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# Soil Contamination in Nuclear Reactor Surrounding Areas in Savar, Bangladesh using Instrumental Neutron Activation Analysis Method

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## ABSTRACT

In this paper, the contamination level of fourteen elements (Al, Ca, Mg, V, Ti, Na, Mn, As, Br, La, Sm, Sc, U, Yb) from different soil samples of the nuclear reactor surrounding areas in Savar, Bangladesh was investigated with instrumental neutron activation analysis (INAA) method. Generally, neutron activation is most reliable tool for determining the concentration of the trace elements and heavy metals by measuring the gamma rays released while decaying of the radioisotopes created from the interaction of neutrons with atoms. In this study, the soil contamination level of all heavy metals and trace elements was compared to the range, mean, and median values of the World soil as well as with other studies. The concentration of K (1.65%), U (3.17 mg kg$^{-1}$), Sm (6.10 mgkg$^{-1}$) and Sc (10.53 mg kg$^{-1}$) is relatively higher than that of the World mean value. Furthermore, compared to world range value for soil revealed that the high concentration range is also observed for Al (3.87-9.39%), Na (0.37-0.76%) and Yb (0.11-5.36 mg kg$^{-1}$). However, contamination level of all elements was not evenly distributed in the studied areas. For instance, the pollution levels of U, Yb, Mn, and V were unevenly higher in the areas near to the overhead tank, decay tank, in the vicinity of the underground tank, cooling tower and reactor building area. Interestingly, the contamination level of potassium is high everywhere near the nuclear reactor installations.

**Key words:** Elemental analysis, neutron activation, heavy metals, nuclear reactor, trace element

## 1. Introduction

The soil, a main part of the terrestrial ecosystem, is a heterogeneous mixture of different organisms and minerals, organic, and organo-mineral substances present in three phases: solid, liquid and gas [1-2]. At the same time, soil is perhaps the most endangered component of our environment open to potential contamination by a variety of different pollutants arising from human activities such as nuclear, industrial, agricultural, etc., [3-5]. Although the trace elements in soil are very important for the quality of soil and environment, excessive level of trace elements can cause pollution of waters, toxicity in plants, foods and ultimately in animals and humans that feed upon them [6-8]. As a result, the limits of metal deposition rates to soils should take into account the general ecotoxicity, phytotoxicity, transfer to animals and risk to the human health. The trace metal concentrations in soils may be affected by the deposition of wastes released from various industries, nuclear research and other related establishments. The erosive weathering, lead-base paints from the outer walls of buildings, land treatment of sewage sludge and natural sources of trace elements, e.g., windblown dust, forest wildfires, sea salt emission and vegetation may also contribute to the soil trace metal elevation [9]. Uncontrolled development of industry, agriculture and urbanization accelerates the input of heavy metals into the environment in many parts of the world [1].

Heavy metals have been the subject of particular attention because of their long-standing toxicity, mobility in the ecosystems and transfer into the food chains when specific thresholds have been exceeded [10-16]. Many procedures have been devoted to determining the sources, types, and degrees of heavy metal pollution in soil [17-20]. An important background for this kind of work requires the knowledge of geochemical baseline concentrations of elements. The trace element pollution depends on geochemical and biochemical properties of a given element. There is an increasing demand to measure background levels of inorganic materials in soils because of the need to determine whether a soil is contaminated or not.

In 1981, a research reactor was installed at Atomic Energy Research Establishment (AERE), Savar, Dhaka and used for training, research, and isotope production. Some other nuclear installations such as the decay tank, cooling tower, neutron generator and detection laboratory, isotope production laboratory, chimney, water treatment plant, and underground tank are also available nearby the research reactor. Although the reactor and the nearby installations are shielded well, there is still some probability of polluting the soil with heavy metals and other harmful substances. The geochemical baseline concentrations of metals in soil for the region are not available. The aim of the present work is to assess the contamination level of the soil samples taken at different points from the surrounding areas of the research reactor. The risk assessment of the present study is based on the comparison between the levels of contamination in the studied areas and the established guidelines or screening values [21, 22]. In addition, level of contamination in the soil samples was estimated by comparing with the world average levels and the other specified guidelines for the element in soils. It is more likely that the high content of some elements in the soils is a result of activities in the nuclear installations.

## 2. Materials and Methods

The soil samples were collected from the different locations of the surrounding areas of the TRIGA MARK II Research Reactor and other nearby nuclear installations of the Bangladesh Atomic Energy Commission (BAEC), Savar, Dhaka. Global Positioning System (GPS) technology was used to mark the sampling points (Table 1). The samples were collected in polyethylene bags, which were previously cleaned with dilute nitric acid, pure water, acetone, and then dried. The samples were at first dried naturally at room temperature in a clean room and then dried in an oven for 7 days at 50ºC. The samples were then crushed into powers of 200 microns size particles in an agate mortar. About 50 mg of each sample was put in a clean polyethylene bag which was doubly heat-sealed, and later used for irradiation. For quality assurance purpose about 50 mg of three certified reference materials (CRM)

**Table 1:** Sampling points and location of investigated soil samples

| Sample No. | Sampling points by **GPS** Longitude/ Latitude | Sample collection places surrounding the TRIGA MARK II Research Reactor | Sample No. | Sampling points by **GPS** Longitude/ Latitude | Sample collection places surrounding the TRIGA MARK II Research Reactor |
|---|---|---|---|---|---|
| RFS-1 | N:23°57.122´<br>E:90°16.787´ | Close to decay tank | RFS-8 | N:23°57.105´<br>E:90°16.816´ | Water treatment plant |
| RFS-2 | N:23°57.108´<br>E:90°16.805´ | South side of Mehadi tree | RFS-9 | N:23°57.082´<br>E:90°16.784´ | South west of reactor boundary |
| RFS-3 | N:23°57.105´<br>E:90°16.813´ | East side of water tank plant | RFS-10 | N:23°57.090´<br>E:90°16.792´ | West of Underground tank |
| RFS-4 | N:23°57.091´<br>E:90°16.799´ | Near the over head tank | RFS-11 | N:23°57.100´<br>E:90°16.783´ | Garden beside lemon tree |
| RFS-5 | N:23°57.089´<br>E:90°16.803´ | Near the over head tank(South side of palm tree) | RFS-12 | N:23°57.103´<br>E:90°16.789´ | West side cooling tower pipe |
| RFS-6 | N:23°57.106´<br>E:90°16.794´ | North side of cooling tower | RFS-13 | N:23°57.131´<br>E:90°16.789´ | North-East corner of reactor building |
| RFS-7 | N:23°57.118´<br>E:90°16.807´ | Far from decay tank | RFS-14 | N:23°57.112´<br>E:90°16.781´ | West side of reactor building |

RFS: Reactor Facility Soil, GPS: Global Positioning System.

of International Atomic Energy Agency (IAEA) such as IAEA-soil-7, NBS-1633b Coal fly ash, and IAEA-SL-1 were also put in polyethylene bags for irradiation.

The samples and standards were simultaneously irradiated using 3MW neutron beam research reactor, TRIGA MARK II at the Bangladesh Institute of Nuclear Science and Technology (INST) under the Atomic Energy Research Establishment (AERE) of Bangladesh Atomic Energy Commission (BAEC). The short irradiation was performed using the pneumatic transfer system. Each sample and standard were irradiated for two minutes with 250 kw reactor power having a thermal neutron flux of $2.75\times10^{13}$ neutrons per cm$^2$ per second. The long irradiation was performed in the rotary specimen rack (Lazy Susan). For long irradiation all the samples and standards were packed together in an irradiation vial and irradiated simultaneously for four hours with a reactor power of 250 kw and a thermal neutron flux of $2\times10^{12}$ neutrons per cm$^2$ per second.

After irradiation the cover bag was removed and the bag the containing radioactive sample was again covered with a new clean polyethylene bag to avoid contamination during gamma-ray measurements. The activities of the irradiated samples and standards were measured nondestructively using a high purity germanium (HPGe) detector coupled with a pulse-height multi-channel (4,096 channels) analyzer. The γ-rays emitted from both the samples and standards were measured at the same geometry. The dead time of the detector was kept below 3%. The cooling time varied from 2 minutes to 72 h for the measurement of γ-rays depending on the irradiation (short and long) process. The counting time also varied with the irradiation process. Target and daughter nuclides, as well as other nuclear data pertinent to this study are presented in Table 2. In this study, the elemental concentrations in the soil samples were calculated using the comparative method. The gamma peak analysis was performed using the software Hypermet PC version 5.12. The concentration was calculated manually in an Excel spread sheet as well as with the Peakgr-10.

**Table 2:** Decay data of the radionuclides and the contributing reactions

| Element | Isotopic abundance $I_\gamma$ (%) | Contributing reaction | Half-life | γ -ray energy (keV) |
|---|---|---|---|---|
| As | 44.6% | $^{75}$As (n, $\gamma$)$^{76}$As $\xrightarrow{\beta}$ $^{76}$Se | 26.3 h | 559.1 |
| Br | 83.2%, 72% | [$^{81}$Br (n, $\gamma$)$^{82}$Br] | 35.3h | 776.5, 554.3 |
| La | 100% | [$^{139}$La (n, $\gamma$)$^{140}$La] | 40.3 h | 818.5 |
| Sm | 28.3% | [$^{152}$Sm (n, $\gamma$)$^{153}$Sm] | 46.8 h | 103.2 |
| Sc | 100% | [$^{45}$Sc (n, γ) $^{46}$Sc] | 3.41d | 889, 1120 |
| Yb | 3.7%,6% | [$^{176}$Yb (n,2n)$^{175}$Yb +γ] | 4.2d | 282.6, 396 |
| U | 12%, 18% |  | 2.4 d | 103.7,277.6 |
| Ti | 95% | [$^{50}$ Ti (n,γ) $^{51}$Ti] | 5.76 m. | 320 |
| Mg | 100% | [$^{26}$Mg (n,γ)$^{27}$Mg] | 9.45 m | 1014.4 |
| V | 100% | [$^{51}$V(n,γ)$^{52}$V] | 3.755 m | 1434.2 |
| Al | 100% | [$^{27}$Al(n,γ)$^{28}$Al] | 2.246 m | 1778.8 |
| Ca | 91.7% | [$^{48}$Ca(n,γ)$^{49}$Ca] | 8.72 m | 3084.4 |
| Na | 100% | [$^{23}$Na(n, γ)$^{24}$Na] | 15.02 h | 1368.6 |
| K | 17.9% | [$^{41}$K(n,γ)$^{42}$K] | 12.36 h | 1524.7 |
| Mn | 99% | [$^{55}$Mn(n, γ)$^{56}$Mn] | 2.582 h | 846.6 |

## 3. Results and Discussions

The measured concentrations of Al, Ca, Mg, V, Ti, Na, Mn, K, As, Br, La, Sm, Sc, U and Yb in the soil samples with the absolute standard deviations and the World median values of the elements estimated by Bowen [23] are presented in Table 4. In order to evaluate the accuracy of this method, three IAEA certified reference materials, (CRM) IAEA-soil-7, NBS-1633b Coal fly ash and IAEA-SL-1 were analyzed with the INAA-technique. The measured concentrations of different elements in the IAEA certified reference materials (NBS-1633b Coal fly ash, soil-7 and SL-1) are consistent with the certified values, with the exception of Na, Lu and Yb in IAEA-CRM-SL-1 which significantly deviated (±24.82%) from the certified values (Table 3). In Table 5, the mean concentrations, medians and the ranges of concentrations in the reactor surrounding soils were compared with that of the world soils. In almost all the samples, the lowest concentration is found except for Br, Yb and U which are above the corresponding range of the world. However, the maximum values of all the elements except Al, Na and Yb are found to be below the given world range. The mean value of Sc, K, U and Sm are higher than that of the world. In most cases the median values of the present experiment show close agreement with that of the world median [23]. On the other hand, median values of measured elements except K, U, Sm, Sc and Na are below to the World median [23]. The concentrations of major elements (major nutrients) such as Na and K are in the range of 0.281-2.101%. On the regional scale, these soils are relatively rich in uranium and several other heavy metals such as potassium, vanadium and ytterbium.

According to Mattigot and Page, 1983 [27], concentrations of heavy metals are relatively higher in the nearby areas of reactor plants due to parent materials or secondary dispersion constitutes which can naturally cause the metal pollution. According to GLC (Great London Council) guidelines in Table 6, the measured concentration values are grouped into the following categories: uncontaminated, slightly contaminated, contaminated, heavily contaminated and unusually heavily contaminated. The pollution analysis of the soils of the present study revealed that Category II are slightly contaminated by manganese, Category I are not contaminated by arsenic and Category I and II are uncontaminated and slightly contaminated by vanadium (V). The highest concentrations of metals shown in Table 4 were observed in the samples of RFS 1, 7, 9, 10, 11, 13 and 14 ( see Table1 for soil samples position).

The highest values of arsenic are observed in the samples RFS 6, 7 and 10, collected from areas at the north side of cooling tower, far from the decay tank and the west side of the underground tank, respectively. The lowest and highest concentrations of As are 1.58 and 7.13 mg $kg^{-1}$ respectively. The observed concentrations of As lie within the limiting values of world natural soil value (Mean 5 mg $kg^{-1}$) which is in agreement with the report by [28]. Furthermore, the concentration of As observed in the study area is comparable with the soil of coal-fired power plant (7.85±0.25 mg $kg^{-1}$) of South Carolina [29], different sites of Florida (0.02-7.01 mg $kg^{-1}$) [30], pre and post flooded area of New Orleans (3.69-23.36 mg $kg^{-1}$ ) [31] of the United States, King's Bridge Park sediments (5.07 mg/kg) of the Niagara river watershed at the U.S.- Canada border site [32]. However, the arsenic concentration is much lower than the value observed in the arsenic affected Singair area (44-60 mg $kg^{-1}$) in Bangladesh [33], Grand Duchy of Luxembourg (9-278 mg $kg^{-1}$) [34], Atlas steel mills (134 mg $kg^{-1}$ in oiled sample, 117 mg $kg^{-1}$ in de-oiled sample) of the city of welland, Ontario, Canada [32].

Vanadium is toxic to humans and other animals [35]. The greater part of the region does not seem to be polluted with Vanadium, except for the samples RFS 10, 12 and 14 collected from the west of the underground tank, the west side of the cooling tower pipe and the west side of reactor building, where V concentrations are higher than that of other areas. The concentration of V varies between 49.745-120.680 mg $kg^{-1}$, which is very much lower than the value observed (565 mg $kg^{-1}$) in the study conducted by [34]. However, the concentration of V is consistent with the Pre-Katrina and post-Katrina V concentrations (0.7-82.47 mg $kg^{-1}$) in soil in the area between the 17th Street Canal and Industrial Canal of Orleans Parish of United States [36, 37].

It is well known that Manganese is a very important metallic redox catalyst that governs the behavior of most trace metals in soils [38]. The concentrations of Mn in the samples RFS 1, 7 and 8 collected from the vicinity of the decay tank, far from the decay tank and the water treatment plant are higher than that of the other samples. The lowest and highest concentrations of Mn in the present study are 196.06 and 921 mg $kg^{-1}$, respectively whereas the range is 0.36-339.36 mg/kg in the soil of suburban

**Table 3:** Comparison of the measured elemental concentrations (in mg/kg) with the certified values

| Certified Reference Materials | Element | This study | Certified values | RSD (%) |
|---|---|---|---|---|
| IAEA-SL-1 | Ti | 4642.3±733.4 | 5170±430 | +10.2078 |
| | V | 143.23±9.309 | 170±15 | +15.7475 |
| | Na | 1291.45±55.6 | 1700±100 | +24.030 |
| | K | 12007±2425.4 | 14500±2100 | +17.192 |
| | Mn | 3307±62.833 | 3460±160 | +4.4218 |
| | As | 30.587±3.1 | 27.6±2.9 | +10.82 |
| | La | 51.141±3.5 | 52.6±3.1 | -2.77 |
| | Lu | 0.673±0.11 | 0.54±0.13 | +24.63 |
| | Sm | 8.845±0.48 | 9.25±0.51 | -4.37 |
| | Yb | 4.269±0.43 | 3.42±0.65 | +24.82 |
| IAEA-soil-7 | Na | 1921.7±42.32 | 2400±100 | +19.921 |
| | K | 11116±800.35 | 12100±800 | +8.1287 |
| | Mn | 639.42±44.75 | 631±27 | -1.33367 |

areas of Varanasi, India [39], 26.9-5883 mg kg$^{-1}$ in Medvednica Nature Park, Croatia [40], 1.74-236 mg kg$^{-1}$ in different sites of Florida [30], 7.39-36.9 mg kg$^{-1}$ in the Al-Taif district of Saudi Arabia [41], 278.50-649.80 mg kg$^{-1}$ in Hangzhou, China [42]. In present study, the manganese concentration is much higher than the arsenic affected Singair area (22-80 mg kg$^{-1}$) in Bangladesh [33].

The observed range of samarium (Sm) in the soils of the area is 2.807-7.667 mg kg$^{-1}$, which is consistent with the values of world soils (2.3-7.7 mg kg$^{-1}$) [23, 43], sediments of King's Bridge Park (4.03 mg kg$^{-1}$) of the Niagara river watershed at the U.S.-Canada border site. However, the concentration of samarium (Sm) is greater than the value observed in the Atlas steel mills (0.48 mg kg$^{-1}$ in oiled sample, 0.58 mg kg$^{-1}$ in de-oiled sample) of the city of welland, Canada [32]. Although the median value of Sm (6.342 mg kg$^{-1}$) exceeds the world median (4.5 mg kg$^{-1}$) [23], the areas are not contaminated by Sm. The highest values are found in the samples RFS 7 and 6 collected from the vicinity of the decay tank and the north side of the cooling tower, respectively.

**Table 4:** Concentrations of various elements in soils (in mg/kg, unless otherwise stated)

| | Ti | Mg | V | Al | Ca |
|---|---|---|---|---|---|
| World median [a] | 5000 | | 90 | | 15000 |
| RFS-1 | 3480.9±250.624 | 1967.2±106.228 | 63.786± 1.9773 | 47463± 237.315 | 12133± 1807.81 |
| RFS-2 | 3049.5±195.168 | 1482.8±105.278 | 50.81± 1.67673 | 39517± 158.068 | ND |
| RFS-3 | 2820.7±172.062 | 1554.6±79.2846 | 54.527± 1.6358 | 39003± 195.015 | 9072.7± 1705.6 |
| RFS-4 | 3440.9±230.200 | 2002.85±94.791 | 69.493± 2.0425 | 51266± 288.094 | 11430.35±1480.1 |
| RFS-5 | 4061.1±288.338 | 2451.1±110.299 | 84.459± 2.4493 | 63529± 381.174 | 13788± 1254.70 |
| RFS-6 | 3772.7±279.179 | 1962.8±121.693 | 61.722± 2.2837 | 46866± 187.464 | ND |
| RFS-7 | 2717.8±236.448 | 1718.7±96.2472 | 49.745± 1.1441 | 38750± 193.75 | ND |
| RFS-8 | 3910±281.224 | 2070±116.1255 | 71.057±2.0425 | 52060±381.174 | 8680±1707.81 |
| RFS-9 | 5260±320.052 | 3040±201.2583 | 89.808±1.9773 | 75330±288.094 | 10710±1827.31 |
| RFS-10 | 5100±334.047 | 2970±111.0132 | 120.680±2.4493 | 78890±195.015 | 8190±807.21 |
| RFS-11 | 5640±343.208 | 2980±107.0245 | 101.159±1.6767 | 75530±193.75 | 9350±1209.82 |
| RFS-12 | 5340±298.034 | 3220±98.01254 | 104.827±2.2837 | 81090±237.315 | 10860±1877.51 |
| RFS-13 | 6790±361.029 | 2740±119.1254 | 86.681±1.9773 | 75060±195.015 | 12510±1254.70 |
| RFS-14 | 6700±362.025 | 3310±145.0125 | 105.319±2.0425 | 93930±158.068 | 13900±1802.81 |

[a] Values from Ref.[23], N.D. Not Detected

**Table 4:** Concentrations of various elements in soils (in mg/kg) (*Continued*)

| | Na | K | Mn | As | Br | La |
|---|---|---|---|---|---|---|
| World median [a] | 5000 | 14000 | 1000 | 6 | 10 | 40 |
| RFS-1 | ND | 2805.7±530.277 | 920.99±4.60495 | 1.5850±0.4 | 2.713±0.89 | 16.533±5.21 |
| RFS-2 | ND | 10058±382.204 | 328.81±4.27453 | ND | ND | ND |
| RFS-3 | 5213.875± 65.131 | 12871±592.066 | 503.15±5.0315 | 3.3440±0.7 | 5.826±1.25 | 30.370±12.22 |
| RFS-4 | 3772.325±68.740 | 17763±515.127 | 507.88±15.7442 | 5.0550±1.1 | 5.749±1.63 | 35.981±5.212 |
| RFS-5 | 6428.5±87.61265 | 19933±657.789 | 609.06±21.3171 | 4.1050±0.2 | 1.707±0.544 | 35.657±11.21 |
| RFS-6 | 5754.15±75.849 | 18093±470.418 | 612.42±18.9850 | 6.0640±2.2 | 2.114±0.99 | 43.543±2.29 |
| RFS-7 | 5792.175±92.196 | 18407±552.21 | 800.55±24.0165 | 6.2680±1.9 | 3.228±0.08 | 50.801±10.29 |
| RFS-8 | 6054.7±125.5036 | 19184±633.072 | 777.03±25.6419 | 4.1640±1.2 | 3.138±1.23 | 42.316±12.31 |
| RFS-9 | 7669.625±76.922 | 21012±693.396 | 546.18±18.0239 | 4.6410±1.6 | 4.886±1.10 | 36.025±6.21 |
| RFS-10 | 5287.675±84.630 | 19737±532.899 | ND | 7.1330±2.1 | 3.143±1.47 | 46.374±11.91 |
| RFS-11 | 6712.65±155.077 | 18398±754.318 | 646.23±32.3115 | 5.0870±1.1 | 5.406±1.23 | 35.376±7.25 |
| RFS-12 | 6581.725±88.395 | 20372±855.624 | 672.46±38.3302 | 4.3840±1.6 | 2.813±0.54 | 37.849±10.21 |
| RFS-13 | 3988.275±74.267 | 16396±705.028 | 698.22±32.1181 | 4.1920±0.9 | 7.015±2.32 | 43.757±10.33 |
| RFS-14 | 4632.65±41.693 | 16093±675.906 | 196.06±12.3517 | ND | ND | ND |

[a] Values from Ref.[23], N.D. Not Detected

**Table 4:** Concentrations of various elements in soils (in mg/kg) (*Continued*)

| | Sm | Sc | Yb | U |
|---|---|---|---|---|
| World median [a] | 4.5 | 7 | | 2 |
| RFS-1 | 2.807±0.245 | 8.234±2.782 | 2.328±0.4 | 1.9±0.3428 |
| RFS-2 | ND | 9.169±3.214 | 0.159±0.06 | 0.016±0.0098 |
| RFS-3 | 5.016±1.042 | 6.805±2.451 | 2.721±0.7 | 0.953±0.246 |
| RFS-4 | 5.931±2.275 | 10.140±0.789 | 2.667±1.1 | 2.743±0.486 |
| RFS-5 | 5.637±1.245 | 10.545±1.245 | 5.178±0.9 | 5.371±2.1031 |
| RFS-6 | 7.022±1.127 | 12.501±0.847 | 2.007±0.6 | 2.331±0.5428 |
| RFS-7 | 7.667±2.242 | 12.795±3.542 | 4.036±0.2 | 4.705±1.785 |
| RFS-8 | 6.730±1.225 | 11.481±2.461 | 5.271±1.2 | 6.170±2.432 |
| RFS-9 | 6.003±2.149 | 12.977±1.125 | 2.714±0.5 | 3.189±0.285 |
| RFS-10 | 6.884±1.845 | 12.561±0.987 | 1.987±0.8 | 2.345±0.5452 |
| RFS-11 | 6.148±1.245 | 10.034±1.52 | 5.365±0.56 | 6.356±2.036 |
| RFS-12 | 6.536±2.234 | 11.354±2.14 | 4.403±1.2 | 5.237±1.932 |
| RFS-13 | 6.935±2.115 | 8.893±3.21 | 2.606±1.1 | 3.113±0.985 |
| RFS-14 | ND | 9.925±3.25 | 0.112±0.03 | 0.013±0.009 |

[a] Values from Ref.[23], N.D. Not Detected

The mean and median values (10.53 and 10.34 mg kg$^{-1}$)of scandium in the study is exceed over the mean (7 mg kg$^{-1}$) and median(7 mg kg$^{-1}$) value of the world soil, the soil of King's Bridge Park (5.5 mg kg$^{-1}$) and in the sediments of Atlas steel mills (0.31 mg kg$^{-1}$ in oiled sample, 0.54 mg kg$^{-1}$ in de-oiled sample) of the city of welland, Canada [32], although the observed concentrations of Sc (6.805 to 12.977 mg kg$^{-1}$) lie within the limiting value of world natural soil (0.5-45 mg kg$^{-1}$) [23,43]. The highest value of Sc was found in samples RFS 6, 9, and 10 collected from the vicinity of the cooling tower, the southwest boundary wall of reactor and the underground tank, respectively. Severe pollution is observed for ytterbium (Yb) in the sample RFS 5, 8 and 11collected from the vicinity of the over- head tank, water treatment plant and garden beside the lemon tree. The greater part of the region is not however appreciably polluted. The highest value of Yb observed in samples from the garden beside the lemon tree is nearly double the world mean value for natural soil [23]. The lowest and highest concentrations of Yb are 0.112 and 5.365 mg kg$^{-1}$ respectively. The range of Yb for this region is above the range of world soil(1.8 - 3.4 mg kg$^{-1}$) and the mean value (2.96 mg kg$^{-1}$) of the study area exceeded the value found in the soil of King's bridge park (1.87 mg kg$^{-1}$) and Atlas steel mills(<1 mg kg$^{-1}$) of Canada [32].

The concentrations of Mg, Ca and Br are relatively low in the study area. The obtained means and medians for these elements are below the means and medians of world soils. The maximum values of Mg are found in samples RFS 9, 12, 14 collected from the south west of reactor boundary, west side of the cooling tower pipe and the west side of reactor building respectively. The higher values are found in samples RFS 5, 10, 14 for Ca and samples RFS 3, 11, 13 for Br where the locations are mentioned in Table1. The lowest and highest concentration varies between 0.1483 and 0.331% for Mg, 0.82 and 1.38% for Ca, whereas this limit observed very lower in the soil of Al Taif district of Saudi Arabia, 0.0115-0.0118% for Mg and 0.0547-0.0889% for Ca [41]. The lowest and highest concentrations for

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Br are 1.707 and 5.826 mg kg$^{-1}$. The measured Br of this area (3.97 mg kg$^{-1}$) is considerably lower than the soil of the King's bridge park (10.37 mg kg$^{-1}$) of Canada [32]. The soil of this area is not contaminated by Mg, Ca and Br (Table 4,5,6).

**Table 5:** Range, mean and median value for reactor surrounding soils and world soils. All values are in (mg/kg) unless otherwise specified

| Element | Soil Surround the TRIGA MARK II Research Reactor and nearby nuclear installations | | | World | | |
|---|---|---|---|---|---|---|
| | Range | Mean | Median | Range | Mean[c] | Median[a] |
| Al (%) | 3.87-9.39 | 6.13 | 5.77 | 1-6.4[d] | 7.13 | NA |
| As | 1.58-7.13 | 4.80 | 4.84 | 0.1-40[e] | 5 | 6 |
| Br | 1.70-5.82 | 3.97 | 3.18 | 5-40[b] | 5 | 10 |
| Ca (%) | 0.81-1.37 | 0.97 | 1.07 | NA-NA | 1.37 | 1.5 |
| La | 16.53-50.80 | 37.88 | 36.93 | 13.9 - 56.3[b] | 40 | 40 |
| Mg (%) | 0.14-0.33 | 0.23 | 0.22 | NA-NA | 0.63 | NA |
| Mn | 196.06-920.99 | 601.46 | 612.42 | 100-4000[c] | 850 | 1000 |
| Na (%) | 0.37-0.76 | 0.56 | 0.57 | 0.07-0.74[d] | 0.63 | 0.50 |
| Sc | 6.80-12.97 | 10.53 | 10.34 | 0.5-45[b] | 7 | 7 |
| Sm | 2.80-7.66 | 6.10 | 6.34 | 2.3-7.7[b] | 4.5[a] | 4.5 |
| Ti (%) | 0.27-0.67 | 0.44 | 0.39 | 0.1-0.9[b] | 0.46 | 0.50 |
| U | 0.01-6.35 | 3.17 | 2.98 | 0.79- 11[b] | 1 | 2 |
| V | 49.74-120.68 | 79.57 | 77.75 | 3-500[a] | 100 | 90 |
| Yb | 0.11-5.36 | 2.96 | 2.69 | 1.8 - 3.4[b] | 3[a] | NA |
| K(%) | 0.28-2.10 | 1.65 | 1.82 | NA | 1.40[b] | 1.40 |

[a]Ref.[23], [b]Ref.[43], [c]Ref.[1], [d] Ref.[25]., [e] Ref.[28], NA : No available data.

The lowest and highest concentrations of Ti are 0.272% and 0.68 % which is within the limiting values of world soil (0.1-0.9%). Similar trend is observed for La in the present study. The concentration range for La in the present study is 16.53-50.80 mg kg$^{-1}$ which is also comparable with world soil (13.9-56.3 mg kg$^{-1}$) in Table 5. In addition the amount of La observed in the King's bridge park soil (15.67 mg kg$^{-1}$) [32] is comparable to the lowest limit of the present study. The highest values of Ti are observed in samples of RFS 13 and 14 from the north-east corner of the reactor building and the west side of the reactor building, respectively. The highest values of La are found in samples RFS 7 and 10 collected from the vicinity of the decay tank and the underground tank. The region seems to be not contaminated by Ti and La (Table 4).

**Table 6:** The classification of soils based on G.L.C guidelines (elements values in mg/kg unless otherwise specified)

| Element | Range in reactor surrounding soils | Mean in reactor surrounding soils | Average soil composition[a] | G.L.C. guidelines [b] | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | I | II | III | IV | V[c] |
| Mn | 196.06-921.00 | 601.50 | 320 | 500 | 1000 | 2000 | 1% | >1% |
| As | 1.59-7.13 | 4.80 | 7.5 | 30 | 50 | 100 | 500 | >500 |
| V | 49.75-120.70 | 79.57 | 57 | 200 | 200 | 500 | 2500 | >2500 |

[a] Average soil composition from Ref.[26], [b]GLC (Great London Council), [c] Ref.[46], I=Typical values for uncontaminated soils, II=Slight contamination, III=Contaminated, IV=Heavy contamination, V =Unusually heavy contamination

Heavy pollution by K is observed in the soil surrounding the reactor, where its median value (1.8%) exceeds the median (1.4%) of world soil [23]. All samples except the sample of RFS 1, 2 and 3 have a higher value of K (Table 4). The observed limiting value for K of this area 0.28-2.1% is remarkably greater than the corresponding values measured in Saudi Arabia 0.03-0.04% [41]. The vicinity of the over head tank, south west of reactor boundary and the west side of the cooling tower pipe are polluted by K. This area is totally not contaminated by Na as it's limiting values (0.37-0.76%) are comparable with the range of world soils (0.07-0.74%) [23] and the soil of Saudi Arabia (0.01-0.24%) [41]. The few sites of the study area are slightly contaminated by Al. The concentrations obtained for Al (3.8-9.3%) are comparable with the world soil (1.0-6.4%) with the exception of RFS 12 (8.1%) and RFS 14 (9.3%). In addition, a significant difference is shown for the value of Al (0.01-1.2%) in Finland [44].

The maximum value found for Uranium is nearly three times higher than the value for natural soil estimated by [23]. The lowest and highest concentration varies from 0.01 to 6.35 mg kg$^{-1}$ (Table 5), which is remarkably higher than the background level observed in Belgium (1 mg kg$^{-1}$) [45], King's bridge park area (1.3 mg kg$^{-1}$) and the Atlas Steels (0.65-0.81 mg kg$^{-1}$) of Canada [32]. In addition the sediments of the Quirke (24.3±12.2 mg kg$^{-1}$), McCarthy (44.6±9.9 mg kg$^{-1}$), McCabe (38.6 mg kg$^{-1}$ ), and Elliot (133±46.1 mg kg$^{-1}$) lakes of the Ontario in Canada showed significant difference with the uranium observed in the study area as well as the control lake Semiwite (4.1 mg kg$^{-1}$) [24]. The higher values of Uranium are observed in the samples of RFS 5, 8, 11 collected from the vicinity of the overhead tank, water treatment plant and the vegetable garden. The chief sources are primarily nuclear activities of the coolant tower, underground tank and overhead tank beside the vegetable garden. It seems that the larger parts of the region are significantly polluted by Uranium.

## 4. Conclusion

The study clearly showed that in certain location, the soil samples have higher values of concentration( mean, median and range) compared to that of the world which indicating that the soils of these sites have been contaminated by the nuclear activities of the reactor and other nearby installations. The measured results show that surface soils in this region are polluted to a certain extent with several metals, for example K, U, Sm, Sc, Al, Na, and Yb. The heavy metal (U and Yb) pollution is particularly pronounced in areas near the overhead tank, water treatment plant and the vegetable garden, K everywhere. The contamination level is relatively high for Mn in decay tank and water treatment plant area and V in the vicinity of the underground tank, the cooling tower and the west side of reactor building area. However, there are no available scientific studies that indicate that there are harmful effects of this pollution on the human population or other biological species. Still, large amounts of vegetables and fruits are harvested in the gardens and farmlands beside the TRIGA reactor and are regularly taken by the people of the surrounding area. It is therefore, necessary to determine the levels of heavy metals and other trace elements in soils, and uptake by vegetations and other biological species and take appropriate steps to protect the people from the health hazard of the excessive levels of metals. The degree of soil pollution around the TRIGA reactor poses a risk to human health, because it may pollute the fresh water sources that supply drinking water to the institute and the nearby areas. Further studies should be carried out to understand the full-phase level of contamination in the water and vegetation of the nearby areas of the reactor plant.

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