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ORIGINAL ARTICLE

Assessment of toxic metals in wheat crops grown on selected soils, irrigated by different water sources

Zeid A. Al-Othman [a], Rahmat Ali [a,*], Abdulaziz M. Al-Othman [b], Jawad Ali [c], Mohamed A. Habila [a]

[a] *Advanced Material Research Chair, Department of Chemistry, College of Science, Building-5, King Saud University, Riyadh, Saudi Arabia*
[b] *Department of Community Health Sciences, College of Applied Medical Science, King Saud University, Riyadh 11433, Saudi Arabia*
[c] *Institute of Chemical Sciences, University of Peshawar, Peshawar 25120, Pakistan*

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Abstract We describe a comparative study of the concentration of different metals (e.g., Cd, Pb, As, Ni, Cu, Zn, Mn, and Cr) in various parts of wheat plants (e.g., roots, stem, leaves and seeds) collected at several locations in Khyber Pukhtoon Khaw, Pakistan. The wheat crop in these areas was irrigated using different irrigation sources, including rain, tube well, river, and canal. In wheat samples, the concentration of metals was analyzed using an atomic absorption spectrophotometer. Among the various parts of the plant, the roots had the highest levels of heavy metals, followed by the vegetative parts. By comparison, the seeds and grains had the lowest levels of heavy metals. The levels of heavy metals in all of the studied areas were not significantly localized to any particular area. The general order for the accumulation of studied metals in wheat was found to be Mn > Zn > Cu > Ni > Cr > As > Pb > Cd.

1. Introduction

The world is focusing on the problem of pollution, which is an undesirable change in the physical, chemical and biological characteristics of air, water and soil that affects the lives of humans and animals (Misra and Mani, 1991; Jamal et al., 2002; Al-Othman et al., 2012a). All over the world, industrialization has resulted in the degradation of environmental quality, resulting in long-term, adverse health effects (Vander

* Corresponding author. Tel.: +966 560467434.
E-mail address: rahmat_chemistpk@yahoo.com (R. Ali).
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Gaag et al., 1991). Soil is a mixture of a variety of inorganic, organic, gaseous and liquid substances, so it acts as a sink for these pollutants, to varying degrees (McLaren and Crawford, 1973; Evans, 1989; Schnitt and Sticher, 1991). Identified routes for the introduction of heavy metals into the human body include direct inhalation of contaminated air, ingestion of contaminated water, and direct ingestion of soil and consumption of food plants grown in metal-contaminated soil (Dudka and Miller, 1999; Bhagure and Mirgane, 2011). In addition, studies have indicated that crops grown in metal-contaminated soil have higher concentrations of metals than those in uncontaminated soil (Dowdy and Larson, 1975). Certain trace metals are essential for plants, playing important roles in plant metabolism and biosynthesis, both as cofactors for enzymes and as metabolic products (Rattan et al., 2005). For example, Zn, Fe, Cu, Cr, and Co are essential nutrients but become toxic at high concentrations. By contrast, Pb and Cd have no known beneficial effects in plants and are exclusively toxic (Radojevic and Bashkin, 1999; Mohamed and Ahmed, 2006). Thus, plants grown in a polluted environment can accumulate trace elements at high concentrations and may serve as a main pathway for transferring metals into the food chain. These plants then pose a serious risk to consumers (Alloway et al., 1990).

Heavy metal accumulation is one of the most serious environmental concerns of the present day, not only because many of these metals are toxic to the crops themselves, but also because of their potential harm to animals and humans. Metals are non-biodegradable and are considered major environmental pollutants resulting in cytotoxic, mutagenic and carcinogenic effects in animals (More et al., 2003; Al-Othman et al., 2011). The accumulation of heavy metals in plants occurs both in roots and aboveground tissue, so monitoring of the bioavailable pool of metals has attracted a lot of interest (Rattan et al., 2005; Rajurkar and Daman, 1998).

Wheat is one of the main crops and an integral constituent of the national diet. It plays a vital role in human growth by providing carbohydrates, proteins and certain inorganic micronutrients (Anita et al., 2010). Consumption of grain is safe when accumulation of metals is under the permissible limits (Das, 1990; Khan et al., 2008). However, when accumulations exceed the permissible limit, it exerts toxic effects and may produce a variety of diseases in human (Nariago, 1990; Melamed et al., 2003; Al-Othman et al., 2012b). In the past, the study of heavy metal pollution focused primarily on certain industrialized regions. In the present investigation, we focused on both polluted and unpolluted areas of Khyber Pukhtoon Khaw, Pakistan, that were irrigated with different water systems (canal, river, tube well and rain). The data collected helped us to understand the distribution of heavy metals in the studied areas. The study was important for assessing the suitability of irrigation system and for increasing public awareness of the threat of heavy metal pollution. The present investigation was carried out with the following objectives.

- To determine the quality of our irrigation system being used for the irrigation of crops.
- To evaluate the distribution of metals in the sampling area.
- To determine the concentration of different metal ions in the irrigated crops.
- To track the movement of heavy metals across different plant parts.

2. Experimental

2.1. Collection of samples

Wheat plants and respective soil samples were collected from twelve areas of Khyber Pukhtoon Khaw which included Swabi, Shergarh, Dir, Takhtbai, Mardan, Batkhela, Swat, Bara, Kohat, Karak, Nowshera and Peshawar, where the fields were irrigated with different water systems (canal, river, tube well and rain). Soil samples were stored in glass containers for further study, while the plant samples were subjected to further processing. Specifically, the plants were rinsed with deionized water, dried in the shade and then in an oven at 110 °C for 2–4 h. The roots, stem, leaves and seeds were then separated and crushed to powder. The dried and powdered samples were subsequently stored in bottles for further study. During all these steps, necessary measures were taken to avoid any loss of sample or contamination of the sample with heavy metals.

2.2. Sample preparation

One gram of crushed, powdered plant parts was weighed in crucibles and heated in a furnace for 5 h at 550 °C. The content of the crucibles was then cooled under desiccating conditions. Next, 2.5 ml of 6 M HNO_3 was added to dissolve the samples (AOAC, 2000). All the required glassware was first washed with standard detergent followed by tap water, soaked in an acid bath (30% nitric acid) and placed in a fume hood to dry. Thereafter, glassware was rinsed first with tap water and then with de-ionized water (Robert, 1981). The sample solution was then filtered, transferred to 20 ml volumetric flasks, diluted to the mark and examined by atomic absorption spectrophotometer.

2.3. Analysis of metals

Concentrations of Cd, Pb, As, Ni, Cu, Zn, Cr, and Mn in the plant samples were measured by an atomic absorption spectrophotometer (Vario 6, Analytic Jena), operated in single-beam mode. The instrumental parameters are listed in Table 1. All the chemicals used were of analytical grade (Merck). The deionized water used in the analysis had an electrical resistivity of 10 MΩ/cm. The reference materials (commercial standards) used were from CPA Chem. Ltd., Bulgaria. Calibration with a linear regression value (R^2) of 0.999 was established for each element.

Maximum care was taken to minimize random and systematic errors. Calibration curves were obtained and the tests were carried out in duplicate to establish confidence in the accuracy, reproducibility and reliability of the data. Health and safety measures were also observed.

2.4. Soil characterization

The soil samples collected from different locations were characterized by pH and by soil moisture, as % weight, to aid in

Table 1 Instrument parameters used for metal analysis.

Metals	Wavelength (nm)	Atomization mode	Lamp current (mA)	Slit width (nm)
Cd	228.8	GF	4	0.8
Pb	283.3	GF	8	0.5
As	193.7	HS	8	0.8
Ni	193.7	A/A	6	0.2
Cu	324.8	A/A	3	1.2
Zn	219.9	A/A	4	0.5
Cr	357.9	GF	4	0.8
Mn	279.5	A/A	10	0.2

GF = graphite furnace, A/A = air/acetylene, HS = hydride.

Table 2 pH and % grain moisture content of the soils of selected areas.

Location	Irrigation source	pH	% Moisture
Swabi	Tube well	6.29	8.0
Shergarh	Canal	6.54	8.1
Dir	Rain	6.34	5.0
Takhtbai	Canal	6.97	9.4
Mardan	Canal	7.33	6.7
Batkhela	River	6.84	4.6
Swat	Rain	6.94	5.4
Bara	Rain	6.97	4.4
Kohat	Tube well	7.06	5.9
Karak	Rain	7.17	3.6
Nowshera	River	6.79	7.6
Peshawar	Canal	6.41	6.9

interpreting the concentration of the metals in the respective plants and the modes of irrigation, respectively.

3. Results and discussion

3.1. Soil parameters

Soil parameters that influenced metal solubility and movement included pH, total metal concentration, texture, and organic matter (Welch and Lund, 1987). Table 2 summarizes the pH and moisture content of all the soil samples. The availability of metals from the soil to the plant is generally dependent on the soil pH. Ordinarily, at pH higher than 6.5 metals tend to be less available to plants, especially when they are present in their oxidized form (Harrisn and Waites, 1998). Thus, at high pH most soils will tie up large quantities of these metals and they will not be available for plants. In Table 2, the pH ranged from 6.29 to 7.33, so low concentrations of heavy metals were expected in the crops cultivated in the study areas. The data in Table 2 indicated that the pH of the soil did not seem to be dependent on the irrigation source, but rather on the geological strata of the ground.

Table 2 indicates that the moisture content of the soil samples was highest in areas irrigated by canals (6.9–9.4%), followed by those irrigated via tube wells (5.9–8.0%), rivers (4.6–7.06%) and rain water (3.6–4.4%). The moisture content is related to the mobility of metallic contaminates in the soil.

3.2. Concentration of metals

Table 3 exhibits the maximum permissible level of different metals in crops. The concentration of each metal in different parts of plants collected from various areas is given in Table 4, and Figs. 1 and 2 indicate the mean concentration of each metal in the wheat plants collected from different areas. Fig. 3 shows the selected areas in Khyber Pukhtoon Khaw from where the samples were collected. The concentration of different metals in various parts of the plants is discussed below.

3.2.1. Cadmium

The level of Cd in different plant parts ranged from a minimum of 0.011 mg/kg to a maximum of 0.039 mg/kg (Table 4). The highest concentration (0.039 mg/kg) was found in plant leaves from the Takhtbhai area and (0.038 mg/kg) in plant stems from the Kohat area. Similarly in the case of seed and roots, the highest concentrations of Cd were found in the Dir area (0.030 mg/kg) and the Kohat area (0.036 mg/kg). It was also observed that the general pattern for the distribution of Cd in different parts of the plant was roots > leaves > stem > seed.

The distribution of Cd revealed that the highest mean level was found in samples from Kohat (0.030 mg/kg) followed by samples from the Dir area (0.028 mg/kg). The irrigation sources in these areas were found to be tube well and rain, respectively. In the Kohat area the soil pH was high but the irrigation mode was tube well, where water is drawn from sufficient depth where most of the salts available in the geological strata are easily available to be dissolved in the water. Therefore, it could be concluded that the concentration of Cd in water for plant absorption was high. In the Dir area the soil pH was below 6.5, making whatever quantity of Cd in the soil or water readily available for plant uptake.

The lowest mean level was observed in samples obtained from the Batkhela region (0.017 mg/kg), where the soil pH was high. Specifically, the levels of Cd were found to be lower than the critical level (0.20 mg/kg) in all of the samples from this region (Weigert, 1991; Pendias and Pendias, 1984).

3.2.2. Lead

The concentration of Pb in various parts of the wheat plant is shown in Table 4. The concentrations were in the range of 0.044–0.209 mg/kg, with the maximum concentration in plant roots collected from the area of Swat (0.209 mg/kg) and in plant leaves from Dir (0.190 mg/kg). In the case of seeds and stems, the highest concentrations were recorded in samples collected from the Mardan area (0.186 mg/kg and 0.171 mg/kg, respectively). The order for the levels of Pb in different plant parts was found to be roots > leaves > stem > seed.

The maximum mean level of Pb was found in the samples collected from Mardan and Peshawar (0.169 mg/kg) followed by samples from Takhtbai (0.166 mg/kg) and Shergarh areas (0.162 mg/kg). The lowest mean value was found in Karak (0.060 mg/kg). The source of irrigation was surface water (i.e., rivers and canals) in Mardan, Peshawar, Takhtbai and Shergarh. As surface water collects most of the aerial pollution, the fact that these areas are home to some major highways and support heavy transportation suggested that the cause of high Pb in plant samples of these areas was Pb

Table 3 Permissible levels of trace metals in agronomic crops (mg/kg) (Weigert, 1991; Pendia and pendias, 1984).

Metal	Cd	Pb	As	Ni	Cu	Zn	Cr	Mn
Maximum permissible limit	0.20	0.30	0.43	67.90	73.30	99.40	2.30	500

Table 4 Concentration of various metals in different parts of wheat plants (mg/kg).

Area	Swabi	Shergarh	Dir	Takhtbai	Mardan	Batkhela	Swat	Bara	Kohat	Karak	Nowshera	Peshawar
Cd												
Roots	0.023	0.029	0.016	0.020	0.030	0.027	0.028	0.028	0.036	0.025	0.032	0.021
Leaves	0.017	0.028	0.034	0.039	0.013	0.012	0.029	0.024	0.019	0.025	0.019	0.017
Stem	0.034	0.017	0.031	0.031	0.023	0.017	0.015	0.03	0.038	0.027	0.016	0.024
Seeds	0.025	0.022	0.030	0.011	0.027	0.014	0.020	0.019	0.026	0.029	0.029	0.015
Mean	0.025	0.024	0.028	0.025	0.023	0.017	0.023	0.025	0.029	0.026	0.024	0.019
Pb												
Roots	0.114	0.176	0.157	0.183	0.187	0.146	0.209	0.119	0.099	0.073	0.121	0.185
Leaves	0.118	0.164	0.190	0.185	0.152	0.161	0.164	0.092	0.075	0.074	0.081	0.173
Stem	0.115	0.159	0.162	0.168	0.171	0.158	0.157	0.121	0.069	0.052	0.064	0.164
Seeds	0.134	0.151	0.129	0.131	0.186	0.183	0.063	0.113	0.081	0.044	0.044	0.152
Mean	0.12	0.162	0.159	0.166	0.169	0.162	0.148	0.111	0.081	0.060	0.077	0.169
As												
Roots	0.014	0.028	0.009	0.110	1.113	0.425	0.114	0.112	0.146	0.112	0.159	0.147
Leaves	0.136	0.124	0.179	0.128	0.089	0.185	0.143	0.083	0.008	0.022	0.016	0.153
Stem	0.067	0.013	0.019	0.056	0.136	0.274	0.067	0.122	0.165	0.121	0.133	0.124
Seeds	0.184	0.051	0.114	0.175	0.116	0.134	0.127	0.043	0.039	0.005	0.015	0.012
Mean	0.100	0.054	0.080	0.117	0.363	0.254	0.112	0.090	0.089	0.065	0.080	0.109
Ni												
Roots	0.055	0.036	0.069	0.084	1.150	1.041	1.034	2.056	2.060	0.186	0.156	0.250
Leaves	0.147	0.120	1.059	1.026	1.030	0.538	0.521	0.043	0.045	0.015	0.060	0.113
Stem	0.024	0.042	0.015	0.061	0.230	0.243	0.618	1.053	1.030	0.132	0.138	0.094
Seeds	0.123	0.119	1.139	1.047	0.524	0.150	0.148	0.072	0.091	0.057	0.057	0.120
Mean	0.087	0.079	0.570	0.554	0.733	0.493	0.580	0.806	0.806	0.097	0.102	0.143
Cu												
Roots	0.202	4.625	2.208	1.029	1.212	1.099	1.870	0.213	0.450	0.205	0.356	0.520
Leaves	0.302	0.119	0.112	0.089	0.453	0.426	0.142	0.196	0.173	0.330	0.185	0.360
Stem	0.154	0.424	0.189	0.133	0.124	0.280	0.225	0.154	0.143	0.234	0.164	0.230
Seeds	0.150	0.150	0.095	0.127	0.172	0.139	0.092	0.124	0.163	0.122	0.114	0.420
Mean	0.202	1.330	0.651	0.344	0.490	0.486	0.582	0.171	0.232	0.222	0.204	0.382
Zn												
Roots	3.169	2.262	1.163	1.199	1.174	0.599	1.492	0.292	0.282	0.424	0.136	3.150
Leaves	1.230	0.089	0.140	0.111	0.554	0.230	0.143	0.297	1.150	1.100	2.152	0.360
Stem	1.143	2.143	1.164	0.130	0.182	0.342	0.134	0.324	0.230	0.520	0.118	0.520
Seeds	0.206	0.206	0.153	0.248	0.177	0.160	0.166	0.162	0.814	1.167	3.114	0.420
Mean	1.437	1.175	0.655	0.422	0.521	0.332	0.483	0.269	0.619	0.802	1.380	1.112
Cr												
Roots	0.119	0.035	1.016	0.122	0.133	0.125	0.195	0.015	0.027	0.031	0.026	0.110
Leaves	0.050	0.019	0.110	0.019	0.095	0.170	0.129	0.125	1.018	0.120	0.130	0.052
Stem	0.126	0.128	1.014	0.120	0.150	0.142	0.098	0.016	0.075	0.023	0.016	0.046
Seeds	0.138	0.095	1.015	0.122	0.127	0.115	0.082	0.013	0.024	0.018	0.018	0.043
Mean	0.108	0.069	0.789	0.095	0.126	0.138	0.126	0.042	0.286	0.048	0.047	0.062
Mn												
Roots	0.514	0.333	0.513	0.522	0.717	1.249	3.359	0.404	0.953	0.319	0.884	4.467
Leaves	0.120	0.101	0.130	0.124	0.568	0.310	0.140	0.112	0.100	0.110	0.326	4.420
Stem	0.468	0.241	0.134	0.328	0.310	0.342	0.464	1.324	0.314	0.550	0.523	0.850
Seeds	0.378	0.378	0.284	0.846	0.340	0.264	0.349	0.320	0.353	0.318	0.520	4.150
Mean	0.370	0.263	0.265	0.455	0.484	0.541	1.078	0.540	0.430	0.324	0.563	3.471

released by transportation. However, the concentration of Pb in all of the samples was still within the maximum permissible level (0.30 mg/kg).

On other hand, rain irrigated areas had the lowest levels of Pb, as in Karak. In this area, transportation is not as developed and the frequency of irrigation by rainfall remained

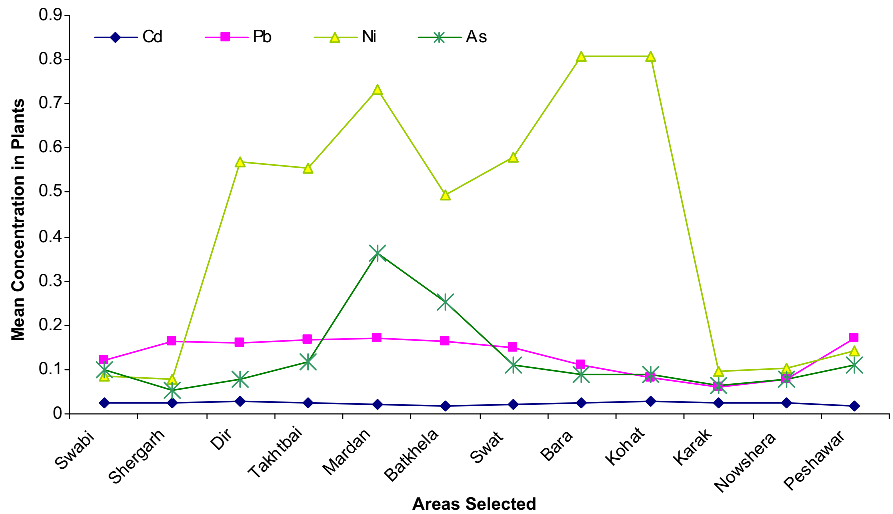

Figure 1 The mean concentration (mg/kg) of Cd, Pb, Ni and As in wheat plant of selected areas.

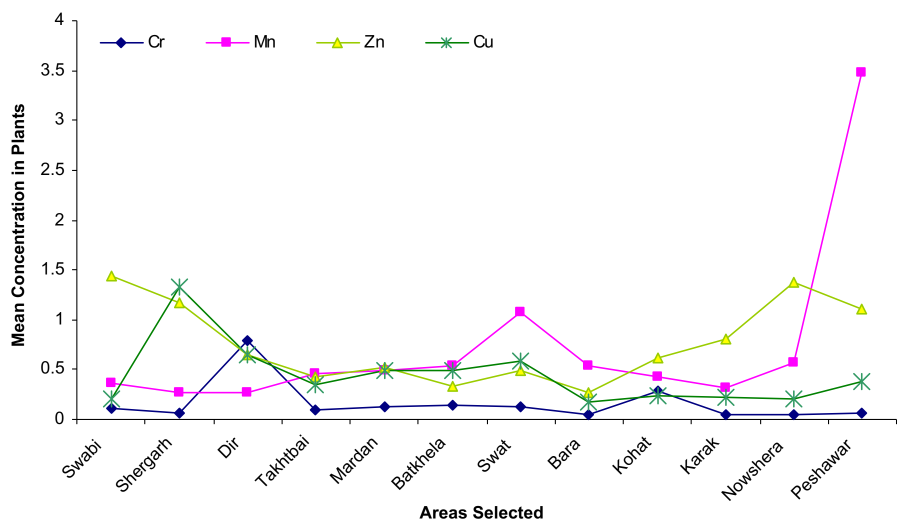

Figure 2 The mean concentration (mg/kg) of Cr, Mn, Zn and Cu in wheat plant of selected areas.

lower than by canal or rivers. Therefore, the plants in this area received the lowest doses of Pb.

3.2.3. Arsenic

The concentrations of arsenic (As) in different parts of the plant (root, stem, leaves and seeds) were in the range 0.005–1.113 mg/kg. In plant roots and leaves, the highest concentrations were found in samples collected from Mardan (1.113 mg/kg) and Batkhela (0.425 mg/kg). In the case of plant stem, the highest concentration of As was observed in samples from Batkhela (0.274 mg/kg). In seeds the maximum level was found in the samples from Dir (0.184 mg/kg), while in plant leaves it was observed in samples from the Swabi area (0.179 mg/kg). The considerable level of As in aerial parts suggested that the wheat plant is a strong bioaccumulator. The pattern of accumulation of As in the various parts of the plant was roots > stem > leaves > seed.

The study of the distribution of As revealed that the maximum mean level was found in Mardan (0.363 mg/kg), followed by Batkhela (0.254 mg/kg) and Takhtbai (0.117 mg/kg). Meanwhile, the lowest mean level was observed in the Shergarh area (0.049 mg/kg). These results illustrated that the concentration of As in wheat plants from different areas was not related to the type of irrigation, but rather to the agro-climatic conditions of the area (the main source of As to the environment is agrochemicals (pesticides) or volcanic eruptions). In Mardan, Batkhela and Takhtbai, the application of pesticides is more common than in the other areas because of increased production of vegetables and fruits on their fertile land, with suitable irrigation systems and a favorable climate. Therefore, As finds its way to the groundwater and contaminates the soil in these areas, which is then transferred to plants.

Except for the plant root samples collected from the Mardan area, the concentrations of As in various parts of the plants were below the permissible limit for As in crops (0.43 mg/kg).

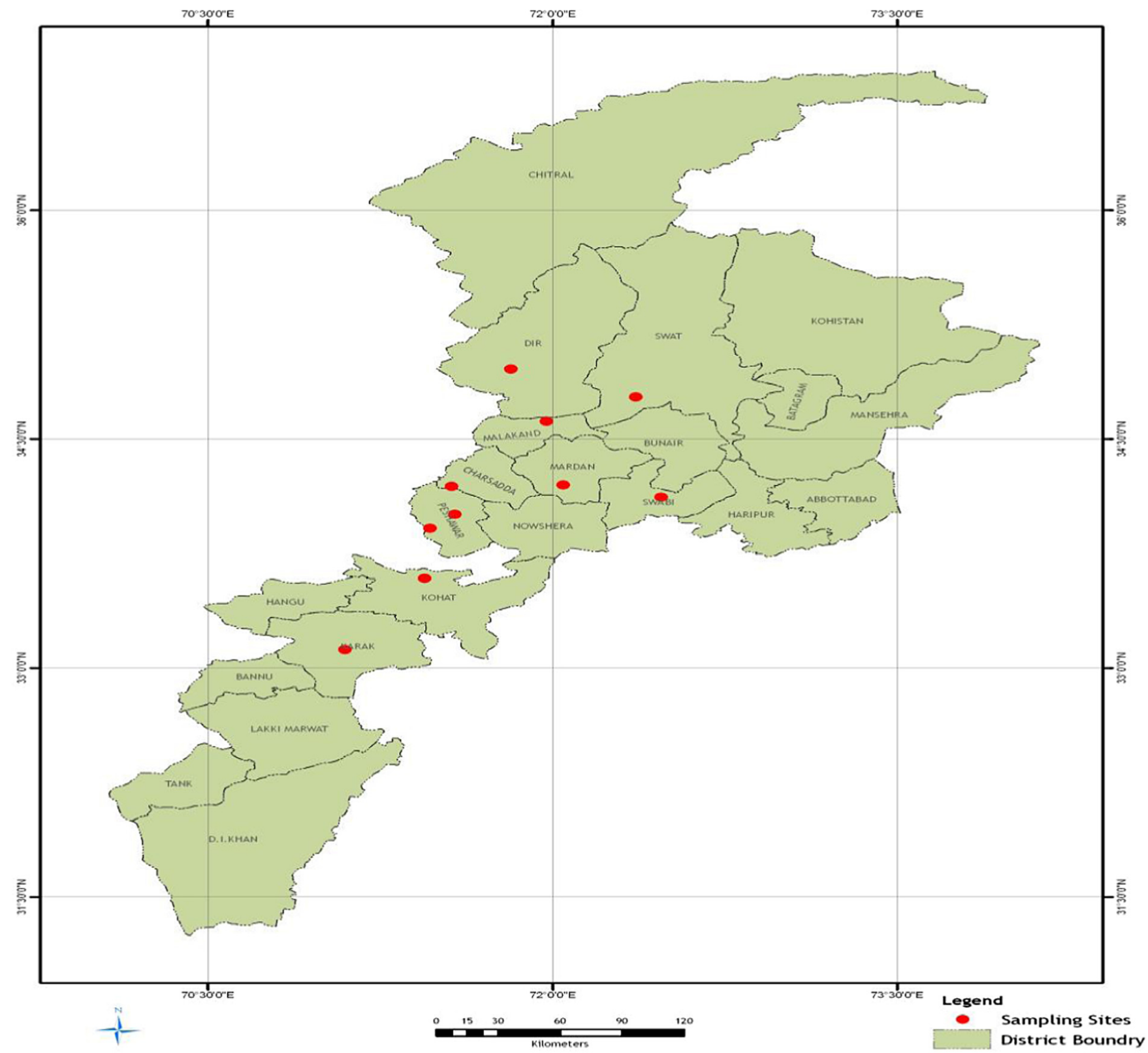

Figure 3 The location of sampling sites in NWFP, Pakistan.

3.2.4. Nickel

Nickel content in the tested samples occurred in the range 0.015–2.060 mg/kg. The highest level was found in plant root samples collected from Kohat (2.060 mg/kg) and Bara (2.056 mg/kg). In stems and seeds, the maximum level was found in samples from Bara (1.053 mg/kg) and Dir areas (1.139 mg/kg), respectively. The lowest level was observed in plant leaves of samples from Karak (0.015 mg/kg) and in plant stems from the Dir area. The considerable level of Ni in the aerial parts indicated their strong bioaccumulation. The general behavior for the accumulation of Ni in various parts of the plants was found to be roots > leaves > stem > seed.

The highest mean level of Ni was found in plants from Bara and Kohat areas (0.806 mg/kg), followed by Mardan (0.733 mg/kg). The lowest mean level was found in plant samples from Shergarh (0.079 mg/kg). Possible sources of Ni contamination are industrial effluents and the geological strata. In the case of the Kohat area the high concentration of Ni may be attributed to the irrigation source (tube well), where the water table lies at a sufficient depth to dissolve Ni from the geological strata as soluble salts. In the case of the Bara area the irrigation source was rain, which does not supply Ni. It could thus be assumed that Ni present in the soil came from municipal sewage or organic and synthetic manure applied to the soil. The low pH of the soil then facilitated plant uptake, as mentioned earlier. In general, however, the level of Ni in all the samples was below the maximum permissible level (67.90 mg/kg).

3.2.5. Copper

The level of Cu fell in the range 0.089–4.625 mg/kg for all the samples studied. Among the different parts of the plants, the highest concentration in roots, leaves and stem was found in plants collected from the Shergarh area (4.625, 0.453 and 0.424 mg/kg, respectively). In plant seeds, the high concentration was found in samples from the Peshawar area (0.420 mg/kg). From the results it was found that the pattern of Cu accumulation in the different parts was roots > leaves > stem > seed.

The maximum mean concentration of Cu was found in plants from Shergarh (1.330 mg/kg), followed by Dir (0.651 mg/kg). The lowest mean level was found in plant samples collected from the area of Bara (0.171 mg/kg). The wheat crops were irrigated by a canal in Shergarh and by rain water in Dir and Bara. It could thus be assumed that the copper levels in the wheat plants were not dependent on the irrigation system, but rather on the geological strata of the area. The level of Cu in all samples was observed to be lower than the permissible level in crops (73.30 mg/kg).

3.2.6. Zinc

Zinc is an essential element for the growth of plants, and is also vital for a variety of functions in humans, including growth, brain development, behavioral response, bone formation and wound healing. The concentration of Zn in all the plant samples was found to be in the range 0.111–3.169 mg/kg. Among the various parts, the concentration of Zn in plant roots was highest from the Swabi (3.169 mg/kg) and Peshawar (3.150 mg/kg) areas. In plant leaves and seeds, the maximum concentrations were found in samples from Nowshera (2.152 and 3.114 mg/kg, respectively), while in plant stem high levels of Zn were found in plants of the Shergarh area (2.143 mg/kg). From these results it was concluded that excess bioaccumulation of Zn occurred in the aerial parts of the plant. The concentration of Zn in various parts of the plant was found to be in the order roots > leaves > seed > stem.

The distribution of Zn indicated that maximum mean levels of Zn were found in samples collected from Swabi (1.437 mg/kg), followed by those from Nowshera (1.380 mg/kg) and Shergarh (1.175 mg/kg). Meanwhile, the lowest mean concentration was found in Bara (0.269 mg/kg). In the case of Swabi, the source of irrigation was a tube well, indicating that the origin of the high levels of Zn in plants was due to the geological strata (tube well water is rich in dissolved metal salts). In contrast, Nowshera and Shergarh systems of irrigation were surface water (canal and river), so it was assumed that water flowing in these areas carried Zn salts from the geological strata of that specific area. On the other hand, in areas where irrigation is by rain water, the concentration of Zn was very low. The level of Zn in all the samples was found to be lower than the maximum permissible level in crops (99.40 mg/kg).

3.2.7. Chromium

Chromium concentrations in wheat plants were found in the range 0.013–1.018 mg/kg. Among different parts of the plant, maximum Cr concentration was found in leaves from the Kohat area (1.018 mg/kg), whereas in plant roots, stem, and seeds, Cr was highest in samples from Dir area (1.016, 1.014 and 1.015 mg/kg, respectively). The high levels in the green parts of the plants indicated the tendency of this metal for bioaccumulation there. The order of accumulation for Cr in various parts of the plants was found to be roots > stem > leaves > seed.

Among the locations, the mean level of Cr was found to be maximum in Dir (0.789 mg/kg), followed by Kohat (0.286 mg/kg). The lowest mean level was found in Bara (0.042 mg/kg). Furthermore, the level of Cr in all the samples was found to be below the maximum permissible level of Cr in crops (2.30 mg/kg). These results demonstrated that Cr contamination in plants was of geological origin. In the case of Kohat, wheat crop is irrigated with tube well water, which draws a variety of salts from the underground deposits. In the Dir area, there is no industrial or transportation emission and the source of irrigation is rain fall, which have no direct influence on the Cr level in soil.

3.2.8. Manganese

The level of Mn in the various parts of the plant was found in the range 0.100–4.467 mg/kg. Among the various parts, the highest concentration of Mn was found in plant root samples collected from Peshawar (4.467 mg/kg), followed by those from Swat (3.359 mg/kg). In plant stem, the maximum concentration was found in plants from Bara (1.324 mg/kg), while for plant seeds and leaves, it was highest in the Peshawar area (4.150 and 4.420 mg/kg, respectively). The significant level of Mn in the aerial parts of the plant was indicative of strong bioaccumulation. The level of Mn accumulated in different parts of the plants followed the order roots > stem > seed > leaves.

The comparative study of the distribution of Mn in wheat plants revealed that the maximum mean level of Mn was found in the Peshawar area (3.471 mg/kg), followed by Swat (1.078 mg/kg). The lowest mean level, however, was found in Shergarh (0.263 mg/kg). Additionally, the level of Mn in all the tested samples was found lower than the maximum permissible level for Mn in crops (500 mg/kg). Mn is an essential element for the growth of plants, preventing yellowing of the leaves. The main source of Mn is its salts found underground. In the Swat area, the method of irrigation was rain, which is not directly related to the addition of Mn to the soil. However, it may be assumed that Mn of geological origin is responsible for the high levels in plants. This was further supported by the fact that in both Peshawar and Shergarh, the source of irrigation was surface water, but in the former the level of Mn in plants was maximum but in the later it was minimum. This phenomenon showed that the soil of Peshawar was richer in Mn salts than Shergarh.

4. Conclusions

Based on the results of this investigation it can be concluded that roots retained higher levels of metals than the aerial parts, whereas the seeds and grains had the lowest levels of metals. These findings revealed that metals were not distributed in a uniform pattern. The bioaccumulation of metal in wheat plants is important. This fact supports the theory of phytotoxicity, by which metals are transported to the food chain. In some areas, industrialization and transportation are not well developed, but the high concentration of metals in crops suggests the geological origin. Since wheat plants tend to accumulate heavy metals in their aerial parts, and in view of their important role in the food chain, it is recommended that this type of plant should not be cultivated in farms and fields contaminated by heavy metals.

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