i.e. lead cadmium and chromium, respectively. This could be due to the reality that the residents claim source their protein from other sources hence, seldom consume fish. However, the risk that they could have given inaccurate information taking into account that a critical number had no objection to consuming fish from Sosiani warrants attention. Moreover, as stated earlier there is need for investigation into other pathways of heavy metal ingestion. Finally, an evaluation of risks as exhibited by manifestation of symptoms within the catchment indicated that most of the inhabitants were symptomatic since 64, 90.95, 85.84, 86.45, 67.77, 91.97, 62.9% 90.66 and 87.95% reported rashes, heartburn, tiredness, joint pains, irritability, stomach pains, fatigue, chest palpitations and high blood pressure, respectively. Despite this, it was not possible to relate these symptoms with heavy metal exposure since the respondents did not indicate the duration of being symptomatic, despite most of the symptoms having an association with heavy metal toxicity. However, the fact that most of the symptoms were reported in more than 60% of the population it warrants further research. Basically, it is concluded that water from river Sosiani had higher THQ and HI values and hence higher risk values than both the fish species. This rendered water from this location unfit for human consumption. The study recommends that urgent measures like pollution control through enforcement of the Kenyan regulations and proper engineering guidance for drainages and wastewater treatment plants will reverse and eventually stop this trend. The communities are also supposed to be sensitised and encouraged not to use river water for domestic use.

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