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Original Article

Cobalt availability in the soil plant and animal food chain: a study under a peri-urban environment

Disponibilidade de cobalto no solo na cadeia alimentar vegetal e animal: um estudo em ambiente periurbano

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Abstract

Cobalt metal is considered as an essential trace element for the animals. Present investigation was undertaken in the peri-urban area to analyze the cobalt availability in animal food chain by using different indices. Cow, buffalo and sheep samples along with forage and soil samples were collected from the three different sites of District Jhang and analyzed through atomic absorption spectrophotometer. Cobalt values differed in soil samples as 0.315-0.535 mg/kg, forages as 0.127-0.333 mg/kg and animal samples as 0.364-0.504 mg/kg. Analyzed cobalt concentration in soil, forage and animal samples was found to be deficient in concentration with respect to standard limits. Soil showed the minimum cobalt level in *Z. mays* while maximum concentration was examined in the forage *C. decidua* samples. All indices examined in this study has values lesser than 1, representing the safer limits of the cobalt concentration in these samples. Enrichment factor (0.071-0.161 mg/kg) showed the highly deficient amount of cobalt enrichment in this area. Bio-concentration factor (0.392-0.883) and pollution load index (0.035-0.059 mg/kg) values were also lesser than 1 explains that plant and soil samples are not contaminated with cobalt metal. The daily intake and health risk index ranged from 0.00019-0.00064 mg/kg/day and 0.0044-0.0150 mg/kg/day respectively. Among the animals, cobalt availability was maximum (0.0150 mg/kg/day) in the buffaloes that grazed on the *C. decidua* fodder. Results of this study concluded that cobalt containing fertilizers must be applied on the soil and forages. Animal feed derived from the cobalt containing supplements are supplied to the animals, to fulfill the nutritional requirements of livestock.

Keywords: cobalt, peri-urban area, food-chain, enrichment factor, animal supplements.

Resumo

O metal cobalto é considerado um oligoelemento essencial para os animais. A presente investigação foi realizada na área periurbana para analisar a disponibilidade de cobalto na cadeia alimentar animal usando diferentes índices. Amostras de vacas, búfalos e ovelhas, juntamente com amostras de forragem e solo foram coletadas em três locais diferentes do Distrito Jhang e analisadas por meio de espectrofotômetro de absorção atômica. Os valores de cobalto diferiram em amostras de solo como 0,315-0,535mg/kg, forragens como 0,127-0,333 mg/kg e amostras de animais como 0,364-0,504 mg/kg. A concentração de cobalto analisada no solo, forragem e amostras de animais foi considerada deficiente em relação aos limites padrão. O solo apresentou o teor mínimo de cobalto em Z. mays enquanto a concentração máxima foi examinada nas amostras de forragem C. decidua. Todos os índices examinados

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neste estudo possuem valores menores que 1, representando os limites mais seguros da concentração de cobalto nestas amostras. O fator de enriquecimento (0,071-0,161 mg/kg) mostrou a quantidade altamente deficiente de enriquecimento de cobalto nesta área. Os valores do fator de bioconcentração (0,392-0,883) e do índice de carga de poluição (0,035-0,059 mg/kg) também foram menores que 1, o que explica que as amostras de plantas e solo não estão contaminadas com cobalto metálico. A ingestão diária e o índice de risco à saúde variaram de 0,00019-0,00064 mg/kg/dia e 0,0044-0,0150 mg/kg/dia, respectivamente. Entre os animais, a disponibilidade de cobalto foi máxima (0,0150 mg/kg/dia) nos búfalos que pastaram na forragem de C. decidua. Os resultados deste estudo concluíram que fertilizantes contendo cobalto devem ser aplicados no solo e nas forragens. A ração animal derivada dos suplementos contendo cobalto é fornecida aos animais, para atender às necessidades nutricionais do gado.

Palavras-chave: cobalto, zona periurbana, cadeia alimentar, fator de enriquecimento, suplementos animais.

1. Introduction

Heavy metal contamination is a major ecological threat to both terrestrial and aquatic life owing to their persistency and non-degradable nature. The physical and chemical interaction of metal with the natural components of environment either precipitates them or changes their oxidation state which affects the metal mobility and bioaccumulation pattern in environment (Yasotha et al., 2021). Metal availability in soil, water and plants has significantly influence the ruminants and human health. Therefore, heavy metal monitoring in the soil, plant and animal food chain was important to ascertain the human and ecological ramifications (Miclean et al., 2019; Saleh et al., 2019)

Polluted irrigation water from industrial or municipal discharges have undesirable residues of zinc, vanadium, chromium, cadmium, nickel, arsenic, copper, uranium, lead, thorium and antimony to be deposited on soil which affect the vegetation production or contaminate the groundwater which threaten the human health (Ge et al., 2021). In ecological network, earth is an eventual dealer of all existing metals because it proceeds as a sink of heavy metals as well as a supplier to plants that impart considerable effect on the living biota. Soil properties can be determined by the nature of rock that undergoes weathering process. Rocks such as mafic and ultra-mafic can degrade the adjacent soil and crops because they have prominent extent of heavy metal quantity. Metals combined with particles of soil that are negatively charged, once disengage of metal take place, it enter into the soil solution and easily accessible to plants. Transmission of metal from soil to plants rely upon the various characteristics of soil such as presence of primal matter, clay content, the acidity or alkalinity of soil as well as category of metal (Aboubakar et al., 2021).

Heavy metals may be alienated into essential and non-essential elements in accordance with the demand of plant-animal-human system. For example, Iron (Fe), Molybdenum (Mo), Copper (Cu), Manganese (Mn) and Zinc (Zn) are important for plants-animals-human being. Selenium (Se) and Cobalt (Co) are important to animal-human being. Nickel (Ni) and Chromium (Cr) are important to plants-human being. Lead (Pb), Mercury (Hg), Cadmium (Cd) and Arsenic (As) are not needed by any one organism and serve as a toxicant metals for all the living organisms (Alysson and Fabio, 2014).

Plants can intake both essential and non-essential metals from soils by countering electrical and chemical acclivity in the plasma-lemma of root cells. Beside soil, other route of entry is foliage which absorbed metals from aerial deposition through air-plant pathway. Therefore, noxious fumes of motor vehicles put detrimental effects on the roadside plants (Dogan et al., 2014a, b). As metal enter into plants by any route, it starts accrual process in their tissues. Their greater level can upset various vital physiologic activities and put negative effects on their nutritional quality. Animals are the biological markers toward heavy metal contamination in environment. All intrinsic and extrinsic intakes of metals from plants are accessible to livestock. On feeding these metals contaminated forages, several types of metabolized disturbances noticed in the animals (Ahmad et al., 2022). Bone deformity, impaired breeding, sterility and tetanus can be induces due to mineral insufficiency as well as their disproportion level of metal in soil and forages. Toxicant outcomes of metal base on their ratio, duration of contact, endurance capacity and eco-conditions of organism. As the presence of one metal can enhance or reduce the deleterious effects of other metal in the organisms. Thus, the toxicity relationship between metals-forages-animals has been measured profoundly (Hussain et al., 2021; Khan et al., 2015)

Among heavy metals, cobalt metal enters into the soil environment by the applications of phosphate fertilizers, industrial waste water and sewage sludge. Sandy soils obtained from igneous and calcareous rocks exhibit copper deficiency and mostly present on the upper surface of soil. Mostly, legumes require cobalt to fix nitrogen by rhizobia (Kafeel et al., 2023; Hu et al., 2021). It stimulates the activity of nitrate reductase and dehydrogenase enzymes. According to some reports cobalt toxicity, shows inhibitory effect on the electron transport chain of PS-II. Plant shows the signs of cobalt toxicity, if the range of cobalt content is beyond than 6ppm. Bioaccumulation of Co causes reduction biomass, nutrient uptake, growth and protein content of plants (Ozfidan-Konakci et al., 2022; Salam et al., 2022). In root cells, calcium ion binds with the cobalt binding sites which reduce the cobalt toxicity in plants (Lwalaba et al., 2020). The imbalanced metal concentration in animal diet, also affects the livestock production. McDowell et al. (1983) reported that if the feed contain lesser amount than 0.07mg/kg, than animals undergoes its deficiency. Insufficient amount of cobalt metal in animal diet causes deficiency of Vitamin B12, reduction in the body weight, growth size and impaired reproduction function (Yusof et al., 2023; González-Montaña et al., 2020).

As per scientific surveys, water scarcity is an emerging worldwide problem including Pakistan. As a result, agricultural practices prefer alternative water resources such as pond water, rain water, municipal and industrial waste water to cope up with these alarming situations. Recently researchers cited that Zn, Cr, Mn, Fe, Cd and Pb entry from wastewater irrigated soil to plants and animal products which opens the heavy metal entry into human beings (Chen et al., 2022a, b; Ge et al., 2021, 2022; Ejaz et al., 2022a, b). Therefore, aim of study is to evaluate the cobalt transfer from soil and forages to animal food chain. This study focused on the cobalt availability in buffalo, cow and sheep, and possible health risks in animals through intake of these forages. This study also assessed the deficiency or toxicity status of cobalt to grazing animals by applying various indices.

2. Materials and Method

2.1. Study area

Present research was conducted in District Jhang which is located at a distance of nearly 40 km from Gojra and Toba Tek Singh, 76 km to Faisalabad city and 86 km from Chiniot (Figure 1). The temperature in this study area varies between 52-4.5 °C. Approximately, 150-350mm is the rainfall annually and moisture (humidity) is about 32-80% (Khan et al., 2022).

2.2. Sampling locations

Three selected sites of this study were: Jhang (Jh-I) irrigated with ground-water, Shorkot (Sh-II) irrigated with canal-water and Ahmad Pur Sial (Aps-III) irrigated with sewage water, were selected in this research work. Soil, fodder plants and animal samples (blood, hair and feces) were collected randomly from these sampling locations. Sampling was done in the District Jhang during 2019-2020.

2.3. Soil sampling

Five replicates of each soil sample were collected from each site. Soil sample (100g) used to grow collected forages were sampled from 0-20cm depth. Firstly, these samples were dried in an open air and placed them at 75°C in an oven for almost 3-4 days. Properly labeled them and stored in sealed bags (Chen et al., 2022c).

2.4. Forage sampling

Aerial parts of these forages were collected that were mostly consumed by the grazing animals. Five replicates of forage randomly collected from each site and make a composite sample (Table 1). Forage sample were rinsed with distilled water to eliminate all the dust contamination deposit on the surface of these plants. These sample were dried in open air and then in oven (70-75°C) to remove all the moisture content. After oven drying process, forages were grinded into a fine powder and stored in sealed-labeled bags.

2.5. Animal sampling

Cow, Buffalo and Sheep were the selected animal categories in this study. 10 animals from each category of selected animal were used to collect blood, hair and fecal samples. All the animals were about 3-5 years in age and mainly feed on these collected forages.

Blood (5ml) was sampled from the animal jugular vein into the test tubes. Blood plasma was separated by centrifuging the blood samples at 3500rpm (15 minutes) then stored at -20 °C for digestion process. Collected hair

Table 1. Enlist of collected forage samples.

Plant No:	Scientific names	Local/ Common names	Family
1	*Acacia nilotica*	Kikar	Mimosaceae
2	*Capparis decidua*	Karir	Capparaceae
3	*Zea mays*	Maize	Poaceae
4	*Medicago sativa*	Leucen	Fabaceae
5	*Pennisetum glaucum*	Millet	Poaceae

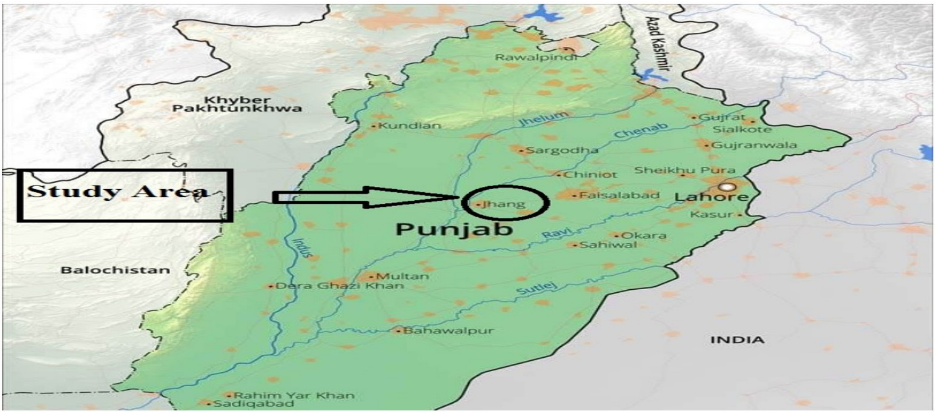

Figure 1. Map of study area.

samples from the animal body were washed with acetone to remove externally deposited contaminants and cut into small pieces. Both hair and fecal samples were air-dried and kept in oven for at least 3-4 days (Chen et al., 2022b).

2.6. Sample digestion

Two gram weighted each samples with a mixture of H_2SO_4 and H_2O_2 (2:1) was taken in a digestion flask. Heat this mixture in a digestion chamber for 30 minutes until yellow color of the solution appeared. Further, add H_2O_2 in the digestion flask to completely digest the samples and finally a colorless solution was obtained in the flask. Allow this solution to cool down at a room temperature to filter it. Add distilled water in this filtered solution to make its final volume 50ml and stored it for next step (Ge et al., 2021).

2.7. Cobalt analysis

After digestion, all the sample solutions were examined in the atomic absorption spectrophotometer to evaluate the cobalt concentration in the respective samples. Cobalt concentration measured for solid samples was in mg/kg but the liquid samples were measured in mg/l.

2.8. Statistical analysis

The presented data was analyzed statistically with the help of Two-way-ANOVA and SPSS-20 software. Further, mean concentrations were also calculated in the collected samples.

2.9. Pollution Load Index (PLI)

Liu et al. (2005) determined the heavy metal contamination in the soil by using PLI index (Equation 1):

$$PLI = \frac{(M)SS}{(M)RS} \quad (1)$$

(M) SS = Metal concentration in soil sample (mg/kg)
(M) RS= Metal reference value in soil as 9.07mg/kg (Singh et al., 2010)

2.10. Enrichment Factor (EF)

Buat-Menard and Chesselet (1979) mentioned the EF formula as (Equation 2):

$$Enrichment\ factor(EF) = \frac{\left(\frac{Metal\ concentration\ in\ forage\ /}{Metal\ concentration\ in\ soil}\right) sample}{\left(\frac{Metal\ concentration\ in\ plant\ /}{Metal\ concentration\ in\ soil}\right) standard} \quad (2)$$

Standard value of cobalt in soil and plants are 9.1mg/kg (Dutch Ministry of Housing, Spatial Planning and Environment, 2000) and 50mg/kg (FAO, 2001) respectively

2.11. Bio-Concentration Factor (BCF)

Cui et al. (2004) gave the BCF index to examine the metal transfer from soil to forage tissues by following formula (Equation 3):

$$BCF\ soil - forage = \frac{(M)Forage}{(M)Soil} \quad (3)$$

(M) Forage represents the analyzed metal concentration in forage samples.
(M) Soil represents the analyzed metal concentration in soil samples.
Daily intake of metals (DIM)

To determine DIM values, equation was (Equation 4):

$$DIM = \frac{C\ metal * CF * D\ food\ intake}{BW} \quad (4)$$

C_{metal} means conc. of metals in forages
CF means conversion factor whose value was 0.085 (Jan et al., 2010).
$D_{food\ intake}$ means daily food intake whose value for cows was 12kg, for sheep was 1.3kg (Johnsen and Aaneby, 2019) and 12.5kg was recommended for buffalo (Briggs and Briggs, 1980)
BW= Average body weight of animals whose value was 550kg for buffalo (Briggs and Briggs, 1980), 600kg for cows and 75 kg in case of sheeps (Johnsen and Aaneby, 2019).

2.12. Health Risk Index (HRI)

According to Cui et al. (2004), calculate this index by following Equations 5-6 (USEPA, 2010):

$$HRI = \frac{DIM}{RfD} \quad (5)$$

$$R_f D = \ Oral\ reference\ dose\ of\ metal\ which\ was\ 0.043 mg / kg\ in\ case\ of\ cobalt \quad (6)$$

3. Results

3.1. Soil analysis

According to the analysis of variance, the cobalt concentration demonstrated the non-significant effect in the all the sources of variation (p>0.05) such as Soil, Site and Soil * Site (Table 2). The observed concentration of Co was between the ranged of 0.315-0.535 mg/kg (Table 3). Highest concentration of this range was present in the soil of

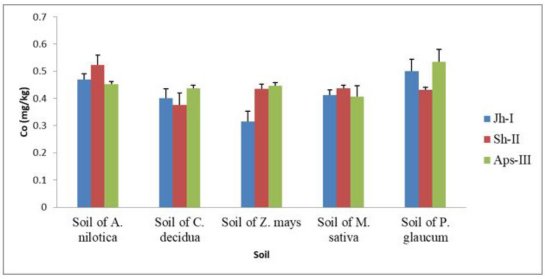

Figure 2. Cobalt concentration in soil samples with respect to various sites.

Table 2. ANOVA table for cobalt availability in sampled soil, forage and animal samples.

Soil			Forage		
Source of Variation	**Degree of freedom**	**Mean Square**	**Source of Variation**	**Degree of freedom**	**Mean Square**
Site	2	0.010 ns	**Site**	2	4.535ns
Soil	4	0.011 ns	**Forage**	4	0.140 ns
Site * Soil	8	0.008 ns	**Site *Forage**	8	1.386 ns

Animal							
Source of Variation	**Site**	**Animal**	**Source**	**Site * Animal**	**Site * Source**	**Animal * source**	**Site * Animal * Source**
Degree of freedom	2	2	2	4	4	4	8
Mean Square	0.166***	0.021*	0.013 ns	0.024**	0.020*	0.012 ns	0.007 ns

ns = Non-significant. *Significant at 0.05 level; **Significant at 0.01 level; ***Significant at 0.001 level.

Table 3. Mean Co concentration (mg/kg) in soil and forage samples with respect to various sites (Mean±S.E).

Cobalt	Soil			Forage		
	Jh-I	**Sh-II**	**Aps-III**	**Jh-I**	**Sh-II**	**Aps-III**
A. nilotica	0.470±0.021	0.523±0.036	0.452±0.016	0.283±0.133	0.205±0.023	0.215±0.100
C. decidua	0.402±0.034	0.377±0.041	0.437±0.012	0.170±0.064	0.333±0.108	0.205±0.028
Z. mays	0.315±0.039	0.435±0.018	0.447±0.019	0.127±0.062	0.263±0.012	0.258±0.017
M. sativa	0.413±0.019	0.437±0.012	0.407±0.039	0.190±0.031	0.193±0.031	0.267±0.011
P. glaucum	0.500±0.044	0.432±0.009	0.535±0.048	0.207±0.010	0.285±0.026	0.243±0.014

Aps-III that raises *P.* glaucum while lowered concentration was present in the *Z. mays* soil of Jh-I (Figure 2).

3.2. Forage analysis

The analysis of variance pointed out the non-significant impact of cobalt on all the observed Site and Forage interactions (Table 2). The Co concentration in the forages was varied as 0.127-0.333 mg/kg (Table 3). Highest concentration was accessed in the canal water irrigated Sh-II in which *C. decidua* was grown but the *Z. mays* presents lowest concentration in ground water irrigated, Jh-I site (Figure 3).

3.3. Animal analysis

The significantly affected variations for Co were noted in the Site, Animal, Site*Animal (p<0.01) and Site*Source treatments (Table 2). The observed reading for cobalt in animal blood was found between the 0.390-0.504 mg/l (Table 4). At the Sh-II site, sheep blood showed the concentration of Co as maximum and minimum was located in the cow blood at Jh-I (Figure 4). Cobalt variation in the animal hair was ascertained between the limits of 0.372-0.477 mg/kg (Table 4). Highest concentration was encountered in the buffalo reared on the Aps-III whereas Jh-I buffalo showed the lowered content of cobalt (Figure 4). Co content in fecal samples lied within the range of 0.364-0.504 mg/kg (Table 4). The least amount of present range

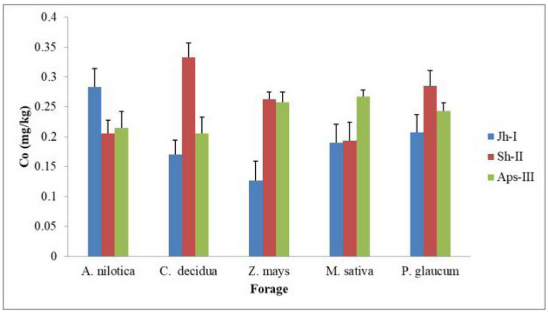

Figure 3. Cobalt concentration in forage samples with respect to various sites.

is revealed in the cows of Aps-III but the buffalo of Sh-II represented the highest concentration of cobalt (Figure 4).

3.4. Pollution load index

The observed PLI for Co concentration in all the sites were lowered than 1which highlighted that the sites are non-contaminated with this metal. The PLI concentrations expressed for cobalt were varied from 0.035-0.059 mg/kg. The *Z. mays* depicted the minimum concentration at Jh-I sampling point while higher PLI level for cobalt was existed in *P. glaucum* collected from Aps-III (Table 5).

Table 4. Mean Co concentration (mg/kg) in animal samples with respect to various sites (Mean±S.E).

Animals	Sources	Sampling Locations		
		Jh-I	Sh-II	Aps-III
Cow	Blood	0.390±0.034	0.447±0.037	0.395±0.013
	Hair	0.402±0.043	0.463±0.014	0.380±0.015
	Feces	0.490±0.014	0.459±0.050	0.364±0.038
Buffalo	Blood	0.473±0.015	0.502±0.012	0.401±0.015
	Hair	0.372±0.012	0.468±0.012	0.477±0.043
	Feces	0.493±0.014	0.504±0.013	0.368±0.012
Sheep	Blood	0.480±0.014	0.504±0.010	0.414±0.013
	Hair	0.454±0.013	0.377±0.014	0.397±0.014
	Feces	0.503±0.013	0.378±0.040	0.374±0.015

Table 5. PLI, EF and BCF for Co concentration with respect to various sites.

Cobalt	PLI			EF			BCF		
	Jh-I	Sh-II	Aps-III	Jh-I	Sh-II	Aps-III	Jh-I	Sh-II	Aps-III
A. nilotica	0.052	0.057	0.050	0.110	0.071	0.087	0.602	0.392	0.476
C. decidua	0.044	0.041	0.048	0.077	0.161	0.085	0.423	0.883	0.469
Z. mays	0.035	0.0478	0.049	0.073	0.110	0.105	0.403	0.605	0.577
M. sativa	0.045	0.0480	0.0447	0.084	0.080	0.119	0.460	0.442	0.656
P. glaucum	0.055	0.0475	0.059	0.075	0.120	0.083	0.414	0.660	0.454

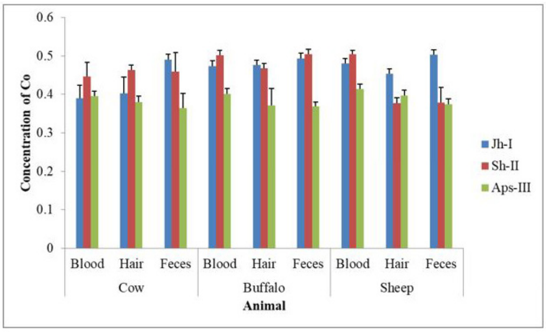

Figure 4. Cobalt concentrations in different animal samples with respect to various sites.

3.5. Enrichment factor

The results of cobalt displayed the EF range within 0.071-0.161 mg/kg. The minimum EF was noticed in *A. nilotica* sampled from the Sh-II but the *C. decidua* implied the maximum enrichment cultivated on the Sh-II (Table 5).

3.6. Bio-concentration factor

Analyzed BCF level for Co was fluctuated between the ranges of 0.392-0.883(Table 5). Greatest BCF level of this range was present in the *C. decidua* of Sh-II while minimal value was analyzed in *A. nilotica* of the same site.

3.7. Daily intake of metal & health risk index

Cobalt concentration varied from 0.00019-0.00064mg/kg/day for the daily intake indices. Least daily intake value was perceived by the sheep of Jh-I whosever feed on *Z. mays.* Maximum daily intake was observed in the buffaloes that grazed on the *C. decidua* located in the Sh-II site. Health risk index value for the cobalt metal was assorted between the ranges of 0.0044-0.0150mg/kg/day. Highest HRI value was commenced by the buffaloes of Sh-II area while minimal risk of health index was noticed in the sheep animal that nurtured on the *Z. mays* forage cultivated at Jh-I (Table 6).

4. Discussion

FAO (2001, 2000) suggested the standard values of cobalt as 100 mg/kg and 10mg/kg respectively in soil which were quite higher than present concentrations. These standards suggested that cobalt concentration in the soil samples was found within safe level. Wu et al. (2020) declared that Co amount in soil of control (6.85-7.18mg/kg) and experimental pastures (6.83-7.13mg/kg) of Weining. These reported concentrations are higher against our study while lesser concentration was regarded by Patel et al. (2019) in both industrial (0.019mg/kg) and non-industrial area (0.017mg/kg). Numerous studies reported in the India (Sharma et al., 2018), Moa city (Rizo et al., 2011), Peshawar (Jan et al., 2010) and in Siberia (Syso et al.,

Table 6. Daily intake and health risk index of Co metal in animals with respect to various sites.

Forages	Cow			Buffalo			Sheep		
	Jh-I	**Sh-II**	**Aps-III**	**Jh-I**	**Sh-II**	**Aps-III**	**Jh-I**	**Sh-II**	**Aps-III**
Daily intake of metal (DIM)									
A. nilotica	0.00048	0.00035	0.00037	0.00055	0.00040	0.00042	0.00042	0.00031	0.00032
C. decidua	0.00029	0.00057	0.00035	0.00033	0.00064	0.00040	0.00025	0.00049	0.00030
Z. mays	0.00022	0.00045	0.00044	0.00025	0.00051	0.00050	0.00019	0.00039	0.00038
M. sativa	0.00032	0.00033	0.00045	0.00037	0.00037	0.00052	0.00028	0.00028	0.00039
P. glaucum	0.00035	0.00049	0.00041	0.00040	0.00055	0.00047	0.00031	0.00042	0.00036
Health risk index (HRI)									
A. nilotica	0.0112	0.0081	0.0085	0.0127	0.0092	0.0097	0.0097	0.0070	0.0074
C. decidua	0.0067	0.0132	0.0081	0.0076	0.0150	0.0092	0.0058	0.0114	0.0070
Z. mays	0.0050	0.0104	0.0102	0.0057	0.0118	0.0116	0.0044	0.0090	0.0088
M. sativa	0.0075	0.0076	0.0106	0.0085	0.0087	0.0120	0.0065	0.0066	0.0091
P. glaucum	0.0082	0.0113	0.0096	0.0093	0.0128	0.0109	0.0070	0.0098	0.0083

2017) showed elevated cobalt level as compared to this study. Alejandro et al. (2020) study corroborated that acidic nature of soil promotes the binding of cobalt with the manganese oxide which reduces its transportation to plants. Alengebawy et al. (2021) mentioned that level of Co, Zn, Pb and Cd in soil is enhanced by fungicidal, herbicidal and sewage water applications. That's why, current study area also showed greater concentration at Aps-III site due to these man-induced activities but within the standard limits.

Cobalt concentrations in forages were placed within the acceptable limit of 52mg/kg, according to the FAO (2001) criteria. Alghobar et al. (2014) ascertained the greater cobalt level (7-8mg/kg) then studied values of this study. Patel et al. (2019) and Syso et al. (2017) mentioned the Co content as 0.219 & 0.1 mg/kg respectively that was found to be lowered than current study. Conversely, various studies conducted by Marijanusic et al. (2017) and Rizwan et al. (2019) showed higher content of Co than investigated results. Co level in plant was antagonistically effected by concentration of Mn and Fe concentration. Little amount of Co was absorbed by the plants because Ca^{2+} competes with the binding site of cobalt and overcome their toxicity effects. On the other hand, formation of organic complexes also reduces its movement from root to the aerial parts (Lwalaba et al., 2020).

Bisen et al. (2019) observed the elevated cobalt concentration in both cyclic (0.76-1.12mg/l) and non-cyclic buffalo blood (0.76-1.27 mg/l). Omoniwa et al. (2017) determined the lowered concentration (0.135mg/l) in animal serum of Zaria. In addition to this study, an increased Co concentration between 1.34-1.61mg/l was noted by the Tahir et al. (2017) in blood samples. The emitted concentration of both Zn and Pb decreases the availability of cobalt (Duan et al., 2022). The decreased concentration of cobalt in blood was attributed the higher Zn and Pb level in the study area.

Vorobyov et al. (2019) also stated the higher concentration of Co metal in sheep and goat hairs (4.25 & 3.16mg/kg) of Volga region. Against Patkowska-Sokoła et al. (2009) study, similar Co concentration observed in sheep wool of Poland (0.98mg/kg), lowered level was found in the sheep hair of Greece (0.65mg/kg) whereas greater Co content was revealed in the hair of sheep (2.31mg/kg) at Syria.. Demirel et al. (2013) measured the Co amount in animal feces as 0.10mg/kg that was lowered against this investigation. Ukpe and Chokor (2018) declared the mean Co value (0.43mg/kg) within the analyzed range of present results. This study also highlighted that Co content in animal wastes was significantly higher in relation to intake of metal through feed. These stated outcomes showed correspondence with the existing investigation.

Present PLI values were much lowered than reference level of Co (9.1mg/kg) given by Dutch standard (2000). Similarly, El-Alfy et al. (2017) studied the pollution load for cobalt in soil irrigated with Kitchener drain of Egypt (0.30mg/kg) that was compatible to current result. The studied range in this study was lowered than the PLI observed by Kalavrouziotis et al. (2012) and Likuku et al. (2013). Hussain et al. (2015) evaluated the value 3.008 as an average PLI for cobalt level that was considered to be much greater with respect to present analysis.

Rizo et al. (2011) found least enrichment of Co in urban soil of Cuba. Ezemokwe et al. (2017) and Hussain et al. (2015) suggested the higher enriched value of Co (2.61 &1.53mg/kg respectively) in their studied samples with respect to current investigation. Similarly, Likuku et al. (2013) also analyzed the higher enriched value (0.28-2.11) in Selebi Phikwe Region of Botswana. With respect to Barbieri (2016) standards, studied range represented the highly deficient amount of Co enrichment in the study area.

BCF is actually the comparison of heavy metal content absorb by plants to their amount present in soil. Elamin and Saeed (2019) evaluated the soil to plant transfer of Co in three different irrigating systems: 0.62mg/kg in river Nile water, 0.74mg/kg in treated waste water and 0.77mg/kg in treated waste water + River Nile water source. All observed concentration of these three treatments was appeared to be within the investigated range. Alghobar and Suresha (2015) appraised the Co transfer in plant as 0.50 in all sources of irrigation (ground water & waste water) which was lowered than observed range of existing study. Similarly, lesser concentration (0.023-0.066) was also reported by the Taha et al. (2013) in the plant *Sorghum color* of Sudan country. An elevated accumulation of cobalt in sampling sites (0.56-4.95) was measured by the study of Lago-Vila et al. (2015). Different studies also stated that Co and Ni were poorly transferred from root to the plant shoot. Therefore, all the BCF values were less than 1 and showed that plants cannot accumulate the cobalt concentration in their aerial parts.

As compared to the present range of Co daily intake, a higher concentration was calculated by Khan et al. (2019) in the buffaloes (0.001-0.03 mg/kg/day). Roggeman et al. (2013) calculated the Co intake in cows that varied from 0.1-0.9 mg/kg/day and found to be higher than the investigated Co intake in different animals. Khan et al. (2019) study on buffaloes estimated the HRI values as 0.240-0.697 mg/kg/day that was considered to be greater than observed HRI of animals in this research. In this study, the measured HRI level for cobalt was considered to be much lowered than HRI standards specified by USEPA (2002).

5. Conclusion

In this work, cobalt concentration was varied within sites and animal samples. The cobalt concentration available to animals is occupied by the forage intake as well as the presence of antagonistic metals (zinc & lead). Research work concluded that as soil and forages samples are deficient of cobalt metal. Therefore, minimum amount of this metal is transferred from soil and forage to animals and deficiency of cobalt level was prevailed in the studied animal samples. The poor absorption of cobalt in the animal blood exposed the lead and zinc toxicity in the study area. Study suggested that precautionary measures regarding the emissions of antagonistic metals must be carried out in the present area and to fulfill the nutritive value of farm animals and their products, cobalt containing fertilizers are recommended for the soil/forage system while a high quality animal feed containing cobalt supplements must be accomplished.

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References

ABOUBAKAR, A., HAJJAJI, S., DOUAIK, A., MEWOUO, Y.C.M., MADONG, R.C.B.A., DAHCHOUR, A., MABROUKI, J. and LABJAR, N., 2021. Heavy metal concentrations in soils and two vegetable crops (Corchorus olitorius and Solanum nigrum L.), their transfer from soil to vegetables and potential human health risks assessment at selected urban market gardens of Yaoundé, Cameroon. *International Journal of Environmental Analytical Chemistry*, pp. 1-22. Online. http://dx.doi.org/10.1080/03067319.2021.1910251.

AHMAD, K., KHAN, Z.I., NAZAR, S., MALIK, I.S., ASHFAQ, A., MUNIR, M., BASHIR, H., MUHAMMAD, F.G., AKHTAR, S., NADEEM, M., MEHMOUD, S., AWAN, M., AKHTAR, M. and MAHPARA, S., 2022. Estimation of chromium in soil-plant-animal continuum: a case study in ruminants of Punjab, Pakistan. *Journal of Bioresource Management*, vol. 9, no. 1, pp. 81-89.

ALEJANDRO, S., HÖLLER, S., MEIER, B. and PEITER, E., 2020. Manganese in plants: from acquisition to subcellular allocation. *Frontiers in Plant Science*, vol. 11, p. 300. http://dx.doi.org/10.3389/fpls.2020.00300. PMid:32273877.

ALENGEBAWY, A., ABDELKHALEK, S.T., QURESHI, S.R. and WANG, M.Q., 2021. Heavy metals and pesticides toxicity in agricultural soil and plants: ecological risks and human health implications. *Toxics*, vol. 9, no. 3, p. 42. http://dx.doi.org/10.3390/toxics9030042. PMid:33668829.

ALGHOBAR, M.A. and SURESHA, S., 2015. Evaluation of nutrients and trace metals and their enrichment factors in soil and sugarcane crop irrigated with wastewater. *Journal of Geoscience and Environment Protection*, vol. 3, no. 8, pp. 46-56. http://dx.doi.org/10.4236/gep.2015.38005.

ALGHOBAR, M.A., RAMACHANDRA, L. and SURESHA, S., 2014. Effect of sewage water irrigation on soil properties and evaluation of the accumulation of elements in grass crop in Mysore city, Karnataka, India. *American Journal of Environmental Protection*, vol. 3, no. 5, pp. 283-291. http://dx.doi.org/10.11648/j.ajep.20140305.22.

ALYSSON, R.B.S. and FABIO, C., 2014. Risks of heavy metals contamination of soil-pant system by land application of sewage sludge: a review with data from Brazil. In: M.C. HERNANDEZ-SORIANO, ed. *Environmental risk assessment of soil contamination*. London: IntechOpen, pp. 873-908. http://dx.doi.org/10.5772/58384.

BARBIERI, M., 2016. The importance of enrichment factor (EF) and geoaccumulation index (Igeo) to evaluate the soil contamination. *Journal of Geology & Geophysics*, vol. 5, no. 1, pp. 1-4. http://dx.doi.org/10.4172/2381-8719.1000237.

BISEN, A., SHUKLA, S.N. and MISHRA, A., 2019. Blood biochemical profile in sub-oestrus buffaloes. *Journal of Pharmacognosy and Phytochemistry*, vol. 8, no. Spe 5, pp. 17-20.

BRIGGS, H. and BRIGGS, H.M., 1980. *Modern breeds of livestock*. 4th ed. London: McMillion Publishing Co.

BUAT-MENARD, P. and CHESSELET, R., 1979. Variable influence of the atmospheric flux on the trace metal chemistry of oceanic suspended matter. *Earth and Planetary Science Letters*, vol. 42, no. 3, pp. 399-411. http://dx.doi.org/10.1016/0012-821X(79)90049-9.

CHEN, F., MUHAMMAD, F.G., KHAN, Z.I., AHMAD, K., MALIK, I.S., ASHFAQ, A., NAEEM, M., NADEEM, M., MA, J., AWAN, M.U.F., MAHPARA, S. and MEHMOOD, M., 2022a. Bioaccumulation and transfer of zinc in soil plant and animal system: a health risk assessment for the grazing animals. *Environmental Science and Pollution Research International*, vol. 29, no. 2, pp. 2718-2727. http://dx.doi.org/10.1007/s11356-021-15808-z. PMid:34378137.

CHEN, F., MUHAMMAD, F.G., KHAN, Z.I., AHMAD, K., NADEEM, M., MAHMOOD, S., AWAN, M.U.F., MUNIR, M., MALIK, I.S., ASHFAQ, A., SULTANA, R., MAQSOOD, A., SAQLAIN, L., NAEEM, M. and MA, J., 2022b. Ecological risk assessment of heavy metal chromium in a contaminated pastureland area in the Central

Punjab, Pakistan: soils vs plants vs ruminants. *Environmental Science and Pollution Research International*, vol. 29, no. 3, pp. 4170-4179. http://dx.doi.org/10.1007/s11356-021-15904-0. PMid:34405324.

CHEN, F., SAQLAIN, L., MA, J., KHAN, Z.I., AHMAD, K., ASHFAQ, A., SULTANA, R., MUHAMMAD, F.G., MAQSOOD, A., NAEEM, M., MALIK, I.S., MUNIR, M., NADEEM, M. and YANG, Y., 2022c. Evaluation of potential ecological risk and prediction of zinc accumulation and its transfer in soil plants and ruminants: public health implications. *Environmental Science and Pollution Research International*, vol. 29, no. 3, pp. 3386-3393. http://dx.doi.org/10.1007/s11356-021-15821-2. PMid:34387818.

CUI, Y.J., ZHU, Y.G., ZHAI, R.H., CHEN, D.Y., HUANG, Y.Z., QIU, Y. and LIANG, J.Z., 2004. Transfer of metals from soil to vegetables in an area near a smelter in Nanning, China. *Environment International*, vol. 30, no. 6, pp. 785-791. http://dx.doi.org/10.1016/j.envint.2004.01.003. PMid:15120196.

DEMIREL, B., GOL, N.P. and ONAY, T.T., 2013. Evaluation of heavy metal content in digestate from batch anaerobic co-digestion of sunflower hulls and poultry manure. *Journal of Material Cycles and Waste Management*, vol. 15, no. 2, pp. 242-246. http://dx.doi.org/10.1007/s10163-012-0107-4.

DOGAN, Y., BASLAR, S. and UGULU, I., 2014a. A study on detecting heavy metal accumulation through biomonitoring: content of trace elements in plant at Mount Kazdagi in Turkey. *Applied Ecology and Environmental Research*, vol. 12, no. 3, pp. 627-636. http://dx.doi.org/10.15666/aeer/1203_627636.

DOGAN, Y., UNVER, M.C., UGULU, I., CALIS, M. and DURKAN, N., 2014b. Heavy metal accumulation in the bark and leaves of Juglans regia planted in Artvin city, Turkey. *Biotechnology, Biotechnological Equipment*, vol. 28, no. 4, pp. 643-649. http://dx.doi.org/10.1080/13102818.2014.947076. PMid:26019552.

DUAN, R., FEDLER, C.B., LI, X. and JIAO, X., 2022. Co-transport of Cu^{2+}, Pb^{2+}, Cd^{2+}, and Zn^{2+} in the columns of polyaluminium chloride and anionic polyacrylamide water treatment residuals. *Journal of Water Process Engineering*, vol. 45, p. 102475. http://dx.doi.org/10.1016/j.jwpe.2021.102475.

DUTCH MINISTRY OF HOUSING, SPATIAL PLANNING AND ENVIRONMENT, 2000. *Circular on target values and intervention values for soil remediation*. Netherlands: Netherlands Government Gazette.

EJAZ, A., KHAN, Z.I., AHMAD, K., MUHAMMAD, F.G., AKHTAR, S. and HUSSAIN, M.I., 2022a. Appraising growth, daily intake, health risk index, and pollution load of Zn in wheat (Triticum aestivum L.) grown in soil differentially spiked with zinc. *Environmental Science and Pollution Research International*, vol. 29, no. 23, pp. 34685-34700. http://dx.doi.org/10.1007/s11356-021-18130-w. PMid:35040053.

EJAZ, A., KHAN, Z.I., MUHAMMAD, F.G., AHMAD, K., NADEEM, M. and ASHFAQ, A., 2022b. Copper bioaccumulation pattern in different wheat varieties grown on organic waste amended soil: a public health impact assessment. *Fresenius Environmental Bulletin*, vol. 31, no. 6A, pp. 6349-6356.

EL-ALFY, M.A., EL-AMIER, Y.A. and EL-HAMID, H.T., 2017. Soil quality and health risk assessment of heavy metals in agricultural areas irrigated with wastewater from Kitchener Drain, Nile Delta, Egypt. *Journal of Scientific Agriculture*, vol. 1, pp. 158-170. http://dx.doi.org/10.25081/jsa.2017.v1.50.

ELAMIN, A.W.N. and SAEED, A.B., 2019. Impact of using treated wastewater for irrigation on soil chemical properties, plant growth and forage yield. *University of Khartoum Journal of Agricultural Sciences*, vol. 16, no. 1, pp. 75-87.

EZEMOKWE, D.E., ICHU, C.B., OKORO, J.N. and OPARA, A.I., 2017. Evaluation of heavy metal contamination of soils alongside Awka-Enugu road, southeastern Nigeria. *Asian Journal of Environmental Science*, vol. 4, no. 1, pp. 1-11.

FOOD AND AGRICULTURE ORGANIZATION – FAO. WORLD HEALTH ORGANIZATION – WHO, 2001. *Food additive and contaminants*. Geneva: FAO/WHO. 289 p. Alinorm 1/12A.

FOOD AND AGRICULTURE ORGANIZATION – FAO. WORLD HEALTH ORGANIZATION – WHO, 2000. *Report of the 32nd session of the Codex Committee on Food Additives and Contaminants, Beijing, People's Republic of China, 20-24 March 2000*. Rome: FAO/WHO.

GE, X., CHEN, F., SAQLAIN, L., MA, J., KHAN, Z.I., AHMAD, K., MALIK, I.S., ASHFAQ, A., SULTANA, R., MUNIR, M., NADEEM, M., AWAN, M.U.F. and SOHAIL, M., 2021. Evaluation of pasture allowance of manganese for ruminants. *Environmental Science and Pollution Research International*, vol. 28, no. 40, pp. 56906-56914. http://dx.doi.org/10.1007/s11356-021-14666-z. PMid:34076814.

GE, X., KHAN, Z.I., CHEN, F., AKHTAR, M., AHMAD, K., EJAZ, A., ASHRAF, M.A., NADEEM, M., AKHTAR, S., ALKAHTANI, J., DWININGSIH, Y. and ELSHIKH, M.S., 2022. A study on the contamination assessment, health risk and mobility of two heavy metals in the soil-plants-ruminants system of a typical agricultural region in the semi arid environment. *Environmental Science and Pollution Research International*, vol. 29, no. 10, pp. 14584-14594. http://dx.doi.org/10.1007/s11356-021-16756-4. PMid:34617216.

GONZÁLEZ-MONTAÑA, J.R., ESCALERA-VALENTE, F., ALONSO, A.J., LOMILLOS, J.M., ROBLES, R. and ALONSO, M.E., 2020. Relationship between vitamin B12 and cobalt metabolism in domestic ruminant: an update. *Animals*, vol. 10, no. 10, p. 1855. http://dx.doi.org/10.3390/ani10101855. PMid:33053716.

HU, X., WEI, X., LING, J. and CHEN, J., 2021. Cobalt: an essential micronutrient for plant growth. *Frontiers in Plant Science*, vol. 12, p. 768523. http://dx.doi.org/10.3389/fpls.2021.768523. PMid:34868165.

HUSSAIN, M.I., KHAN, Z.I., NAEEM, M., AHMAD, K., AWAN, M.U.F., ALWAHIBI, M.S. and ELSHIKH, M.S., 2021. Blood, hair and feces as an indicator of environmental exposure of sheep, cow and bufalo to cobalt: a health risk perspectives. *Sustainability*, vol. 13, no. 14, p. 7873. http://dx.doi.org/10.3390/su13147873.

HUSSAIN, R., KHATTAK, S.A., SHAH, M.T. and ALI, L., 2015. Multistatistical approaches for environmental geochemical assessment of pollutants in soils of Gadoon Amazai Industrial Estate, Pakistan. *Journal of Soils and Sediments*, vol. 15, no. 5, pp. 1119-1129. http://dx.doi.org/10.1007/s11368-015-1075-9.

JAN, F.A., ISHAQ, M., IHSANULLAH, I. and ASIM, S.M., 2010. Multivariate statistical analysis of heavy metals pollution in industrial area and its comparison with relatively less polluted area: a case study from the City of Peshawar and district Dir Lower. *Journal of Hazardous Materials*, vol. 176, no. 1-3, pp. 609-616. http://dx.doi.org/10.1016/j.jhazmat.2009.11.073. PMid:20031313.

JOHNSEN, I.V. and AANEBY, J., 2019. Soil intake in ruminants grazing on heavy-metal contaminated shooting ranges. *The Science of the Total Environment*, vol. 687, pp. 41-49. http://dx.doi.org/10.1016/j.scitotenv.2019.06.086. PMid:31202012.

KAFEEL, U., JAHAN, U. and KHAN, F.A., 2023. Role of mineral nutrients in biological nitrogen fixation. In: T. AFTAB and K.R. HAKEEM, eds. *Sustainable plant nutrition: molecular interventions and advancements for crop improvement*. London: Academic Press, pp. 87-106. http://dx.doi.org/10.1016/B978-0-443-18675-2.00004-3.

KALAVROUZIOTIS, I.K., KOUKOULAKIS, P. and KOSTAKIOTI, E., 2012. Assessment of metal transfer factor under irrigation with treated municipal wastewater. *Agricultural Water Management*, vol. 103, pp. 114-119. http://dx.doi.org/10.1016/j.agwat.2011.11.002.

KHAN, S.A., LIU, X., SHAH, B.R., FAN, W., LI, H., KHAN, S.B. and AHMAD, Z., 2015. Metals uptake by wastewater irrigated vegetables and their daily dietary intake in Peshawar, Pakistan. *Ecological Chemistry and Engineering. S*, vol. 22, no. 1, pp. 125-139. http://dx.doi.org/10.1515/eces-2015-0008.

KHAN, Z.I., ARSHAD, N., AHMAD, K., NADEEM, M., ASHFAQ, A., WAJID, K., BASHIR, H., MUNIR, M., HUMA, B., MEMOONA, H., SANA, M., NAWAZ, K., SHER, M., ABBAS, T. and UGULU, I., 2019. Toxicological potential of cobalt in forage for ruminants grown in polluted soil: a health risk assessment from trace metal pollution for livestock. *Environmental Science and Pollution Research International*, vol. 26, no. 15, pp. 15381-15389. http://dx.doi.org/10.1007/s11356-019-04959-9. PMid:30937740.

KHAN, Z.I., MUHAMMAD, F.G., AHMAD, K., AKHTAR, S., SOHAIL, M., NADEEM, M., MAHPARA, S., AWAN, M.U.F., ALWAHIBI, M.S., ELSHIKH, M.S. and HUSSAIN, M.I., 2022. Effects of diverse irrigation with wastewater in soil and plants: assessing the risk of metal to the animal food chain. *Environmental Science and Pollution Research International*, vol. 29, no. 18, pp. 27140-27149. http://dx.doi.org/10.1007/s11356-021-17559-3. PMid:34978030.

LAGO-VILA, M., ARENAS-LAGO, D., RODRÍGUEZ-SEIJO, A., COUCE, M.L.A. and VEGA, F.A., 2015. Cobalt, chromium and nickel contents in soils and plants from a serpentinite quarry. *Solid Earth*, vol. 6, no. 1, pp. 323-335. http://dx.doi.org/10.5194/se-6-323-2015.

LIKUKU, A.S., MMOLAWA, K.B. and GABOUTLOELOE, G.K., 2013. Assessment of heavy metal enrichment and degree of contamination around the copper-nickel mine in the Selebi Phikwe Region, Eastern Botswana. *Environment and Ecology Research*, vol. 1, no. 2, pp. 32-40. http://dx.doi.org/10.13189/eer.2013.010202.

LIU, W.-H., ZHAO, J.-Z., OUYANG, Z.-Y., SÖDERLUND, L. and LIU, G.-H., 2005. Impacts of sewage irrigation on heavy metal distribution and contamination in Beijing, China. *Environment International*, vol. 31, no. 6, pp. 805-812. http://dx.doi.org/10.1016/j.envint.2005.05.042. PMid:15979146.

LWALABA, J.L., LOUIS, L.T., ZVOBGO, G., RICHMOND, M.E., FU, L., NAZ, S., MWAMBA, M., MUNDENDE, R.P. and ZHANG, G., 2020. Physiological and molecular mechanisms of cobalt and copper interaction in causing phyto-toxicity to two barley genotypes differing in Co tolerance. *Ecotoxicology and Environmental Safety*, vol. 187, p. 109866. http://dx.doi.org/10.1016/j.ecoenv.2019.109866. PMid:31677568.

MARIJANUSIC, K., MANOJLOVIC, M., BOGDANOVIC, D., CABILOVSKI, R. and LOMBNAES, P., 2017. Mineral composition of forage crops in respect to dairy cow nutrition. *Bulgarian Journal of Agricultural Science*, vol. 23, no. 2, pp. 204-212.

MCDOWELL, L.R., CONRAD, J.H., ELLIS, G.L. and LOOSKI, J.K., 1983. *Minerals of grazing ruminants in tropical regions*. Gainesville: University of Florida.

MICLEAN, M., CADAR, O., LEVEI, E.A., ROMAN, R., OZUNU, A. and LEVEI, L., 2019. Metal (Pb, Cu, Cd, and Zn) transfer along food chain and health risk assessment through raw milk consumption from free-range cows. *International Journal of Environmental Research and Public Health*, vol. 16, no. 21, p. 4064. http://dx.doi.org/10.3390/ijerph16214064. PMid:31652702.

OMONIWA, O.D., UCHENDU, C., ABDULLAHI, S.U., BALE, J.O.O. and ABDULLAHI, U.S., 2017. Survey of trace elements and some heavy metals in goats in Zaria and its environs, Kaduna State. *Nigerian Veterinary Journal*, vol. 38, no. 4, pp. 280-287. http://dx.doi.org/10.4314/nvj.v38i4.1.

OZFIDAN-KONAKCI, C., ALP, F.N., ARIKAN, B., BALCI, M., PARMAKSIZOGLU, Z., YILDIZTUGAY, E. and CAVUSOGLU, H., 2022. The effects of fullerene on photosynthetic apparatus, chloroplast-encoded gene expression, and nitrogen assimilation in Zea mays under cobalt stress. *Physiologia Plantarum*, vol. 174, no. 3, p. e13720. http://dx.doi.org/10.1111/ppl.13720. PMid:35596692.

PATEL, B.R., PATEL, H.B., SINGH, R.D., SARVAIYA, V.N., PAWAR, M.M. and MODY, S.K., 2019. Comparative study on heavy metal contamination in soil, water and fodder between industrial and non-industrial areas of Kutch District, Gujarat, India. *International Journal of Current Microbiology and Applied Sciences*, vol. 8, no. 10, pp. 2096-2103. http://dx.doi.org/10.20546/ijcmas.2019.810.244.

PATKOWSKA-SOKOŁA, B., DOBRZAŃSKI, Z., OSMAN, K., BODKOWSKI, R. and ZYGADLIK, K., 2009. The content of chosen chemical elements in wool of sheep of different origins and breeds. *Archiv fur Tierzucht*, vol. 52, no. 4, pp. 410-418. http://dx.doi.org/10.5194/aab-52-410-2009.

RIZO, O.D., HERNÁNDEZ, I.C., LÓPEZ, J.O.A., ARADO, O.D., PINO, N.L. and RODRÍGUEZ, K.D., 2011. Chromium, cobalt and nickel contents in urban soils of Moa, Northeastern Cuba. *Bulletin of Environmental Contamination and Toxicology*, vol. 86, no. 2, pp. 189-193. http://dx.doi.org/10.1007/s00128-010-0173-z. PMid:21161504.

RIZWAN, H.M., SAJID, M.S., IQBAL, Z. and SAQIB, M., 2019. Association of phytomineral with gastrointestinal parasites of grazing sheep in Sialkot district, Punjab, Pakistan. *Pakistan Journal of Agricultural Sciences*, vol. 56, no. 2, pp. 459-468.

ROGGEMAN, S., VAN DEN BRINK, N., VAN PRAET, N., BLUST, R. and BERVOETS, L., 2013. Metal exposure and accumulation pattern in free-range cows (Bos Taurus) in a contaminated natural area: influence of spatial and social behavior. *Environmental Pollution*, vol. 172, pp. 186-199. http://dx.doi.org/10.1016/j.envpol.2012.09.006. PMid:23063994.

SALAM, A., KHAN, A.R., LIU, L., YANG, S., AZHAR, W., ULHASSAN, Z., ZEESHAN, M., WU, J., FAN, X. and GAN, Y., 2022. Seed priming with zinc oxide nanoparticles downplayed ultrastructural damage and improved photosynthetic apparatus in maize under cobalt stress. *Journal of Hazardous Materials*, vol. 423, no. Pt A, p. 127021. http://dx.doi.org/10.1016/j.jhazmat.2021.127021. PMid:34488098.

SALEH, H.N., PANAHANDE, M., YOUSEFI, M., ASGHARI, F.B., CONTI, G.O., TALAEE, E. and MOHAMMADI, A.A., 2019. Carcinogenic and noncarcinogenic risk assessment of heavy metals in groundwater wells in Neyshabur Plain, Iran. *Biological Trace Element Research*, vol. 190, no. 1, pp. 251-261. http://dx.doi.org/10.1007/s12011-018-1516-6. PMid:30225757.

SHARMA, S., NAGPAL, A.K. and KAUR, I., 2018. Heavy metal contamination in soil, food crops and associated health risks for residents of Ropar wetland, Punjab, India and its environs. *Food Chemistry*, vol. 255, pp. 15-22. http://dx.doi.org/10.1016/j.foodchem.2018.02.037. PMid:29571461.

SINGH, A., SHARMA, R.K., AGRAWAL, M. and MARSHALL, F.M., 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*, vol. 48, no. 2, pp. 611-619. http://dx.doi.org/10.1016/j.fct.2009.11.041. PMid:19941927.

SYSO, A.I., SOKOLOV, V.A., PETUKHOV, V.L., LEBEDEVA, M.A. and CHEREVKO, A.S., 2017. Ecological and biogeochemical evaluation of elements content in soils and fodder grasses of the agricultural lands of Siberia. *International Journal of Pharmaceutical Sciences and Research*, vol. 9, no. 4, p. 368.

TAHA, K.K., SHMOU, I.M., OSMAN, M.H. and SHAYOUB, M.H., 2013. Soil-plant transfer and accumulation factors for trace elements at the Blue and White Niles. *Journal of Applied and Industrial Sciences*, vol. 1, no. 2, pp. 97-102.

TAHIR, M., IQBAL, M., ABBAS, M., TAHIR, M.A., NAZIR, A., IQBAL, D.N., KANWAL, Q., HASSAN, F. and YOUNAS, U., 2017. Comparative study of heavy metals distribution in soil, forage, blood and milk. *Acta Ecologica Sinica*, vol. 37, no. 3, pp. 207-212. http://dx.doi.org/10.1016/j.chnaes.2016.10.007.

UKPE, A.R. and CHOKOR, A.A., 2018. Correlation between concentrations of some heavy metals in poultry feed and waste. *Open Access Journal of Toxicology*, vol. 3, no. 2, p. 555609. http://dx.doi.org/10.19080/OAJT.2018.03.555609.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY – USEPA, 2002. *Biosolids applied to land: Advancing standards and practices*. Washington, D.C.: National Research Council/National Academy Press. 282 p.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY – USEPA, 2010. *Risk-based concentration table*. Washington, D.C.: Office of Research and Development/US Environmental Protection Agency.

VOROBYOV, V., VOROBYOV, D., POLKOVNICHENKO, P. and SAFONOV, V., 2019. Evaluation of hematological and metabolic parameters in small ruminants with trace elements deficiency under different biogeochemical conditions. *World's Veterinary Journal*, vol. 9, no. 4, pp. 311-316. http://dx.doi.org/10.36380/scil.2019.wvj39.

WU, T., SONG, M. and SHEN, X., 2020. Seasonal dynamics of copper deficiency in Wumeng semi-fine wool sheep. *Biological Trace Element Research*, vol. 197, no. 2, pp. 487-494. http://dx.doi.org/10.1007/s12011-019-02018-5. PMid:31953598.

YASOTHA, A., DABADÉ, D.S., SINGH, V.P. and SIVAKUMAR, T., 2021. Risk assessment of heavy metals in milk from cows reared around industrial areas in India. *Environmental Geochemistry and Health*, vol. 43, no. 5, pp. 1799-1815. http://dx.doi.org/10.1007/s10653-020-00758-1. PMid:33123929.

YUSOF, H.M., RAHMAN, N.A., MOHAMAD, R., ZAIDAN, U.H. and SAMSUDIN, A.A., 2023. Influence of dietary biosynthesized zinc oxide nanoparticles on broiler zinc uptake, bone quality, and antioxidative status. *Animals*, vol. 13, no. 1, p. 115. http://dx.doi.org/10.3390/ani13010115. PMid:36611723.