**The Impact of Induced Industrial and Urban Toxic Elements on Sediment Quality**

Abstract

The increased population subject the rivers and streams to high levels of pollution from both industrial and domestic sources. The significant environmental challenges have been brought about by their effects, particularly with regards to biota, ecosystem processes, soil quality, and groundwater pollution. This study examined the effects of human activity by applying the pollution indices models to evaluate the input of toxic elements in the river sediments. Prior to sediment quality analysis, the total amount of arsenic (As), lead (Pb), cadmium (Cd), mercury (Hg), thorium (Th) and uranium (U) were determined in the concentration range of 1.09 - 10.0 mg/kg, 8.53 – 475 mg/kg, 0.12 – 0.16, mg/kg 4.85 – 77.5 mg/kg, 3.14 – 5.9 mg/kg and 0.93 – 2.86 mg/kg, respectively. The enrichment factor, contamination factor, pollution load index and geoaccumulation index revealed alarmingly high levels of Pb and Hg contamination in some sampling points which are related to possible human input in the range of severe enrichment and considerable contamination. The low ranges of pollution indices of some of toxic elements suggest enrichment through natural weathering process and atmospheric deposition. The Pearson correlation coefficient revealed significant correlation between Pb-Fe and As-Fe suggesting the possibility of acid mine contamination. Continual monitoring of the river sediment is essential to minimize the impact of toxic elements to sustain quality of sediment health.

Keywords: Pollution indices, enrichment factor, contamination factor, metal pollution, sediment quality

1. **Introduction**

Sediment determines the physical environment of ecological systems of rivers. The degree of water clarity, channel structure and natural terrain can be altered by variations in the quantity and spatial distribution of different types of sediment. The extreme fluctuations in the physical and chemical characteristics disrupt the natural terrain and biological balance of aquatic biomes. The flow and upstream sediment supply have an impact on river sediment transportation, and changes in both variables affect the rate of sediment transport as well as the locations where sediment is deposited or withdrawn [1]. Comprehension of the processes of sedimentation and erosion pertaining to the diverse settings within a river is crucial for the management of sediment and sediment-associated habitat in rivers [2]. Interrelated physical, chemical, and biological processes regulate sediment ecosystems and influence a sediment's capacity to sustain a diverse, active, and well-functioning biological population [3], [4]. Therefore, quality of sediment has become a crucial factor in maintaining the health of benthic ecosystems and safeguarding aquatic biome environments. Sediment contamination is a debilitating issue for scientific community because of the substantial amount of anthropogenic inputs the aquatic biomes are constantly receiving. A widespread of considerable amount of pollutants stimulate changes in ecological equilibrium and degrade water and sediment quality [2], [5]. The hydrological setting and morphology of rivers, wetlands, floodplains, estuaries or coastal lagoons influence accumulation of suspended particles and other related pollutants along water stream. Additionally, these pollutants have the ability to become a component of the bottom sediment, which frequently propagates for several miles downstream from chemical sources [6], [7].

Among the common environmental contaminants that have a significant impact on human health, the environment, and ecosystems are hazardous metals and metalloids, which are released through a variety of anthropogenic and natural processes. The scale and production capacity of numerous industries, including the coal, building materials, metallurgy, and chemical industries, are rising swiftly in tandem with the rapid expansion of the industrial economies in many countries [8]. Like many developing countries worldwide, South Africa has experienced an immense increase in the demand for potable water resources due to a range of activities including mining, urban stormwater, agricultural runoff, industrial discharges, and wastewater discharge which are also the main contributors of aquatic biomes and water resources contamination [9]. South Africa is among the leading mineral-rich nations ranking the fifth globally in terms of the contribution of mining to Gross Development Product [10]. Despite its significance for achieving economic growth, prosperity, and progress on a national and international scale, mining and other sectors have demonstrated adverse environmental consequences [9], [11]. For instance, the processes of gold (Au) mining exposed significant concentrations of radionuclides and other toxic elements on the environmental waters [12]. The ambient environmental surface and aquatic biomes may become increasingly contaminated with hazardous metals and metalloids like arsenic (As), uranium (U), thorium (Th), lead (Pb), mercury (Hg), and cadmium (Cd) as the consequence of mining activities. The distribution of these hazardous elements is often diverse in riverbed sediment and water and their amount transferred across the sediment–water interface depends on the physicochemical properties of the sediment and water [13]. Moreover, their abundance in the mining waste have the potential to constitutes substantial amounts of sulphides, which enters the aquatic environments through acid mine drainage and runoffs. As a results, sedimentation occurs into colloidal material that supplies the essential transportation and reservoirs of these pollutants [14]. In the aquatic reservoirs, As, Pb, Hg, Cd, U, and Th are non-biodegradable and may accumulate in sediments. Their toxicity, bioavailability, and solubility can vary based on their chemical form of which mobility is one of the key mechanisms causing elemental contamination that could be detrimental to human health and the biota [15], [14].

The historical contamination still poses a significant threat for many aquatic biomes because contaminated sediment has been associated to the impacts on both benthic and water column species [2], [9]. Despite that the underlying sediment may act as a reservoir to preserve the quality of the water by forming a long-lasting contaminant sink partitioned between pore water and sediment or suspended particulate [16]. It could emanate as the contamination source under variable environmental conditions. For instance, numerous physicochemical processes, including sorption, oxidation-reduction, hydrolysis, temperature, salinity, and pH, may influence the chemistry of sediments. Consequently, the release of adsorbed contaminants in various chemical forms with high mobility and bioaccumulation rate increasing the amount of toxic elements in both water and sediment. The water flow, the size, and content of geological material can also have an impact on these processes [1], [14], [17]. In addition, the constantly shifting relationship between metals in sediments and water flow is reflected in extreme hydrometeorology, whereas rising river flows as a result of climate change is causing silt from riverbeds to wash into rivers' upper reaches. As such, subterranean pollution deposits have the potential to gradually change the composition and quality of the water [13]. The prompt enrichment of hazardous metals and other pollutants in lake sediments is driven by both the effects of sediment adsorption and pollution source discharge which are creating a major threat to the aquatic ecosystem. For instance, The As, Pb, Hg, Cd, U, and Th have exhibited acute and long-term toxicity to benthic community, water column species and human health, even at extremely low levels. Therefore, to assess the level of contamination and implement pollution control, it is essential to investigate hazardous element pollution in sediment and identify risk zones [13], [18].The scientific community has established systematic methods for the assessment and control of sediment quality as a result of the aquatic biome's acquisition of toxic elements from various sources of contamination. Along with quantifying the concentration of trace elements, pollution indices are critical tools for assessment of sediment quality and may have a major role in forecasting the sustainability of aquatic biomes in the future [8], [19]. The aim of the study was to assess the sediment quality of heavily contaminated perennial Jukskei River in South Africa. Selected hazardous elements were quantified using inductively plasma coupled – mass spectrometry for determination of degree of contamination through the assessment of pollution indices parameters such as contamination factor (CF), enrichment factor (EF), geoaccumulation index (Igeo) and pollution load index (PLI).

1. **Methodology**
   1. Study area

The employment prospects in the mining sector has influenced the South Africa's population growth since the discovery of Au in the 18th century [12]. Mining activity has been concentrated in the Witwatersrand area in Johannesburg, South Africa, which is well-known for having significant Au reserves. Witwatersrand is also known as the ridge of white waters referring to the numerous springs in the area that meander through the area forming tributaries of the Juskei River which originate in Johannesburg [5]. Juskei River is significant for the economy and ecology since it forms largest contributing factor of eutrophication problems in the downstream of Hartbeespoort Dam which is utilized for recreational reasons, farming activities and domestic use. Juskei River is significantly affected by large volumes of runoff from wide variety of human activities in the upstream and downstream of urban areas such as agricultural runoff, industrial activities, mining operations and domestic waste and failure of sewage and poor drainage of wastewater infrastructures entering the watershed. The statistical report revealed deterioration in performance of wastewater treatment systems that results with heavily contaminated rivers due to discharge of municipal effluent that does not meet the specified treatment levels [20], [21]. The river sediment in the proximity of South African mining sites and within urban areas have been identified to have high concentrations of toxic elements, microorganisms, organic waste, and chemical pollutants [22], [23]. Therefore, management of aquatic biome prompted the need to assess the sediment quality of Juskei River which forecast the provision several benefits that are the cornerstone of water security and other policy

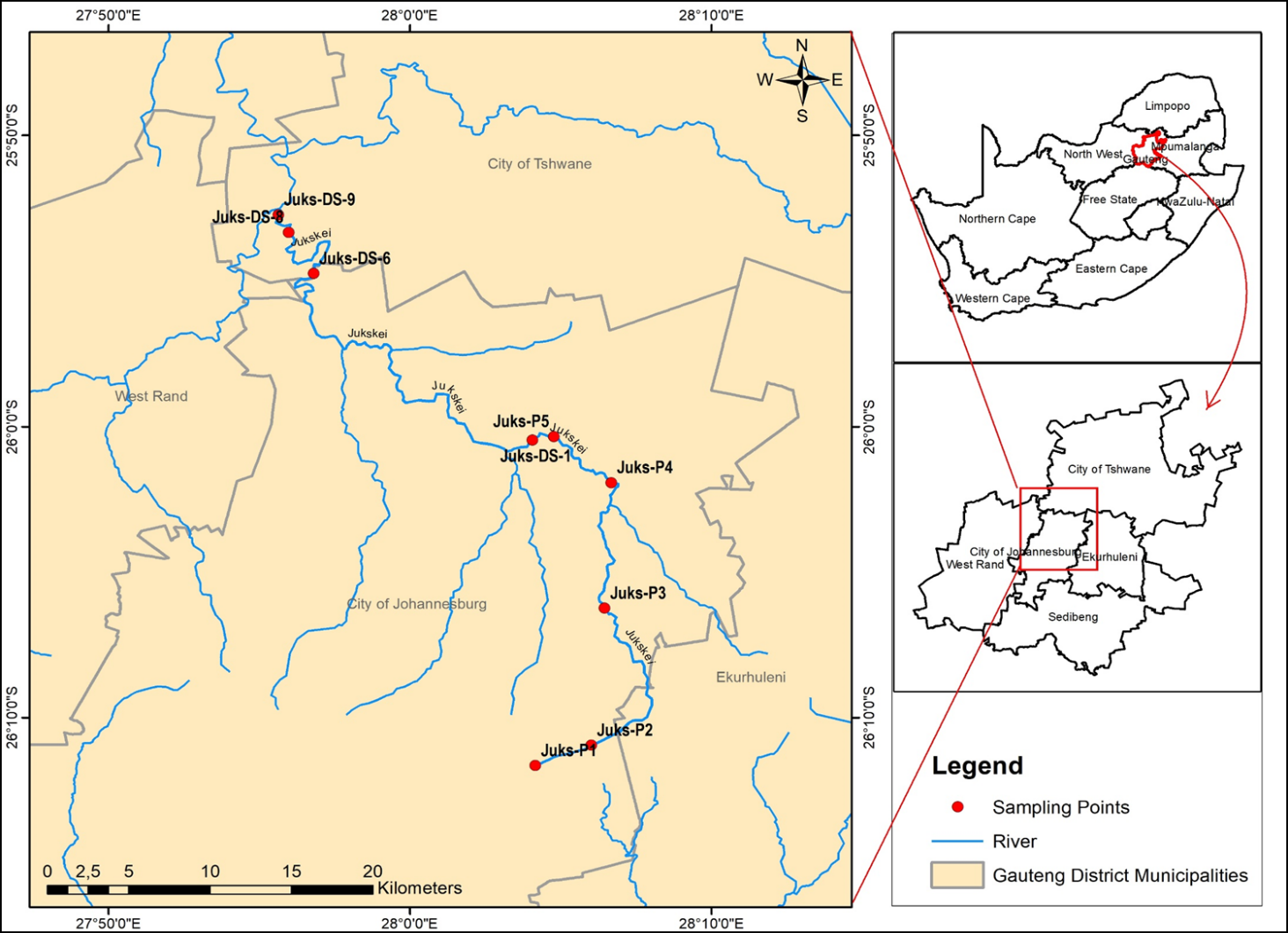
* 1. Sample collection and preparation

Sediment collection campaign was conducted during rainy season by convenience sampling method. The sampling points on the map (Figure 1) were selected based on the accessibility of the river. Samples were scooped using snapper sediment and telescopic rod sampling system and decanted into pre-cleaned high-density polyethylene round bottles of 500 mL. In the laboratory, sediment was air dried and pulverized to achieve particle distribution size than 75 μm aperture, approximately 500 mg of homogenized samples was digested for mineralization of selected toxic elements.

* 1. Reagents and instrumentation

Chemicals of high purity, which include 77% HClO4 (Merck, RSA), 30% H2O2 (Solution AR, RSA), 37% suprapur HCl (Supelco, RSA), 99% suprapur Sc (DLD Scientific, RSA) and 40% HF (Herenba, India) were employed for sample digestion. calibration curves selected elements and the internal standards, rhenium and indium were prepared using stock solutions of 1000 mg/L purchased from Inorganic ventures (Christiansburg, USA). Certified reference materials (CRM) Oreas 121 (Oreas, Australia) were used for quality control check of the analytical procedure. Instruments were optimized and calibrated for accurate analysis of the samples. The 7800X inductively coupled plasma – mass spectrometry (ICP-MS) (Agilent, USA) supplied with argon and helium gas of 99.9% purity were employed for the quantitative determination of toxic elements. Ultra-pure de-ionized water of 18.mΩcm purified from Milli-Q Direct 16 purification system (Merck, France) used for the preparation of standards and sample dilutions.

2.4. Mineralization of Analytes of Interest

Approximately 500 mg was weighed directly into the Teflon digestion vessels fol-lowed by the addition of HNO3, HClO4, and HF for the two-stage refluxing process on the hotplate. After the digestion vessels were completely dry, they were allowed to cool, fol-lowed by the reconstitution step using H2O2 and HCl. The reaction was left to reach room temperature. Then, the samples were transferred to a 50 mL volumetric flask and diluted to the mark with de-ionized water. The Oreas 121 CRM was used to assess the reproducibil-ity and accuracy of the method. Analytes of interest were determined using ICP-MS. The instrumental operating parameters are presented in Table 1. Analytical figures of merit, such as linearity, precision, accuracy, and repeatability of the procedure and quality control checks, were monitored within the scope of ISO 17025 accreditation. ISO 17025 accreditation offers laboratory's capacity to provide testing and calibration analysis under the implementation of an appropriate quality management system [24].

**Figure 1.** Sampling map of Jukskei River.

**Table 1.** Optimal parameters of ICP-MS.

|  |  |
| --- | --- |
| Parameter | Setting |
| Nebulizer gas flow | 0.75 L/min |
| Auxiliary gas flow | 1.4 L/min |
| Plasma gas flow | 12 L/min |
| ICP RF power | 1400 kW |
| Sample intake | 0.8 mL/min |
| Number of replicates | 3 |

* 1. Sediment quality assessment

The EF, PLI, CF and Igeo were the selected pollution indices parameters to evaluate of the degree of contamination and formulae were adopted from Kowalski et al. [7] and  [Vineethkumar](https://bnrc.springeropen.com/articles/10.1186/s42269-020-00455-0#auth-V_-Vineethkumar-Aff1) et al. [19]. Iron (Fe) is a metal with low variability of occurrence that was used as a reference metal in both the geochemical or baseline background and the analyzed samples to evaluate the impact of human activity on accumulation of toxic elements in the sediment using enrichment and contamination factor calculations. The background or reference values are pre-requisite for calculation pollution indices parameters and Table 2, summarizes the background values used.

**Table 2**. Reference values for the elements [25]; [26]

|  |  |
| --- | --- |
| Background element | Reference value (mg/kg) |
| As | 12.7 |
| Pb | 10 |
| Cd | 0.5 |
| Hg | 0.02 |
| Th | 10 |
| U | 10 |
| Fe | 10000 |

The EF, CF and Igeo of selected toxic elements were calculated using the Equation 1-4, respectively. The impact of human activity on toxic element’s accumulation was assessed based on the range of the degree of contamination of each parameter presented in Table 3-5, respectively.

………………………………………………………………………Equation 1

From the equation above: -

(C*x*/Cref)sample = sediment is the ratio of the concentration of the element *x* to that of the reference element in the sediment sample

(C*x*/Cref)background = background value is the ratio of the concentration of the element *x* to that of reference element.

**Table 3.** Enrichment factor in relation to sediment quality [7], [19]

|  |  |
| --- | --- |
| Enrichment factor value | Sediment quality |
| < 1.0 | No enrichment |
| < 2.0 | Minimal enrichment |
| 3 – 5 | Moderate enrichment |
| 5 – 10 | Moderately severe enrichment |
| 10 – 25 | Severe enrichment |
| 25 – 50 | Very high enrichment |
| > 50 | Extremely high enrichment |

When assessing the sediment quality of PLI, for every element greater than one is regarded polluted whereas that of less than one indicate the unpolluted sediment. The PLI was calculated from the Equation 2, where CFn is the CF of the nth metal and n is the number of metals been assessed.

Pollution load index (PLI) = (CF1 x CF2 x CF3 x............CFn) 1/n……………………...…… Equation 2

The values which defined the CF were calculated by the Equation 4, where (C*x*)sediment defined as the concentration of the element *x* in the sample and (C*x*)reference, the concentration of the reference element. The range determining degree of contamination was evaluated based on Table 4.

**Table 4.** Category of contamination factor [19][27].

|  |  |
| --- | --- |
| Contamination factor | Description |
| < 1.0 | Low contamination |
| < 2.0 | Moderate contamination |
| 3.0 – 5.0 | Considerable contamination |
| > 6.0 | Very high contamination |

The Igeo (Equation 4) was employed to estimate the concentration of toxic elements accumulation in sediment above the baseline concentration. In order to compensate for the variations due to the lithogenic effects, a 1.5 background matrix factor is used. Table 5 provides the Igeo classification.

Igeo = log(Cn/1.5Bn) ………………………………………………………...………....… Equation 4

From the Equation above:-

Cn = is the concentration of element *x* in the sediment sample

Bn = is the background or reference value of element n.

**Table 5.** Classification of geo-accumulation index

|  |  |  |
| --- | --- | --- |
| Geoaccumulation index | Geoaccumulation index class | Pollution intensity |
| <0 | 0 | Practically no pollution |
| > 0<1 | 1 | Uncontaminated to moderately  contaminated |
| > 1<2 | 2 | Moderately contaminated |
| > 2<3 | 3 | Moderately to heavily contaminated |
| > 3<4 | 4 | Heavily contaminated |
| > 4< 5 | 5 | Heavily to extremely contaminated |
| > 5 < 6 | 6 | Very strongly polluted |

1. **Results and discussion**

Analysis was performed adhering to the requirements of ISO 17025 accredited Analytical Chemistry Facility and RadioAnalysis and Calibration Laboratories. Analytical figures of merit were within acceptable range of the validated and accredited methods.

* 1. Assessment of selected toxic elements

The rapid advancement of human industrialization and economic growth has led to an increase in the pollution of various environmental matrices with heavy metals. Because of their subtle nature, persistent toxicity, and propensity for accumulation, toxic elements prompted the need for quantitative determination in order to achieve effective environmental pollution monitoring and risk assessment [28]. The total level concentration, radioactivity and Person’s correlation were determined in Juskei River samples.

* + 1. Total quantification of selected toxic elements

The concentrations of As, Pb, Hg, Cd, U, and Th (Table 6) were notable in all of the samples collected in the Juskei River. The Fe was detected with the highest concentration of 1598 mg/kg, followed by Pb, Th, U, Cd and Hg with relative concentrations of 53.4 mg/kg, 4.57 mg/kg, 1.40 mg/kg and Hg 22.2 μg/kg, respectively. The observed concentration of these hazardous elements are concerning for the river that meanders around residential and industrial areas of Gauteng. The different concentrations distributed among the sampling sites can be attributed to different activities. The Juks-P2 has high concentration of Pb which maybe due mishandling of waste from many industries and other human activities. For instance, mini buses taxis are the main source of transport in Johannesburg as a result there is a mushrooming of many informal vehicles maintenance facilities. Paints, oil and petrol three extremely dangerous and poisonous chemicals, have been used in these workplaces on a progressively growing basis. Because these shops and vehicle repair companies are tiny and have few resources, hazardous materials are frequently handled carelessly and disposed of into the environment incorrectly and up accumulating in the river sediments [29].

**Table 6**. Results for ultra-low toxic elements by ICP MS

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Sample ID | As  (mg/kg) | Pb (mg/kg) | Cd (mg/kg) | Hg (µg/kg) | Th (mg/kg) | U (mg/kg) | Fe  (mg/kg) |
| Juks-P1 | 10.0±0.06 | 38.8±1.27 | 0.16±0.03 | 77.5±3.54 | 5.08±0.02 | 2.02±0.03 | 19533±896 |
| Juks-P2 | 8.6±0.06 | 475±4.04 | 0.30±0.03 | 20.7±0.58 | 4.59±0.09 | 1.74±0.06 | 36600±624 |
| Juks-P3 | 2.35±0.29 | 12.6±0.32 | <0.05 | 24.5±2.12 | 3.46±0.08 | 1.26±0.05 | 12567±231 |
| Juks-P4 | 5.77±0.21 | 13.0±0.55 | <0.05 | 10.3±0.99 | 5.31±0.02 | 2.86±0.05 | 16267±1097 |
| Juks-P5 | 2.1±0.14 | 21.2±0.14 | 0.14±0 | 15.0±0 | 5.84±0.02 | 2.25±0.06 | 13233±153 |
| Juks-DS-1 | 1.6±0.14 | 21.8±0.42 | 0.12±0 | 16.0±2.83 | 4.14±0.16 | 1.67±0.01 | 10267±208 |
| Juks-DS-6 | 1.09±0.16 | 15.8±1.56 | <0.05 | 8.4±0.85 | 4.96±0.62 | 1.34±0.00 | 6900±100 |
| Juks-DS-8 | 2.1±0.14 | 28.2±0.42 | 0.26±0.02 | 52.3±4.2 | 5.35±0.29 | 2.81±0.00 | 21867±513 |
| Juks-DS-9 | 1.3±0.35 | 16.3±0.40 | 0.12±0.01 | 22.0±2.83 | 4.72±0.40 | 1.67±0.08 | 11033±416 |

The Pb-compounds originating from these workshops provide significant hazards to human health and the environment. Prolonged exposure to lead compounds in humans can lead to elevated blood pressure, cardiovascular issues, and kidney damage. Pregnant women who are exposed to elevated levels of lead may experience low birth weight, early delivery, miscarriage, and stillbirth. The concentration observed for other elements is concerning because Hg, Th, U, As and Cd do not add any nutritional value to humans. Even at low concentrations, Hg pose significant problems [28]. The Witwatersrand region of Gauteng has been the epicenter of Au mining since the 18th century, liquid Hg has been used to extract pure Au and silver (Ag) from the mineral ores because it creates a stable amalgam with Au and Ag. Heat causes the Hg in the amalgamation to evaporate, resulting in pure Au and Ag [30]. Some of the sickness that results from Hg poisoning is the proper functioning of the kidneys and central nervous system [31]. The significant contribution of U and Th that is found in the Juskei River is the result of the legacy of Au mining. Mine dumps and acid mine drainage are the biggest threat in Gauteng [12]; [32].

* + 1. Radioactivity determination of thorium and uranium

An increase in the ambient natural background radiation can be caused by radiation pollution of the environment from both artificial and natural sources. The rise in radioactive environmental contamination from anthropogenic and natural sources leading to radiation exposure of humans and aquatic biomes has rendered measuring the gross alpha and beta radiation concentrations of various environmental matrices increasingly relevant [33]; [34]. The amount of radionuclides elements, Th and U ranging between 3.46 – 5.88 mg/kg and 1.26 – 2.86 mg/kg were imperative to determine gross alpha and beta radioactivity, which serves as the foundation for evaluating radioactive material and suggesting stringent radiation safety guidelines[33], [35]. The sampling point Juks-P5, Juks-DS-6 and Juks-DS-9 have exhibited considerable amount of gross beta radioactivity whereas the gross alpha beta were notable at Juks-P5, Juks-DS-6, Juks-DS-8 as observed in Figure 2. These notable amount in the river sediment can be attributed to various sources such as natural weathering, atmospheric depositions, anthropogenic activities and traffic emissions. The amount of Th and U as well as their overall beta and alpha radioactivity suggested a possible reflection of radioactive contamination of Juskei River while also showing significant hazard to the benthic community of river sediment [36].

Figure 2. The gross beta and alpha radioactivity of radionuclide elements.

* + 1. Pearson correlation coefficient

The Pearson correlation coefficient is an important criteria used to measure the strength of a linear association between two elements to determine the same type of pollution sources and delivery pathway. It was calculated by plotting the graphs of pairs of toxic element’s concentrations from Table 7 and obtaining the regression coefficient (r). The r values equating to one for each pair exhibit strong correlation which can deviate to no correlation when the value is zero. The correlation analysis (Table 7) obtained using Pearson correlation coefficient shows a moderate correlation between As and Pb indicted by the by the value 0.3241. This may be indicating that the same type of contamination sources is responsible for the contamination of the Juskei river.

The statistical analysis also shows there is weak correlation between As and Hg and also between Hg and Cd. Even though there is weak correlation between Hg and Cd this possible association might be due to artisanal gold mining that is rampant in Gauteng. Hg is used in the processing of gold and it has been reported that artisanal mining is the source of anthropogenic Hg release to the environment [22]. The other negative impact of mining is the generation large amount of Cd-rich wastes, including acid mine drainages tailings, slags, and dust [18]. Acid mine drainage contains high amount of pyrite and the impact of acid mine drainage in the lives, and the environment in Gauteng and beyond is affecting the lively hood of many people. Acid mine drainage contains among other elements Fe, As, Pb, Cd and U [21] Correlation analysis reveals significantly high degree of correlation of Fe and As, and Pb and Fe with the values of 0.5068 and 0.6521 respectively. From Table 7 it is important to note that Cd and Fe and Pb and Cd with the values of 0.374 and 0.3831 respectively were significantly correlated on Pearson correlation test with moderate strong strength. This may indicate that their anthropogenic sources might be the same considering that this metals are present in the mine effluents and has significant impact on the quality of fresh water resources [37]. Moreover, the p values obtained using ANOVA calculations for Pb-Fe and As-Fe were 1.40x-7 and 1.32x-7 and 0.143 respectively showing a significant correlation in relation to their emission source. A P<0.05 is deemed statistically significant and the correlation between Pb and Cd is insignificant with P = 0.143 obtained using ANOVA calculations. Based on the literature a P>0.05 indicates that Pb and Cd does not have significant correlation.

**Table 7**. Pearson correlation matrix

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | As | Pb | Cd | Hg | Th | U | Fe |
| As | 1 | 0.3241 | 0.1546 | 0.1797 | 0.0406 | 0.0974 | 0.5068 |
| Pb | 0.3241 | 1 | 0.3831 | 0.0004 | 0.0004 | 0.0008 | 0.6521 |
| Cd | 0.1546 | 0.3831 | 1 | 0.3003 | 0.0421 | 0.2393 | 0.374 |
| Hg | 0.1797 | 0.0004 | 0.3003 | 1 | 0.0249 | 0.1357 | 0.0175 |
| Th | 0.0406 | 0.0004 | 0.0421 | 0.0249 | 1 | 0.1971 | 0.0102 |
| U | 0.0974 | 0.0008 | 0.2393 | 0.1357 | 0.1971 | 1 | 0.0606 |
| Fe | 0.5068 | 0.6521 | 0.374 | 0.0175 | 0.0102 | 0.0606 | 1 |

* 1. Pollution indices for sediment quality assessment

A sediment quality assessment of the Juskei River using pollution indicators such as EF, PLI, CF, and Igeo is required in considering the accumulation of toxic elements. The pollution indicators serve as key tools in the overall assessment of the degree of sediment contamination.

3.2.1. Enrichment factor and contamination factor

The EF and CF are frequently used complementary metric for assessing sediment quality. The EF is mostly used to determine how much an element's presence in a sample has been enhanced by human activity in comparison to its average natural abundance. Meanwhile, the ratio of the element's pre-industrial reference value to the hazardous element content in sediment can be used to compute the CF [3]; [34]. As observed in the Table 8 and Table 9, Pb shows severe EF at sampling point Juks-P2 and minimal enrichment at the sampling Juks-DS-1 and Juks-DS-6 with the considerable contamination factor within the entire sampling points. The EF and CF of Pb and Hg suggest the anthropogenic input. Additionally, a great concern is the sampling point Juks-1which the enrichment of 1.98 even though is marginally lower than 2. Enrichment factor results showed that there are high Hg activities in the Juskei river. Samples Juks-P4, Juks-DS-8, and Juks-DS-9 showed the EF of over 1. Hg and Pb contamination are observed to be a significant problem for Juskei. The values CF lies on the moderation contamination and for sample Juks-P1, Hg CF is classified as considerable contamination. These finding indicate special attention must be focused on the efforts to reduce toxic metals pollution. Conversely, the pollution indices of other toxic elements indicating no to minimal enrichment and contamination factors suggest that natural processes input. Nonetheless, As is found in all sampling points which indicate the possibility of the anthropogenic sources. With 21 nations reporting environmental contamination from As, chronic As pollution is acknowledged as a global issue [38]. Some of the anthropogenic sources include coal fired power station and pesticides.

**Table 8**. Enrichment factor for toxic elements in the Juskei river

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Toxic metals | Juks-P1 | Juks-P2 | Juks-P3 | Juks-P4 | Juks-P5 | Juks-DS-1 | Juks-DS-6 | Juks-DS-8 | Juks-DS-9 |
| As | 0.40 | 0.19 | 0.14 | 0.28 | 0.13 | 0.12 | 0.12 | 0.08 | 0.09 |
| Pb | 1.99 | 12.98 | 1.00 | 0.80 | 1.09 | 2.12 | 2.29 | 1.29 | 1.48 |
| Cd | 0.16 | 0.16 | 0.3 | 0 | 0 | 0.23 | 0 | 0.24 | 0.22 |
| Hg | 1.98 | 0.28 | 0.28 | 0.98 | 0.32 | 0.78 | 0.61 | 1.19 | 1.00 |
| Th | 0.26 | 0.13 | 0.13 | 0.28 | 0.33 | 0.40 | 0.72 | 0.24 | 0.43 |
| U | 0.16 | 0.05 | 0.05 | 0.10 | 0.32 | 0.16 | 0.19 | 0.13 | 0.15 |

**Table 9.** Contamination factors for toxic elements in the Juskei river

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Toxic metals | Juks-P1 | Juks-P2 | Juks-P3 | Juks-P4 | Juks-P5 | Juks-DS-1 | Juks-DS-6 | Juks-DS-8 | Juks-DS-9 |
| As | 0.79 | 0.68 | 0.19 | 0.45 | 0.17 | 0.13 | 0.09 | 0.17 | 0.10 |
| Pb | 3.88 | 47.5 | 1.26 | 1.3 | 2.13 | 2.18 | 1.58 | 2.82 | 1.63 |
| Cd | 0.32 | 0.6 | 0 | 0 | 0.28 | 0.24 | 0 | 0.52 | 0.24 |
| Hg | 3.88 | 1.04 | 1.23 | 0.52 | 0.75 | 0.80 | 0.42 | 2.62 | 1.10 |
| Th | 0.51 | 0.46 | 0.35 | 0.53 | 0.58 | 0.41 | 0.50 | 0.54 | 0.47 |
| U | 0.20 | 0.17 | 0.13 | 0.29 | 0.23 | 0.17 | 0.13 | 0.28 | 0.17 |

In the area that Juskei transverse closely there is coal fired powered power station. In the seminal study by Rother [39] the detailed proliferation uses of legal and illegal uses of pesticides is explored especially by the users who do not have scientific knowledge to understand risks and health hazards associated with the uses of pesticides. The presence of Cd in the river sediments might be decoding the worrying trend of runaway sewage that polluting the Juskei River as reported by Webster et al. [23]. The burning of fossil fuels releases Cd into the atmosphere. It is used in batteries, paints, plastics, and electroplating, among other products. Phosphorous fertilizers and sewage sludge are also anthropogenic sources of cadmium emissions into the environment [40]. It is reported that one cigarette contains 1–2 mg Cd and most of it is absorbed by the body. Because cations, in particular Zn2+ and Ca2+, have comparable valence and radius, Cd2+ can mimic them, which contributes to some of their toxicity. This element that can be replaced by Cd are essential functioning of the body. All the metals and metalloids discussed above offer no nutritional value and even at ultra-low concentration can pose risk to the environment and humans. The accumulation of these elements in the sediments reveal the anthropogenic sources might be the source of pollution rather than natural occurring considering that potential sources exist around Juskei river and also along the streams that are tributaries of Juskei mentioned above.

3.2.2. Pollution loan Index and geoaccumulation index

The PLI usually quantify the toxic element pollution to provide the insight on contamination status of sediment relative to toxic elements. The amount of toxic elements found in sediment in relation to their natural background values is shown by the Igeo indicator [19]; [34]. For every sampling point, the PLI was determined and as presented in Table 10, pollution is indicated PLI value > 1, whereas no pollution is indicated by a PLI value < 1. The PLI values in for sampling points Juk-P2 and Juks-P5 exhibited 1.08 and 1.00, respectively which indicate a significant pollution in upstream part of the river. As indicated above there are several tributaries to the Juskei river which is evidenced by pollution from these two sampling points whereas the other seven sampling points do not show pollution. Table 11 shows the calculated Igeo values. It is clear from these values that all elements fall into class "o" in all sample sites, with the exception of lead, suggesting no contamination. The values Igeo values for lead for Juks-P3, Juks-P4, Juks-P5, Juks-DS-1, Juks-DS-6, and Juks-DS-9 sampling points uncontaminated to moderately contaminated with the Juks-P1 and Juks-DS-8 sampling points showing moderate lead contamination. Sampling point Juks-P2 shows Class 6 which is extreme contamination for Pb.

**Table 10.** Pollution load index for toxic elements in the Juskei River

|  |  |
| --- | --- |
| Sample ID | Pollution load index |
| Juks-P1 | 0.85 |
| Juks-P2 | 1.08 |
| Juks-P3 | 0 |
| Juks-P4 | 0 |
| Juks-P5 | 1.00 |
| Juks DS-1 | 0.39 |
| Juks DS-6 | 0 |
| Juks-DS-8 | 0.67 |
| Juks-DS-9 | 0.38 |

**Table 11.** Geo-accumulation I(geo) of toxic elements in the Juskei river

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Toxic element | Juk-P1 | Juk-P2 | Juks-P3 | Juks-P4 | Juks-P5 | Juks-DS-1 | Juks-DS-6 | Juks-DS-8 | Juks-DS-9 |
| As | -0.51 | -0.72 | -2.59 | -1.30 | -2.76 | -3.15 | -3.70 | -2.75 | -3.44 |
| Pb | 1.75 | 5.37 | 0.13 | 0.18 | 0.88 | 0.92 | 0.45 | 1.29 | 0.50 |
| Cd | -3.64 | -2.74 | 0 | 0 | -3.84 | -4.06 | 0 | -2.94 | -4.05 |
| Hg | -4.24 | -6.24 | -6.25 | -7.25 | -6.25 | -6.25 | -7.24 | -4.93 | -6.24 |
| Th | -1.18 | -1.33 | -1.73 | -1.11 | -0.98 | -1.47 | -1.21 | -1.10 | -1.28 |
| U | -2.51 | -2.72 | -3.19 | -2.01 | -2.35 | -2.78 | -3.10 | -2.03 | -2.78 |

1. **Conclusion**

The study shows human activities have an impact on the distribution and enrichment of toxic chemicals in the Juskei River. The low enrichment and contamination factors of some of these elements suggest enrichment through natural weathering processes and atmospheric deposition. Nonetheless, Pb and Hg contribution strongly indicate the anthropogenic input through industrial activities, disposal of sewage, use of fertilizers from the agricultural fields, domestic, acid mine drainage and urban wastes in the river system. The Juskei River's sediment quality is not toxic by nature, as demonstrated by the pollution indices, and neither of the toxic elements' levels have surpassed the permissible levels. The pollution indices have shown that there is significant Pb pollution in the Juskei River that necessitate close monitoring of the river sediment samples on a regular basis to assess the impact of toxic elements in the research area.

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