LUPINE PUBLISHERS
An archive of organic and inorganic chemical sciences
DOI: 10.32474/AOICS.2020.04.000197
ISSN: 2637-4609

Research Article

Health Risk Assessment Levels of Selected Heavy Metals on Solanum Nigrum, Soils and Water Collected Along River Moiben, Uasin-Gishu County, Kenya

Teresa Akenga[1], Emmy Kerich[2]* Ayabei Kiplagat[3] and Vincent Sudoi[2]

[1]*Office of the Vice Chancellor, University of Eldoret, Kenya*

[2]*Directorate of Research and Innovation, University of Eldoret, Kenya*

[3]*Departments of Chemistry, University of Eldoret, Kenya*

***Corresponding author:** Emmy Kerich, Directorate of Research and Innovation, University of Eldoret, Kenya

Received: September 10, 2020 **Published:** September 24, 2020

Abstract

The study investigated heavy metals' levels in soil, Solanum nigrum and irrigation water from intense Moiben irrigated farms located in Meibeki Karuna, Uasin Gishu County. Purposive sampling was used to identify farms where there is an intense irrigated agricultural practice. Irrigation water, soil, and Solanum nigrum were randomly sampled, digested, and analyzed for heavy metals with the use of ICP-OES. SPSS Version 21 was used to analyse data statistically and means, Pearson Correlation coefficient, One-Way ANOVA and transfer factor were calculated. The heavy metals were compared from different sites. The soil mean concentration for Zn, Fe, Pb, Mg, Cr, Cu and Cd ranged between 46.90-0.18, 352–181, 10.75-9.91, 1.52-1.34, 10.14 - 9.67, 12.85 - 12.03 and 0.72 - 0.53 mg/kg correspondingly. Irrigation mean water concentration for Zn, Fe, Pb, Mg, Cr, Cu and Cd ranged between 0.071-0.054, 0.81-0.669, 0.05-0.00, 0.05 – 0.045, 0.055-0.015, 0.27-0.197 and 0.005-0.001 mg/l respectively. Solanum nigrum mean concentration for Zn, Fe, Pb, Mg, Cr, Cu and Cd ranged between 0.001209 - 0.000592, 0.004003 - 0.002627, 0.000329 - 0.000079, 0.000837–0.000565, 0.000104-0.000089, 0.000292-0.000204 and 0.000329-0.000004 mg/kg, respectively. One-way ANOVA indicated spatial significantly different in soil, water, and Solanum nigrum. The metal levels in soil were below WHO/FAO standards except Fe and Pb in irrigation water. Levels of Fe as well as Pb in Solanum nigrum were within WHO/FAO standards. Solanum nigrum are safe for consumption nevertheless continuous surveillance of heavy metals in soil, vegetables and irrigation water is vital preventive strategy to avoid accrual of heavy metals in the food chain.

Keywords: Heavy metals; solanum nigrum; soils; water

Introduction

Vegetables especially leafy parts are wealthy sources of vitamins, minerals, fibers and constitute to the vital day to day diets requirements in numerous families worldwide [1-5]. It can be consumed raw, cooked, dried and they are usually used in soups and sauces as an accompaniment for the main staples. Recently, many people have increase intake of vegetables as a way of eating healthy. According to Jarup and Singh [6,7] application of phosphatic farm inputs contribute to elevated heavy metals levels in the soil. Heavy metals are toxic elements that are non-biodegradable. These elements include Lead (Pb), mercury (Hg), Zinc (Zn), Chromium (Cr), Cadmium (Cd) and Copper (Cu) which accumulate in elevated levels in stem, leaf, root, and fruits of plants. Several studies have recorded elevated concentrations of heavy metals in leafy vegetables [8]. In Kenya, a study done by Omambia & Simiyu and Inoti [9,10] on heavy metal (Copper, Zinc, Cadmium and lead) pollution of indigenous green vegetables in Eldoret and Thika Town revealed that the levels lead in vegetable species S. nigrum, C. gynandra and A. blitum which was above the WHO standards. Also, the take up of leafy vegetables is noted to rise in the urban residents Othman [11] various researches revealed heavy metals for instance lead, Copper, cadmium and Chromium among others to be major pollutant of greens in town farming [12,13]. Heavy metals for example Zn, Fe and Cu perform a very important role in plant development but metals like lead, Cadmium, Chromium, and mercury are extremely poisonous and hazardous environmental toxicants [14,15]. It has been noted in a number of studies that vegetables like kales can accumulate heavy metals from irrigation water polluted with heavy metals [16,17]. The ingestion of leafy vegetables is the major path of heavy metal noxiousness to humans [18]. Tomatoes and leafy vegetables are grown in soil that are fertile and uptake of heavy metals can result to their accrual. Toxic heavy metals are known to contaminate agricultural soils and water used for irrigation globally.

The intake of heavy metal polluted crops may result in a range of lasting enduring diseases such as chronic exposure of Cadmium can affect respiratory system and cause cancer Duruibe, Bernhoft [19,20], whereas acute exposure of Cadmium can result to renal effects [21]. The chronic buildup of heavy metals in human organs leads to liver and kidney problems as well as bone diseases, joints problems, heart, and cancer [6,22&23]. Black night shade are the leading vegetable items consumed widely in Eastern Africa region and in our study area, inhabitants of UGC and HBC eat sukuma wiki and tomatoes daily therefore, residents could be exposed to heavy metals contaminants. Shahinasi and Kashuta [24] noted that one of the issues faced by agriculturalist is irrigation water quality which is affected by environmental issues. Agricultural practices with agrochemicals result to chemical pollution of ground water, lakes, rivers and streams and gradually over time collective effects can cause reduction of water quality [25]. Sources of water contamination linked with agricultural systems include pesticides, insecticides, herbicides, phosphates, chemical fertilizers, pathogens, animal dung/ manure, heavy metals, sediment load among others. These pollutants cause possible ecological disparities as well as direct health hazards to local public depending on products from agriculture and the water [26]. Solanum nigrum is universally referred to as "Black night shade" and locally referred to as managu or mnavu, an indigenous type belongs to Solanaceae family [27]. The crop grows up to 60 cm tall and is often found growing as a weed on fertile soils with ovate leaves [28]. It has been found to contain the substances, such as total alkaloid, steroidal saponins, steroid alkaloid, and glycoprotein, exhibiting anti-tumor [29]. It shows medicinal properties like anti-microbial, antioxidant, cytotoxic properties, anti-ulcerogenic, and hepato-protective activity [30]. In Kenya, Solanum nigrum is largely utilized as a vegetable and in Moiben region; the crop is grown in large scale and even supplied to different counties during dry season. Residents from Karuna Meibeki ward Moiben sub-county, Uasin Gishu County practice intense agricultural activities such large maize farming during raining season and tomatoes, kales, and black night shade irrigation during dry season where they source their water from Moiben River. Moiben River is constantly polluted from agrochemicals which are continuously applied to ensure constant and sufficient food production consequently; monitoring water quality for River Moibein is paramount in ensuring production of safe foodstuff from this region. Therefore, the current research assesses the levels of heavy metals (Zinc, Copper, Cobalt, lead and Cadmium) in growing soil, irrigation water and Solanum nigrum a vegetable commonly produces in bulky quantities. The heavy metals concentration found was compared with WHO/FAO standards.

Methodology

Study Area

The research area is located at Karuna-Meibeki ward in Moiben Sub-county of Uasin Gishu County. The County lies between longitude 340 50' east and 35 0 37' west and latitude 00 03' south and 00 55' north and covers a land area of 3,345 square kilometers. The County receives a standard yearly rainfall is between 900 to 1,200 millimeters per year. Based on the Kenya Population and Housing Census (KPHC) of 2009, the overall population of Uasin Gishu County was 894,179 in 2009 [31]. Approximately 64% of the County's population is concentrated in the rural areas whereas 36% lives in urban areas. About 90% of the total county area while forestland (both indigenous and plantations) covers 29,802 ha representing 8.9% of the total county area. Irrigation exists along rivers such as River Sosiani and River Moiben where high value horticultural crops are grown. In Uasin Gishu County, 25% of households are involved in harvesting water to improve their adaptive capacity to climate change [32]. The major crops in the county are variety vegetables, tomatoes, maize, beans, wheat, and sunflower among others. Livestock keeping include animals such as dairy and beef cattle farming, poultry, sheep, goats, pigs, beekeeping, rabbit farming and fish farming [33]. Moiben region is one of the Sub- Counties in Uasin Gishu County and it is positioned in the North East of Eldoret Town. a population of roughly 157,032 people and an area of 777.1 square kilometers. The main Economic activity is agriculture; the sub county has 5 wards namely, Sergoit, Tembelio, Karuna-Meibeki, Kimumu and Moiben.

Experimental design

Soil and Solanum nigrum (black nightshade) Sampling Design

The study was conducted in Moiben Sub-County, Karuna, Meibeki ward was purposely selected where there is intense irrigation along Moiben River. Three farms were purposely selected where there was small, medium and large-scale intense irrigation. Three samples of Solanum nigrum samples were taken using simple random sampling design and 3 samples of soil were hand-picked from the same area where Solanum nigrum were sampled.

Soil sampling collection and preparation

Soil samples were gathered from the three sites of the study site and a line transect was used to identify sites where samples were collected. Amalgamated soil samples were gathered from the selected plots of both Solanum nigrum over two different depths (0-10 and 11-20 cm) in each site. The soil auger was used to collect the approximately 0.5g of soil samples and stored in dry well labeled khaki bags. The samples were collected in triplicate and a total of 18 samples were collected during the research. The collected samples were transported to University of Eldoret biotechnology laboratory where it was dried using an oven at around 90 degrees Celsius and grinded to fine powered before packaging in a well labeled khaki bags. The finally the samples were taken to KALRO Kericho for digestion and analysis using inductive couple plasma.

Solanum nigrum sample collection and preparation

Simple random sampling was employed to choose the leaves at maturity stage and at the pick of harvest. Then 200g of the samples collected were washed to remove impurities. The samples were then dried using an electric oven at 90°C and then sliced into smaller sizes and dried using an oven at 700c for the whole day and night. Nine samples were collected and roughly ten grams of dried samples were then grounded to form fine powder then packed in a well labeled clean polythene bag awaiting digestion [11] .

Water sampling and preparation

Irrigation water which was used for irrigated in the selected three selected farms was sampled into 500ml clean glass vials using purposive sampling. The vials were labeled and a single drop of HNO_3 (65%) was put in the vials to make their pH < 2 to avoid precipitation of metals and stored at 5ºC awaiting transportation to University of Eldoret labs and finally KALRO Kericho for samples digestion. Nine samples were collected during the study.

Cleaning apparatus

Apparatus including plastic containers, polyethylene bags and glassware were cleaned using tap water and detergent after which they were rinsed with deionized water. The apparatus was then soaked in roughly 10% (v/v) nitric acid for twenty-four hours, then they were rinsed many times using deionized water. This apparatus was then dried inside an oven and reserved in dust-free place for more use later.

Solanum nigrum samples digestion

Digital analytical balance having ± 0.0001 g accuracy was employed to evaluate 3 g of the ground samples. Reagents and chemicals applied in the analysis was all of analytical grade. Seventy percent of concentrated $HClO_4$ and 4 mL of newly made 2:2 (v/v) concoction of 70% of concentrated HNO3 was added to the plant samples. 5 ml of conc. HNO_3 and 70% of conc. HClO4 was then added to the sample. The combinations were then processed on block digester at 2700C for one hundred and fifty minutes. The processed solutions were permitted to cool for thirty minutes. Afterward, the digested sample was then solubilized using 5 ml of aqua regia. The solution was warmed gradually to liquify any residues. The solution was sieved with the use of an acid washed Whatman filter paper No forty-two into a 50 mL volumetric flask. Analysis for heavy metals was then done on the digested samples with use of ICP-MS [11].

Water digestion

The samples were shaken in their vials, and then a 100ml was measured and transferred to a conical flask and digested on a burning plate using a mixture of conc HNO_3/HCl until a light coloured clear solution was produced. 2 ml of conc HCL was heated a little to liquify any residue that was remaining. Few drops of hydrogen peroxide were then added to guarantee full digestion. The mixture was then diluted using distilled water to the mark and were analyzed for heavy metals by the use of ICP-MS (Cobbina et al. 2015; Mazira 2012; Du Plessis 2015).

Samples Digestion

2 g of each soil sample bench dried for 5 days in the laboratory then crushed in a mortar with pestle to fineness. The ground soil sample was filtered through a ten-mesh (2 mm) filter and moisture dehydrated in the oven separately at 1050C until persistent weight was attained. The wet digestion was done by reflux digestion of 1 g sub-sample with 10 ml of concentrated HCl/HNO_3 in 1:4 ratios. A few boiling chips were added, and temperature regulated at 1000C for 3 hours by using Aluminium digestion block. The mixture cooled and acid washed with 12.5% v/v HNO_3 then filtered [34]. Inductive couple plasma-Mass spectrometer was employed to analyze the samples using the standard procedure stipulated by the author in (Melaku et al. 2005).

Statistical Analysis

Data was descriptively analysed with the use of SPSS Version 21 and One-Way Analysis of Variance (ANOVA) were employed to compare heavy metals levels from diverse sites. Pearson Correlation coefficient was used to determine if there is an association between heavy metals soil and Solanum nigrum and water and Solanum nigrum. Transfer factor was also calculated to estimate the potential capability of the plants to spread metals from soil to palatable tissues.

Results and Discussion

Heavy metals concentration in the soil samples

The average levels of heavy metals (zinc, lead, iron, chromium, manganese, copper along with cadmium) in soil are displayed in Table 1 below. Concentrations of the metals analysed varied in the soil samples. High Zn concentration (46.90 ± 8.48 mg/kg) was recorded in site 1 and low concentration being of Cd (0.53 ± 0.09 mg/kg) was also reported site 1. The Zinc concentrations ranged between 46.90 ± 8.48 mg/kg and 0.18 mg/kg. These levels are beneath the set limits of 100 mg/kg by WHO/FAO [35]. The concentrations of this study were similar to results of those of

Kerich (2018) who recorded 61.35 to 72.83 mg/kg of Zn found in Eldoret Dumpsite. Njagi (2013) reported much elevated zinc levels of 128.11 mg/kg in soil. Raju & Liu [36,37] and Sayyed and Sayyad [38] reported 28.24 mg/kg, 81.10 mg/kg and 11.56 mg/kg of Zn in agricultural soil in India, Beijing and Iran respectively. Iron concentrations ranged between 352 ± 9.82 mg/kg and 181 ± 25.59 mg/kg, and the mean level was higher than 150 mg/kg set by WHO/FAO [35]. Akubugwo et al. (2012) reported almost similar level of a range among 73.62 mg/kg and 226.39 mg/kg. Njagi (2013) reported levels that extended between 22.01-525.50 mg/kg and results were similar to this study. High levels of Fe could be as a result of diverse agricultural practices employed by farmers in each region and different distribution of Zn in parent rock. Lead concentrations ranged between 10.75 ±1.07 mg/kg and 9.91 ± 1.55 mg/kg. These mean levels were over the acceptable of 1.00 mg/kg set by (SPCR, 2001). Similarly, Liu and , Sayadi [37,38] reported lead values of 18.48 mg/kg and 5.17 mg/kg in agricultural soil from Beijing and Iran correspondingly. Premarathna , Bvenura and Afolayan [39,40] reported a range between 15-311 mg/kg and 5.15 mg/kg - 14.01 mg/kg from Sir lanka and Eastern Cape respectively. High levels of Pb could be due to different agricultural practices employed by farmers in each region and different distribution of Pb in parent rock. Manganese concentrations ranged between 1.52 ±19.78 mg/kg and 1.34 ± 10.31 mg/kg and did not exceed the WHO limit. Salano [34], recorded a mean Mn in the soil to range from 13.370±1.620 to 26.830±3.290 mg/kg in Samburu County. Chromium concentrations extended between 10.14 ± 0.26 mg kg^{-1} and 9.67±0.12 mg/kg. These levels are below the set limits of 100 mg/kg by WHO/FAO [35].

Table 1: Mean heavy metals concentration in soil.

Heavy Metals (mg/kg)	Site 1	Site 2	Site 3
Zn	46.90 ± 8.48	39.68 ± 1.21	29.35 ±1.35
Fe	352 ± 9.82	277 ± 24.31	181 ± 25.59
Pb	9.91 ± 1.55	10.75 ± 1.07	10.09 ± 1.20
Mn	1.47 ± 4.49	1.34 ± 10.31	1.52 ± 19.78
Cr	9.67 ± 0.12	10.14 ± 0.26	9.62 ± 0.39
Cu	12.03 ± 0.04	12.85 ± 0.22	12.30 ± 0.47
Cd	0.53 ± 0.09	0.72 ± 0.04	0.61 ± 0.05

Similarly, Sayyed , Sayadi and Zojaji [38,41] recorded Cr average values of 10.36 mg/kg and 11.15 mg/kg in agricultural soil from Iran correspondingly. Copper levels ranged between 12.85±0.22 mg/kg and 12.03±0.04 mg/kg and the mean level was within the 100 mg/kg set by WHO/FAO [35]. Bvenura and Afolayan [40] during soils analysis from the Eastern Cape recorded copper in soil to range from 4.95 mg/kg to 7.66 mg/kg. Similarly, Liu, Sayyed and Sayadi [37,38] reported cupper mean values of a 24.00 mg/Kg and 9.62 mg/kg in agricultural soil from Beijing and Iran correspondingly. Cd levels extended between 0.72 ± 0.04 mg/kg and 0.53 ± 0.09 mg/kg, and it was within the safe limit of 1mg/kg set by WHO/FAO [35]. The levels of this study were similar to results of those of Kerich (2018) who recorded 1.05 to 1.09 mg/kg of Cd found in Eldoret Dumpsite. Analysis of soils from the Eastern Cape by Bvenura and Afolayan [40] recorded Cd to range between 0.01 mg/kg - 0.08 mg/kg in soils in agricultural land, and the concentrations of Cadmium by Wang [42] was 2.44 mg kg^{-1} in soils of Hunan Province. Mmolawa et al. (2011) recorded 0.02 mg/kg in Cd from soil the found in roads of Botswana. Han et al. (2002) and Raju [36] stated average cadmium values of 0.78 mg/kg and 0.82 mg/kg in agricultural soil from America and India, respectively. The trend of the heavy metals levels in soil were as follows Fe>Zn>Cu>Pb>Cr>Mn>Cd.

Heavy metals in the water samples

Table 2: Mean heavy metals concentration in water.

Heavy Metals (mg/l)	Site 1	Site 2	Site 3
Zn	0.06 ±0.00	0.054 ± 0.004	0.071 ± 0.008
Fe	0.81 ±0.29	0.669 ± 0.065	0.691 ± 0.0740
Pb	0.05 ±0.00	0.050 ± 0.001	0.050 ± 0.002
Mn	0.05 ±0.00	0.045 ± 0.000	0.046 ± 0.000
Cr	0.04 ± 0.01	0.015 ± 0.004	0.055 ± 0.018
Cu	0.27 ± 0.03	0.197 ± 0.004	0.224 ±0.023
Cd	0.001 ± 0.00	0.005 ± 0.000	0.003 ±0.000

The overall mean of heavy metals levels in soil (Zn, Fe, Cd, Pb, Cu, Cr, and Mn) are displayed in Table 2. The highest recorded levels of heavy metal are Fe (0.81 ±0.29 mg/l) was noted for the site 1, the least Cd levels (0.003 ±0.000 mg/l) were recorded site 2. The heavy metals concentrations in the water sources varied considerable from site 1 to 3. Zn ranges between 0.071 ± 0.008 mg/l and 0.054 ± 0.004 mg/l. These levels are lower than the set standards of 2 mg/l by WHO/FAO [35]. Islam et al. (2012) recorded levels of zinc range between 0.00839 and 0.7686 mg/l from the water sampled from Balu River in Bangladesh. The levels of this study were similar to results of those of Arefin [43] who reported Zn to range between 0.06 mg/l and 0.30 mg/l, while studying heavy metal contamination in surface water applied for irrigation in Turag River found in Bangladesh. Mohiuddin et al. (2011) recorded Zn concentration which varied from 0.22 to 0.26 mg/L in water samples from Buriganga River found in Bangladesh. Okoth [44] had Zn mean value of a range of 0.03 and 0.37 mg/l from Nyatike-Karungu Divisions, Migori District, Kenya. Fe ranges between 0.81 ± 0.29 mg/l and 0.669 ± 0.065 mg/l and the mean level was lower than mg/kg set by WHO/FAO [35]. Mwashinga [45] recorded values of Fe (0.19-0.32) mg/l during dry season and (0.07-1.82) mg/l during wet season. Afrin et al. (2014) reported iron concentration in water range from 0.78 and 6.33 mg/L sample from Turag River found in Bangladesh; these values were higher than our current study. Cavin [46] reported mean concentration of Fe in River Nzoia to range between 1.57 mg/l and 12.31 mg/l. Okoth [44] had Fe mean value of a range of 0.44 and 2.43 mg/l from Nyatike-Karungu Divisions, Migori District, Kenya

Lead had the same level of 0.05 ± 0.00 mg/l in the three sites. These values were far beneath the permitted value of 5.00 mg/L set by WHO/FAO [35]. Arefin [46] reported levels of lead in water used for irrigation to range from 0.10 to 0.63 mg/l. Islam et al. (2015) while analyzing water from Karatoa River in Bangladesh found the lead levels to range from 0.008 to 0.064 mg/L. Okoth [44] reported Pb mean value to range between 0.51 and 4.02 mg/l from Nyatike-Karungu Divisions, Migori District, Kenya. The values are similar to our study. Manganese ranges between 0.05 ± 0.00 mg/l and 0.045 ±0.000 mg/l and exceeded the maximum acceptable value of 0.20 mg/L set by WHO/FAO [35]. Zakir et al. (2012) recorded Manganese levels to be 0.32 mg/l from water obtained from Karatoa River in Bangladesh. Arefin [46] reported the levels of Manganese range between 0.35 and 0.92 mg/l which these values were similar to our study. Chromium ranges between 0.055 ± 0.018 mg/l and 0.015 ± 0.004 mg/l and the mean level was within the 0.2 mg/kg set by WHO/FAO [35]. Arefin (2016) reported the concentration of Mn to range between 0.23 and 0.47 mg/L. Cu ranges between 0.27 ± 0.03 mg/l and 0.197 ±0.004 mg/l. and the mean level was within the 0.2 mg/L set by WHO/FAO [35]. Results of analysis of soils from the Nyatike-Karungu Divisions, Migori District by Okoth [44] revealed that copper in water sources extended between 0.01 and 0.05 mg/l. Similarly, Bakali et al., (2014) collected water from Turag River, Bangladesh and recorded Copper levels to range from 0.01 and 0.07 mg/l and the noted values were lower than those of the current study which does not pose and health risks. Finally, Cadmium extended between 0.005 ± 0.000 mg/l and 0.001 ± 0.00. The levels were within the accepted permissible 0.01 mg/L standards set by WHO/FAO [35]. As linked to this research, Singh [13] recorded cadmium range to be (0.00–0.006 mg/L) from water used for crops irrigation at Dinapur, Varanas. Ahmed et al. 2010 similarly noted very low levels of cadmium detected in Buriganga, Turag water samples. The trend of the concentrations of the heavy metals in water were as follows Fe>Cu>Zn>Pb> Mn> Cr> >Cd.

Mean Concentration of Heavy Metals in Solanum nigrum

Solanum nigrum collected from 3 selected sites of Moiben Sub-County Uasin Gishu County were analyzed for the presence of heavy metals. Overall mean levels result for each element from are displayed in Table 3 below.

Table 3: Mean heavy metals concentration in *Solanum nigrum*.

Heavy Metals (mg/l)	Site 1	Site 2	Site 3
Zn	0.001209 ± 0.000172	0.000592 ± 0.000086	0.001000 ± 0.000403
Fe	0.004003 ± 0.000192	0.002627 ± 0.000116	0.003557 ± 0.000468
Cr	0.000103 ± 0.000004	0.000089 ± 0.000000	0.000104 ± 0.000007
Cu	0.000292 ± 0.000028	0.000204 ± 0.000016	0.000235 ± 0.000044
Pb	0.000094 ± 0.000014	0.000329 ± 0.000227	0.000079 ± 0.000012
Mn	0.000567 ± 0.000003	0.000837 ± 0.000093	0.000565 ± 0.000013
Cd	0.000005 ± 0.000001	0.000004 ± 0.000000	0.000004 ± 0.000001

The Zinc levels extended from 0.001209 ±0.000172 mg/kg to 0.000592 ± 0.000086 mg/kg, and never exceeded the WHO/FAO [35] limit of 60 mg/kg. The findings of this research were in far much lower than those reported by Njagi (2013) with a range of 0.38 ± 0.19 mg/Kg to 2.43 ± 0.15 mg/Kg in Zn concentration in vegetable. Akubugwo et al. (2012) also stated higher values of zinc than those reported in this study with values ranging from 1.06 ± 0.02 to 2.82 ± 0.01 mg/kg in Amaranthus hybridus. Gupta et al. (2008) reported Zn levels to be (3.00-171.03) mg/kg in vegetables gathered from Titagarh West Bengal in India which proved much higher as compared to those from the present study. Iron levels extended from 0.004003 ± 0.000192 mg kg^{-1} to 0.002627 ± 0.000116 mg kg^{-1} and was not exceeding the WHO/FAO limit of 48 mg/kg. Aweng et al, (2011) reported Fe concentration in the vegetables of (0.65 - 2.76) mg/kg which were lower as related to those of the current study. Chromium levels ranged between 0.000104 ± 0.000007 mg kg^{-1} and 0.000089 ± 0.000000 mg kg^{-1} and was not exceeding the WHO/FAO [35] limit of 1 mg/kg. Wambua ([47]reported chromium level in medicinal herbs aerial part from South Eastern and Coastal Regions in Kenya to range from 0.06 to 1.49mg/kg which were lower as compared to those of the current study.

Concentrations of lead ranged between 0.000329 ± 0.000227 mg kg^{-1} and 0.000079 ± 0.000012 mean levels of lead in were within the accepted limit of 0.30 mg/Kg set by WHO/FAO [35]. These concentrations were lower than those reported by Orisakwe et al. (2012) and Akubugwo et al. (2012) who reported lead to range from 0.35 to 1.89 mg/Kg and 0.13 to 0.73 in leafy vegetables. Kerich (2018) recorded an average level of lead in kales and spinach to range from 0.91 mg/kg to 1.46 mg/kg. Wambua [47] reported lead level in medicinal herbs aerial part from South Eastern and Coastal Regions in Kenya to range from 0.21 to 7.18 mg/kg. Bvenura and Afolayan [40] lead concentrations in the vegetables Lead was undetectable in all the samples. Manganese concentrations ranged between 0.000837 ± 0.000093mg kg^{-1} and 0.000565 ± 0.000013 mg kg^{-1} and did not exceed the WHO limit of 0.2mg/kg. Bvenura and Afolayan [40] noted heavy metals concentrations in the vegetables to range between 0.04 mg/kg - 373.38 mg/kg. Cupper concentrations ranged between 0.000292 ± 0.000028 mg kg^{-1} and 0.000204 ± 0.000016 mg kg^{-1} and did not exceed the WHO/FAO [35] limit. Njagi (2013) reported levels ranging from the lowermost value of 0.38 ± 0.19 mg/kg to 1.72 ± 0.11 mg/Kg while Uwah et al. (2011) documented copper values ranging between 1.75mg/kg and 0.81mg/kg in lettuce and spinach in Nigeria correspondingly. Akubugwo et al. (2012) and Muhammad et al. (2008) reported low ranges of 1.20 to 3.42 mg/kg and 0.25 mg/kg to 0.92mg/Kg while Sharma [48] reported copper concentration of (2.25-5.42mg/Kg) in Varanasi, India. Cadmium concentrations extended between 0.000329 ± 0.000227 mg kg^{-1} and 0.000004 ± 0.000000 mg kg^{-1} and did not exceed the WHO limit. Wambua [47] reported Cd level in medicinal herbs aerial part from South Eastern and Coastal Regions in Kenya to be (≤ 0.006 mg/kg. Kerich (2018) reported mean concentration of Cd in the vegetables to range from 0.09 mg/Kg to 0.11 mg/kg. Bvenura and Afolayan [40] recorded Cd values in the vegetables were to range from 0.01 mg/kg - 1.12 mg/kg dry weight. The trend of the concentrations of the heavy metals in Solanum nigrum were as follows Fe>Zn>Mn> Cu > Cr>Pb >Cd.

Comparisons of heavy metals found in soil, Solanum nigrum and water

ANOVA for heavy metals in soil for site 1, 2 and 3 from Moiben Sub-County

With the use of one-way analysis of variance the mean, Zn and Fe level recorded was ($p < 0.05$) significantly different among the three sites (P=0.001, df=2, F=11.77) and (P=0.003,df=2, F= 8.08) respectively. However, one way analysis of variance, the mean Pb, Mn, Cr, Cu and Cd level recorded was (p> 0.05) not significantly different among the three sites (P=0.891, df= 2, F=0.116), (P=0.695, df= 2, F=0.372), (P=0.480, df= 2, F=0.766), (P=0.401, df= 2, F=0.962) and (P=0.097, df= 2, F=2.663) respectively. s

ANOVA for heavy metals in water for site 1, 2 and 3 from Moiben Sub-County

With the use of one-way analysis of variance, the mean Cd level recorded was ($p < 0.05$) significantly different among the three sites (P=0.001, df=2, F=17.76). However, one way analysis of variance, the mean Zn, Fe, Pb, Mn, Cr, and Cu level recorded was (p> 0.05) not significantly different among the three sites (P=0.113, df= 2, F=2.81), (P=0.830, df= 2, F=0.190), (P=0.164, df= 2, F=2.221), (P=0.067, df= 2, F=3.704) (P=0.073, df= 2, F=3.561) and (P=0.748, df= 2, F=0.300) respectively.

ANOVA for heavy metals in Solanum nigrum for site 1, 2 and 3 from Moiben Sub-County

To determine if there were any spatial significant differences in heavy metals, One Way analysis of variance was conducted. The mean Fe and Mn level recorded was ($p < 0.05$) significantly different among the three sites (P=0.044, df= 2, F=0.000) and (P=0.019, df=2, F= 0.000) respectively. However, the mean Zn, Pb, Cr, Cu and Cd level recorded was (p> 0.05) not significantly different among the three sites (P=0.301, df= 2, F=0.000), (P=0.668, df= 2, F=0.000), (P=0.101, df= 2, F=0.000) (P=0.212, df= 2, F=0.000) and (P=0.790, df= 2, F=0.000) respectively.

Correlation Studies between heavy metals in soil and Solanum nigrum found in Moiben Sub-County

Correlation tests were carried out between level of the metals in the soil and Solanum nigrum so as to disclose the associations among metals. There were negative correlations between level of heavy metals within soil and Solanum nigrum for all metal in the studied regions, these relations were not statistically significant for all the metals. The correlation coefficients for were as shown Zn (0.970, p>0.05), Fe (0.368, p>0.05), Cr (0.108, p>0.05), Cu (0.009, p>0.05), Pb (0.480, p>0.05), Mn (0.893, p>0.05) and Cd (0.902, p>0.05). Therefore, the level of the metals found in soil appears to not to influence the uptake of metals in Solanum nigrum.

Correlation Studies between heavy metals in irrigation water and Solanum nigrum found in Moiben Sub-County

Correlation tests were carried out between concentrations of the metals in the water and Solanum nigrum so as to reveal the associations among metals. There were negative correlations between concentration of heavy metals in water and Solanum nigrum for all metal in the studied regions, these relations were not statistically significant for all the metals. The correlation coefficients for the heavy metals were as shown: Zn (0.657, p>0.05), Fe (0.723, p>0.05), Cr (0.204, p>0.05), Cu (0.204, p>0.05), Pb (0.966, p>0.05), Mn (0.550, p>0.05) and Cd (0.333, p>0.05). Therefore the concentrations of the metals in water appears to not to influence the uptake of metals in Solanum nigrum.

Transfer Factors of the Heavy Metals from Soil to Vegetables

The Transfer Factor (TF) is used to determine the transfer of heavy metals from soil to the plant tissues and calculating it is important is determining extent of risk due to consumptions of plants polluted by heavy metals [49-52]. It is calculated as follows; Kachenko and Singh [53]

Transfer factor=(Metal Content in plant (mg/kg))/(Metal Content in Soil (mg/kg))

When the TF is high, it is an indication of low retention of heavy metals in soil and increase absorption capability of plants. Low TF indicates high retention of heavy metals in soil and low absorption capability of plants. The Tables below indicate transfer of different types of heavy metals from soil to Solanum nigrum. The mean TF value for Zn, Fe, Cr, Cu, Pb, Mn and Cd from soil to Solanum nigrum found in Moiben Sub-County reached 2.42 × 10-5, 1.26 × 10-5, 1.01 × 10-5, 1.97 × 10-5, 1.63 × 10-5, 0.455× 10-5 and 0.703 × 10-5, respectively as indicated in Table 3. The TF of Mn and Cd from soil to Solanum nigrum was obviously lower than other metals [53]. The TF of the seven heavy metals in the regions showed an order of Zn > Cu > Pb> Fe > Cr > Cd> Mn. A study done by Bhatia [54] reported the TF for the 3 vegetable samples sampled from Peri-Urban Agricultural Areas and Markets of Delhi different field agricultural sites to range from 0.00348 to 0.064 for Cu, 0.0157 to 0.0620 for Zn, 0.00386 to 0.0147 for Pb, and 0.0189 to 0.0932 for Cd, this values were higher than reported from this study. Aktaruzzaman [49] TF or PCF value ranges were: Pb 0.058-0.89, Cr 0.06-0.32, Cd 0.03-1.1, Cu 0.03-0.53 and Zn 0.06-0.37 in the region of Dhaka Aricha Highway, Savar, Bangladesh[55-63].

Conclusion and Recommendations

The mean soil concentration were Zinc (46.90- 0.18) mg/kg, Iron 352 - 181 mg/kg, Lead 10.75 - 9.91) mg/kg, Manganese 1.52 - 1.34 mg/kg, Chromium 10.14 - 9.67 mg/kg, Cupper 12.85 - 12.03 mg/kg and Cd 0.72 ± 0.04 - 0.53 mg/kg. The metal concentrations in soil were within acceptable levels allowable by WHO/FAO except Fe and Pb. One-way ANOVA for the mean Zn and Fe level in soil recorded was ($p < 0.05$) significantly different among the three sites (P=0.001, df=2, F=11.77) and (P=0.003, df=2, F= 8.08) respectively, the rest were not significant. The mean irrigation water concentration were Zinc (0.071 - 0.054) mg/kg, Iron 0.81 - 0.669 mg/kg, Lead 0.05 mg/kg, Manganese 0.05 – 0.045 mg/kg, Chromium 0.055 - 0.015 mg/kg, Copper 0.27 - 0.197 mg/kg and Cd 0.005 - 0.001 mg/kg. The metal concentrations in water were within acceptable levels allowable by WHO/FAO. One-way ANOVA for the mean Cd level in irrigation water recorded was ($p < 0.05$) significantly different among the three sites (P=0.001, df=2, F=17.76), the rest were not significant. The mean Solanum nigrum concentration were Zinc (0.001209 - 0.000592) mg/kg, Iron 0.004003 - 0.002627 mg/kg, Lead 0.000329 - 0.000079 mg/kg, Manganese 0.000837 – 0.000565 mg/kg, Chromium 0.000104 - 0.000089 mg/kg, Copper 0.000292 - 0.000204 mg/kg and Cd 0.000329 - 0.000004 mg/kg. The metal concentrations in Solanum nigrum were within acceptable levels allowable by WHO/FAO. One-way ANOVA for the mean Fe and Mn level recorded was ($p < 0.05$) significantly different among the three sites (P=0.044, df= 2, F=0.000) and (P=0.019, df=2, F= 0.000) respectively, the rest were not significant. There were negative correlations between concentration of heavy metals in soil and Solanum nigrum and water and Solanum nigrum for all metal in the studied regions, these relations were not statistically significant for all the metals. Transfer ratio for all the elements was very low and showed an order of Zn > Cu > Pb> Fe > Cr > Cd> Mn, the metal concentrations in soil were within permissible levels allowable by WHO/FAO except Fe and Pb. From findings of this investigation, it is quite clear that the soil is quite harmless for crops production in these areas and also the Solanum nigrum are safe for consumption. However, dietary consumption of Solanum nigrum may consequence have a long-standing low-level body buildup of heavy metals and finally have unfavorable consequence which can only be seen after numerous years of contact. Therefore, continuous monitoring of heavy metals in soil, irrigation water and vegetables is vital preventive strategy to avoid accrual of the metals in the food chain. Moreover, remediation of heavy metal polluted soils is essential not only to minimize the related risks but also to protect the environment.

Acknowledgement

The authors are indebted to the financial support by University of Eldoret Annual Research Grants. We wish also to acknowledge Cyrus Kuya for his tireless efforts in coordinating the activities of this funded research.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

1. Kearney J (2010) Food consumption trends and drivers. Philosophical transactions of the royal society B: biological sciences 365(1554): 2793-2807.
2. Ali MH, Al-Qahtani KM (2012) Assessment of some heavy metals in vegetables, cereals, and fruits in Saudi Arabian markets. The Egyptian Journal of Aquatic Research 38(1): 31-37.
3. Soeta KO, Olaiya CO, Oyewole OE (2010) The importance of mineral elements for humans, domestic animals, and plants-A review. African Journal of Food Science 4(5): 200-222.
4. Slavin JL, Lloyd B (2012) Health benefits of fruits and vegetables. Advances in Nutrition 3(4): 506-516.
5. Sinha SN, Rao MVV, Vasudev K (2012) Distribution of pesticides in different commonly used vegetables from Hyderabad, India. Food Research International 45(1): 161-169.
6. Järup L (2003) Hazards of heavy metal contamination. British medical bulletin 68(1): 167-182.
7. Singh A, Sharma RK, Agrawal M, Marshall FM (2010) Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India. Food and Chemical Toxicology 48(2): 611-619.

8. Zhou H, Yang WT, Zhou X, Liu L, Gu J and et al., (2016) Accumulation of heavy metals in vegetable species planted in contaminated soils and the health risk assessment. International journal of environmental research and public health 13(3): 289.

9. Omambia BM, Gelas MS (2014) Heavy Metal (Cu, Zn, Cd and Pb) Contamination of Indigenous Green Vegetables in Eldoret Town And Their Health Implications to Consumers. Baraton Interdisciplinary Research Journal 4: 15-21.

10. Inoti, KJ, Kawaka F, Orinda G, Okemo P (2011) Assessment of heavy metal concentrations in urban grown vegetables in Thika Town, Kenya. African Journal of Food Science 6(3): 41-46.

11. Othman OC (2001) Heavy metals in green vegetables and soils from vegetable gardens in Daresalaam, Tanzania. Tanzania Journal of Science 27(1): 37-48.

12. Chauhan G, Chauhan UK (2014) Human health risk assessment of heavy metals via dietary intake of vegetables grown in wastewater irrigated area of Rewa, India. International Journal of Scientific and Research Publications 4(9): 1-9.

13. Singh S, Kumar M (2006) Heavy metal load of soil, water, and vegetables in peri-urban Delhi. Environmental Monitoring and Assessment 120(1-3): 79-91.

14. Rascio N, Navari-Izzo F (2011) Heavy metal hyper accumulating plants: how and why do they do it? And what makes them so interesting? Plant science 180(2): 169-181.

15. Duman F, Aksoy A, Demirezen D (2007) Seasonal variability of heavy metals in surface sediment of Lake Sapanca, Turkey. Environmental monitoring and assessment 133(1-3): 277-283.

16. Sharma RK, Agrawal M, Marshall F (2006) Heavy metal contamination in vegetables grown in wastewater irrigated areas of Varanasi, India. Bulletin of environmental contamination and toxicology 77(2): 312-318.

17. Sahu M, Kacholi, DS (2016) Heavy metal levels in Amaranthus species from Chang'ombe-Mchicha area in Temeke District, Daresalaam, Tanzania. Asian Journal of Chemistry 28(5): 1123-1126.

18. Intawongse M, Dean JR (2006) Uptake of heavy metals by vegetable plants grown on contaminated soil and their bioavailability in the human gastrointestinal tract. Food additives and contaminants 23(1): 36-48.

19. Duruibe JO, Ogwuegbu MOC, Egwurugwu JN (2007) Heavy metal pollution and human biotoxic effects. International Journal of physical sciences 2(5): 112-118.

20. Bernhoft RA (2013) Cadmium toxicity and treatment. The Scientific World Journal 2013.

21. Martin S, Griswold W (2009) Human health effects of heavy metals. Environmental Science and Technology briefs for citizens 15: 1-6.

22. Chen T, Hevi S, Gay F, Tsujimoto N, He T, et al. (2007) Complete inactivation of DNMT1 leads to mitotic catastrophe in human cancer cells. Nature genetics 39(3): 391-396.

23. Silbergeld EK (2003) Facilitative mechanisms of lead as a carcinogen. Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis 533(1-2): 121-133.

24. Shahinasi E, Kashuta V (2008) Irrigation water quality and its effects upon soil. Tirana Agricultural University, Tirana, Albania Balwois.

25. Schilling KE, Wolter CF (2001) Contribution of base flow to nonpoint source pollution loads in an agricultural watershed. Ground Water 39: 49-58.

26. Ndeda LA and Manohar S (2014) Determination of Heavy Metals in Nairobi Dam Water (Kenya). IOSR J Environ Sci Toxicol Food Technol 8: 68-73.

27. Mahmood A, Mahmood A, Malik RN, Shinwari ZK (2013) Indigenous knowledge of medicinal plants from Gujranwala district, Pakistan. Journal of ethnopharmacology 148(2): 714-723.

28. Jagatheeswari D, Bharathi T, Sheik Jahabar Ali H (2013) Black Night Shade (*Solanum nigrum L.*)-An Updated Overview. Int J Pharm Biol Arch 4: 288-295.

29. Alagusundaram M, Deepthi N, Ramkanth S, Angalaparameswari S, Saleem TM, and et al., (2010) Dry powder inhalers-an overview. International Journal of Research in Pharmaceutical Sciences 1(1): 34-42.

30. Hameed IH, Cotos MRC, Hadi MY (2017) A review: *Solanum nigrum L*. antimicrobial, antioxidant properties, hepatoprotective effects and analysis of bioactive natural compounds. Research Journal of Pharmacy and Technology 10(11): 4063-4068.

31. MoALF (2017) Climate Risk Profile for Uasin Gishu County. Kenya County Climate Risk Profile Series. The Ministry of Agriculture, Livestock and Fisheries (MoALF), Nairobi, Kenya.

32. Government of Kenya (2014) Agricultural Sector Development Support Program. Nairobi: Ministry of Agriculture Livestock and Fisheries.

33. County Government of Uasin Gishu (CGUG) (2013) Uasin Gishu County integrated development plan 2013-2018.

34. Salano EM (2013) Assessment of Heavy Metal Pollution in Soils and Water of Samburu County. Kenya (Master Thesis, Kenyatta University, Kenya).

35. FAO/WHO, Joint FAO/WHO (2011) Food Standards program Codex committee on contaminants in foods Food. CF/5 INF/1, pp. 1–89.

36. Raju KV, Somashekar RK, Prakash KL (2013) Spatio-temporal variation of heavy metals in Cauvery River. Proceedings of the International Academy of Ecology and Environmental Sciences3(1): 59-75.

37. Liu WH, Zhao JZ, Ouyang ZY, Söderlund L, Liu GH (2005) Impacts of sewage irrigation on heavy metal distribution and contamination in Beijing, China. Environment International 31(6): 805-812.

38. Sayyedi MRG, Sayadi MH (2011) Variations in the heavy metal accumulations within the surface soils from the the Chitgar industrial area of Tehran. Proceedings of the International Academy of Ecology and Environmental Sciences 1(1): 36-46.

39. Premarathna HMPL, Hettiarachchi GM, Indraratne SP (2011) Trace Metal Concentration in Crops and Soils Collected from Intensively Cultivated Areas of Sri Lanka. Pedologist 54(3): 230-240.

40. Bvenura C, Afolayan AJ (2012) Heavy metal contamination of vegetables cultivated in home gardens in the Eastern Cape. South African Journal of Science 108(9-10): 1-6.

41. Zojaji F, Hassani AH, Sayadi MH (2014) Bioaccumulation of chromium by Zea mays in wastewater-irrigated soil: An experimental study. Proceedings of the International Academy of Ecology and Environmental Sciences 4(2): 62-67.

42. Wang L, Guo Z, Xiao X, Chen T, Liao X, et al. (2008) Heavy metal pollution of soils and vegetables in the midstream and downstream of the Xiangjiang River, Hunan Province. Journal of Geographical Sciences 18(3): 353-362.

43. Arefin MT, Rahman MM, Wahid-U-Zzaman M, Kim JE (2016) Heavy metal contamination in surface water used for irrigation: functional assessment of the Turag River in Bangladesh. Journal of Applied Biological Chemistry 59(1): 83-90.

44. Okoth AM (2011) Determination of selected heavy metal levels in underground water and soil and analysis of water hardness sources in Nyatike-Karungu Divisions, Migori District, Kenya (Doctoral dissertation, Egerton University).

45. Mwashinga E (2018) Determination of Selected Heavy Metals in River Mukurumudzi to Establish Potential Contamination from Land Based Activities and Sources. GRIN Verlag.

46. Cavin O (2017) Distribution of Heavy Metals in Water and Sediments of Lower River Nzoia (Doctoral dissertation, University of Nairobi), Nigeria.

47. Wambua CM (2015) Analysis of Heavy Metal Concentrations in Selected Species of Genus Tephrosia In South Eastern and Coastal Regions in Kenya (Doctoral dissertation, University of Nairobi), Nigeria.

48. Sharma RK, Agrawal M, Marshall FM (2008) Heavy metal (Cu, Zn, Cd and Pb) contamination of vegetables in urban India: A case study in Varanasi. Environmental pollution 154(2): 254-263.

49. Aktaruzzaman M, Fakhruddin ANM, Chowdhury MAZ, Fardous Z, Alam MK (2013) Accumulation of heavy metals in soil and their transfer to leafy vegetables in the region of Dhaka Aricha Highway, Savar, Bangladesh. Pak J Biol Sci 16(7): 332-338.

50. Cui Y, Zhu Y, Zhai R, Chen D, Huang Y, et al. (2004) Transfer of metals from soil to vegetables in an area near a smelter in Nanning, China. Environ Int 30(6): 785–791.

51. Hu J, Wu F, Wu S, Sun X, Lin X, et al. (2013) Phytoavailability and phytovariety codetermine the bioaccumulation risk of heavy metal from soils, focusing on Cd-contaminated vegetable farms around the Pearl River Delta, China. Ecotoxicol Environ Saf 91: 18–24.

52. Peris M, Micó C, Recatalá L, Sánchez R, Sánchez J (2007) Heavy metal contents in horticultural crops of a representative area of the European Mediterranean region. Sci Total Environ 378(1-2): 42–48.

53. Kachenko AG, Singh B (2006) Heavy metals contamination in vegetables grown in urban and metal smelter contaminated sites in Australia. Water Air Soil Pollut 169: 101-123.

54. Bhatia A, Singh S, Kumar A (2015) Heavy Metal Contamination of Soil, Irrigation Water and Vegetables in Peri-Urban Agricultural Areas and Markets of Delhi. Water Environment Research 87(11): 2027-2034.

55. Ayers RS, Westcot DW (2011) Water Quality for Agriculture. FAO Irrigation and Drainage Paper 29 Rev.1; FAO:basin. Proceedings of the International Academy of Ecology and Environmental Sciences 3(1): 59-75.

56. Arti Bhatia, ShivDhar Singh, Amit Kumar (2015) Heavy Metal Contamination of Soil, Irrigation Water and Vegetables in Peri-Urban Agricultural Areas and Markets of Delhi. Water Environ Res Nov 87(11): 2027-2034.

57. Chopra AK, Pathak C, Prasad G (2009) Scenario of heavy metal contamination in agricultural soil and its management. J Appl Nat Sci 1(1): 99-108.

58. Defelice MS (2003) The Black Nightshades, Poison, Poultice, and Pie 1. Weed Technology 17(2): 421-427.

59. Farag AM, Stansbury MA, Bergman HL, Hogstrand C, MacConnell E (1995) The physiological impairment of free-ranging brown trout exposed to metals in the Clark Fork River, Montana. Canadian Journal of Fisheries and Aquatic Sciences 52(9): 2038-2050.

60. Li J, Lu Y, Yin W, Gan H, Zhang C and et al., (2009) Distribution of heavy metals in agricultural soils near a petrochemical complex in Guangzhou, China. Environmental monitoring and assessment 153(1-4): 365-375.

61. Tasrina RC, Rowshon A, Mustafizur AMR, Rafiqul I, Ali MP (2015) Heavy metals contamination in vegetables and its growing soil. J Environ Anal Chem 2(3): 2380-2391.

62. FAO/WHO. Joint Report, Food Standard Programs Codex Committee on Contaminants in Foods (CF/5 INF/1); FAO.

63. Chitgar industrial area of Tehran. Proceedings of the International Academy of Ecology and Environmental.

DOI: 10.32474/AOICS.2020.04.000197