Evaluation of heavy metal pollution along Alamedin River in Bishkek/Kyrgyzstan using woody species, Populus nigra (black poplar) and Salix fragilis (crack willow)

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Research Article

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Abstract

Bishkek is the capital and the most populated city of Kyrgyzstan and home to small scale industrial plants. The city of Bishkek has started to suffer from a widespread pollution after showing a rapid industrial and economic development in recent years. In present work, woody species, *Populus nigra* (black poplar) *and Salix fragilis* (crack willow) chosen as study materials were used for monitoring research for the evaluation of heavy metal pollution. For the assessment of the rate of pollution in the region, the Al, Ca, Cr, Cu, Fe, K, Mg, Ni, Pb and Zn contents of the parts of plants (leaves, stems and roots) and co-located soil samples collected from along Alamedin River passing through Bishkek were determined using ICP-OES. Our data showed that the levels of Cr, Fe, Ni and Pb were found to be above the allowable limits, especially in stations where located in the city in comparison with literature. This indicates that anthropogenic pressure in the city are getting being a serious problem.

Introduction

With ever-increasing industrial and anthropogenic activities over the century, release of toxic heavy metals such as As, Al, Cd, Cr, Pb, Hg and Ni started to pose serious threat to public health as well as to the environment (Zhao et al., 2021; Ozyigit et al., 2022; Wang et al., 2022). Exposure to those heavy metals has been mainly occupational since they are commonly utilized and released into environment as results of industrial, agricultural, mining and transportation activities (Azimi et al., 2017; Turksoy et al., 2021). Metals were not biodegradable in the environment and their depletion has been merely to translocate from one contamination site to the other (Jain et al., 2017; Hocaoglu-Ozyigit and Genc, 2020; Botte et al., 2022; Skorbilowicz et al., 2022). So, they could remain/accumulate in the ecosystems for years and could be taken up by humans via contaminated plants or animals in the food chain (Gall et al., 2015; George, 2017). Besides, heavy metals *e.g.* Al, As, Cd, Hg and Pb have been demonstrated not to be essential for humans, thereby there was no safe exposure limits for them (Ye et al., 2016; Martinez et al., 2017; Karagas, 2017; Turan et al., 2020; Hwang et al., 2022). Thus, regular monitoring of environmental heavy metals has been a must for local and international authorities.

Many analytical techniques have been developed so far to monitor environmental pollution levels (Panuwet et al., 2016; Omwoma et al., 2017; Malaspina et al., 2018). However, in terms of cheapness, availability and easy sampling issues, utilizing biomonitor organisms as pollution indicator provided many advantages and took of great attention (Gorelova and Frontasyeva, 2017). Lower and higher plants could be employed as biomonitor organisms based on location, type or concentration of the pollutants (Saat et al., 2016; Gorelova and Frontasyeva, 2017; Ozyigit, 2020; Ullah and Khan, 2022). Especially woody plants enabled to study long-term biomonitoring of the environmental pollution (Cosma et al., 2016; Chaudhuri and Kumar, 2022).

In this sense, using tree species in biomonitoring or phytoremediation applications have been a non-destructive powerful tool (Yongpisanphop et al., 2017; Verma et al., 2021). Among the various woody species studied so far, *Populus* (poplar) *and Salix* (willow) were two utilized trees in the biomonitoring activities. The biomonitoring potential of poplar species has been reported for various metals/substance such as Co and Cd (Akkus-Ozen and Yaman, 2017), Ag, As, Na, Sb, Sr, Ta, U and Zn (Yalaltdinova et al., 2017), Cr (Alizadeh and Mirarab-Razi, 2016), Cd and Pb (Nickel and Schroder, 2017), Cu, Ni, Pb, Zn, and Cd (Barbes et al., 2014), Hg (Chiarantini et al., 2016), Cd and Pb (Houda et al., 2016), and polycyclic aromatic hydrocarbons (PAHs; An et al., 2017). Besides, biomonitoring feature of willow species have been also demonstrated for Hg (Esbri et al., 2018), Cd (Wu et al., 2016), As (Yanitch et al., 2017), Cd and Pb (Kersten et al., 2017), Cu (Cao et al., 2018), Zn and Cd (McBride et al., 2016), phenanthrene and Cd (Sun et al., 2016), and PAHs (Zhao et al., 2018).

So, considering the importance of poplar and willow species in biomonitoring applications, this work aimed (i) to analyze the concentrations of heavy metals and mineral elements (Al, Ca, Cr, Cu, Fe, K, Mg, Ni, Pb and Zn) in plant and soil samples of black poplar and crack willow plants grown at Alamedin River site in Bishkek/Kyrgyzstan, (ii) to investigate the impacts of heavy metals on mineral nutrient elements, (iii) to determine the extent of pollution levels in the environment, and (iv) to have more insights about the biomonitoring or hyperaccumulator capacities of these tree species.

Materials And Methods

Study area

As a Central Asian country, Kyrgyzstan is bordered by Kazakhstan (to north), Uzbekistan (to west and southwest), Tajikistan (to southwest) and China (to east) and situated between 39°-44° northern parallels and 69°-81° east longitudes. As of 2016 data, its population is about 6 million, 63.9% of which live in cities and the rest are in rural areas. The country is divided into seven regions, with a regionally varying climate. These regions are Batken, Chui (Bishkek), Jalalabat, Naryn, Osh, Talas and Issyk-Kul. Its capital as well as the largest city is Bishkek Province, located on the 42°52'29" N and 74°36'44" E coordinates. Bishkek has been also country’s financial and cultural center.

Plant materials

Populus nigra (black poplar)

“Terrestrial habitat; a tree species; simple leaf blade (lobed or unlobed but not separated into leaflets); one leaf per node along the stem; edge of leaf blade with teeth; leaves drop off in winter (or they wither but persist on the plant); with no spines, prickles or thorns; 50-100 mm leaf blade length; 40-80 mm leaf blade width; leaves with leaf stalks; dry fruit and splits open when ripe; ridged or plated bark texture; twig winter color (brown, green or yellow); three or more scales on winter bud, overlapping like shingles with one edge covered and other edge exposed” (plant characteristics were compiled from “gobotany.newenglandwild.org/species/ populus/nigra”).

Salix fragilis (crack willow)

“Terrestrial habitat; a tree species; 6–20 m height; male and female flowers on separate plants; inflorescence a hairy, long, slender, and nodding catkin; individual flowers in axils of catkin scales, small, lacking perianth; catkin scales pale, soon falling; stamens 2 (3), base of filaments hairy; pistil formed from 2 fused carpels; alternate leaves; stalked, stipulate, stipules cordate, hairless, soon falling; leaf-blade 10–12 cm (4–5 in.) long, narrowly elliptic, tapering to a long point, finely glandular-serrate, hairless, glossy and deep green above, bluish-green and prominent-veined beneath; vein pairs 12–15; hairless, glossy, brown buds; fruit: two-valved capsule containing many plumed hairs; an ornamental; flowering time, June; flowers when already leafy” (plant characteristics were compiled from “luontoportti.com/suomi/en/puut/ crack-willow”).

Sampling, preparation and analysis

Plant (root, stem and leaf) and co-located soil samples were collected during 2016 vegetation period, from along the Alamedin River in Bishkek/Kyrgyzstan. Alamedin River, with 78 km length, extends through Bishkek and about its 20 km flows through the city. Samples were taken from 10 different stations (three samplings from each) about every 3 km along river starting from outside the city as control groups. Sampling stations were (1) Jiluu Bulak (Tepliye, Kluci), (2) Arasan, (3) Tas-Moynok, (4) Bes-Kyngoy, (5) Kok-Jar, (6) Tustuk Magistral, (7) Ahunbaeva Jaddesi, (8) Cuy Jaddesi, (9) Cigis Avtovokzal and (10) Alamudun Kici Rayonu (Figure 1 and Table 1).

<< Figure 1 >>

<< Table 1 >>

The collected samples were carefully labeled and taken to lab in sterile containers. Leaf samples were divided into two groups; one part is washed to eliminate the airborne dusts while other is unwashed. Plant samples were then dried in oven at 80°C for 48 hours, and each sample was grinded separately and sifted through a 1.5 mm sieve. 0.2 g plant samples were put in Teflon vessels and added with 8 ml 65% HNO_3 (Merck). Soil samplings were done from ~10 cm depth with a shovel, dried in open air and sifted through a 2mm sieve. Then, 0.3 g soil samples were added with 6 ml 65% HNO_3, 3 ml 37% HCl and 2 ml 48% HF (Merck). In Berghof-MWS2 microwave, the samples were digested at 145°C for 5 min, at 165°C for 5 min and at 175°C for 20 min (Yalcin et al., 2020a). After cooling of the samples at room temperature, they were filtered through 1-2 μm filter papers and using ultrapure water the volume is added up to 50 ml in falcon tubes. Standard solutions (10, 50, 100, 250 and 500 mg L^{-1}) were prepared using multi-element solution (Merck; stock for 1,000 ppm). The calibration curve was drawn using standard solutions. Al, Ca, Cr, Cu, Fe, K, Mg, Ni, Pb and Zn elements were determined by ICP-OES (Inductively Coupled Plasma Optical Emission Spectroscopy, Perkin Elmer-Optima 7000 DV).

Results And Discussion

Due to the ever-increasing industrial and human-based activities, heavy metal pollution has been turned into a serious global problem with its inevitable consequences. More worse has been that metals are not degraded in the environment and as results they are accumulated in various ecosystems and are subsequently entered into the food chain (Gall et al., 2015; Jain et al., 2017; George, 2017). The consumption of these contaminated foods by consumers exposed them to various health risks (Clemens and Ma, 2016; Toth et al., 2016). In many recent studies have been also reported that exposure to or ingestion of heavy metals is associated with various diseases such as cardiac (Lamas et al., 2016), respiratory (Dunea et al., 2016) and kidney (Lentini et al., 2017) problems, immune system impairment (Lin et al., 2017), cognitive dysfunction (Karri et al., 2016), cancer (Carver and Gallicchio, 2018), and many others. Heavy metals are also known to interfere with mineral element metabolism, leading to various complications (Bravo et al., 2017; Clemens and Ma, 2016; Chauhan et al., 2017). Thus, regular assessment of environmental pollution to figure out presence and quantity of toxic heavy metals has been a must. In this sense, certain woody plants as biomonitor organisms provide great advantages in terms of long-term biomonitoring of the environmental pollutants. So, two woody species *P. nigra* (black poplar) and *S. fragilis* (crack willow) were used in current work to determine the type and extent of pollution levels along the Alamedin River site in Bishkek/Kyrgyzstan. For this, concentrations of heavy metals (Al, Cr, Cu, Ni, Pb and Zn) and mineral elements (Ca, Fe, K and Mg) in plant and soil samples from 10 different stations were analyzed using ICP-OES. In addition, impacts of heavy metals on mineral element uptake were investigated. Throughout the text, commonly repeated words, “washed”, “unwashed” and “stations” were abbreviated as “w”, “u/w” and “st” respectively.

In black poplar, the lowest-to-highest element concentrations (in mg kg^{-1} DW; Table 2) in various plant parts were distributed as: for Al, 6.513 (st3)-39.446 (st8) in u/w leaves, 4.281 (st2)-30.546 (st8) in w leaves, 8.105 (st1)-58.774 (st8) in stems and 53.863 (st10)-544.828 (st6) in roots; for

Ca, 414.242 (st7)-1531.217 (st3) in u/w leaves, 393.710 (st5)-1319.121 (st3) in w leaves, 673.521 (st7)-3069.256 (st4) in stems and 627.755 (st3)-2765.570 (st10) in roots; for Cr, 1.135 (st2)-16.510 (st7) in u/w leaves, 0.945 (st2)-4.862 (st7) in w leaves, 0.302 (st4)-0.974 (st10) in stems and 0.409 (st7)-1.729 (st10) in roots; for Cu, 5.669 (st9)-14.511 (st6) in u/w leaves, 5.471 (st9)-9.337 (st6) in w leaves, 0.383 (st1)-14.134 (st7) in stems and 0.942 (st1)-4.892 (st10) in roots; for Fe, 27.166 (st5)-227.252 (st8) in u/w leaves, 25.229 (st2)-145.273 (st8) in w leaves, 69.567 (st7)-349.379 (st4) in stems and 3.551 (st1)-1679.544 (st9) in roots; for K, 386.164 (st5)-1079.968 (st4) in u/w leaves, 319.908 (st5)-845.572 (st4) in w leaves, 230.200 (st5)-576.023 (st1) in stems and 115.617 (st5)-615.473 (st1) in roots; for Mg, 980.162 (st1)-3379.802 (st2) in u/w leaves, 253.718 (st10)-2053.710 (st2) in w leaves, 379.596 (st3)-1196.398 (st7) in stems and 636.558 (st1)-1730.561 (st4) in roots; for Ni, 0.209 (st1)-1.911 (st7) in u/w leaves, 0.190 (st1)-1.217 (st7) in w leaves, 3.094 (st9)-12.638 (st5) in stems and 0.746 (st1)-4.860 (st10) in roots; for Pb, 4.226 (st2)-43.558 (st6) in u/w leaves, 1.615 (st2)-31.669 (st7) in w leaves, 0.321 (st1)-49.466 (st7) in stems and 0.335 (st1)-9.189 (st5) in roots; and for Zn, 24.096 (st7)-91.594 (st10) in u/w leaves, 18.651 (st10)-57.853 (st5) in w leaves, 17.694 (st7)-38.399 (st5) in stems and 7.950 (st5)-28.939 (st10) in roots.

<< Table 2 >>

In crack willow, the lowest-to-highest element distributions (in mg kg^{-1} DW; Table 3) in different plant parts followed as: for Al, 16.256 (st9)-101.857 (st5) in u/w leaves, 6.526 (st9)-79.013 (st5) in w leaves, 12.301 (st4)-88.072 (st6) in stems and 162.439 (st10)-597.505 (st5) in roots; for Ca, 376.778 (st5)-2011.369 (st9) in u/w leaves, 305.539 (st5)-1223.980 (st9) in w leaves, 1099.889 (st4)-2511.852 (st6) in stems and 870.042 (st4)-1986.633 (st8) in roots; for Cr, 1.135 (st7)-9.653 (st8) in u/w leaves, 0.554 (st4)-1.540 (st3) in w leaves, 0.078 (st4)-0.966 (st10) in stems and 0.170 (st4)-1.130 (st7) in roots; for Cu, 2.133 (st8)-10.551 (st4) in u/w leaves, 1.795 (st8)-7.211 (st7) in w leaves, 3.835 (st8)-13.251 (st1) in stems and 6.246 (st9)-14.167 (st7) in roots; for Fe, 64.672 (st5)-282.144 (st8) in u/w leaves, 21.045 (st4)-167.557 (st1) in w leaves, 58.779 (st9)-327.210 (st8) in stems and 39.868 (st1)-142.098 (st8) in roots; for K, 272.455 (st9)-1124.268 (st5) in u/w leaves, 193.779 (st9)-933.350 (st5) in w leaves, 132.836 (st4)-425.110 (st7) in stems and 161.960 (st4)-659.512 (st7) in roots; for Mg, 395.495 (st5)-2654.158 (st9) in u/w leaves, 381.606 (st5)-2160.486 (st7) in w leaves, 339.606 (st6)-733.232 (st9) in stems and 660.051 (st1)-2032.209 (st9) in roots; for Ni, 0.741 (st1)-1.951 (st10) in u/w leaves, 0.477 (st4)-1.561 (st10) in w leaves, 1.641 (st1)-15.647 (st6) in stems and 0.941 (st3)-2.509 (st1) in roots; for Pb, 10.518 (st1)-196.799 (st4) in u/w leaves, 9.429 (st1)-68.810 (st7) in w leaves, 3.379 (st1)-25.519 (st7) in stems and 4.024 (st1)-77.991 (st8) in roots; and for Zn, 17.395 (st8)-218.522 (st10) in u/w leaves, 16.194 (st8)-216.485 (st10) in w leaves, 20.845 (st7)-81.124 (st10) in stems and 6.630 (st3)-92.979 (st10) in roots.

<< Table 3 >>

In addition, the lowest-to-highest element concentrations (in mg kg^{-1}; refer to Table 4) in the soil samples taken with plant part samples (leaves, stems and roots) were determined as 22491.421 (st1)-43207.508 (st8) for Al, 10212.419 (st3)-46465.531 (st9) for Ca, 68.962 (st7)-126.955 (st10) for Cr, 47.136 (st3)-324.366 (st10) for Cu, 5986.692 (st2)-8281.466 (st8) for Fe, 5061.135 (st2)-13645.647 (st8) for K, 16348.965 (st2)-26718.447 (st8) for Mg, 48.164 (st3)-84.241 (st9) for Ni, 40.660 (st3)-414.466 (st7) for Pb, and 177.298 (st3)-345.098 (st10) for Zn.

<< Table 4 >>

The stations in the research area can be divided into two groups. The first group includes the stations found to be in rural area of the city, which comprises stations 1-5. The second group includes the stations found to be within the city, which comprises stations 6-10. Subsequently, natural (acceptable/safe) element concentrations for plants and soils were acquired from literature data and used as reference values to compare with herein findings. Values exceeding acceptable limits were accepted as pollution indicators for given element/s and emphasized for their health implications. Relevant works from literature indicated that Ca in plants (in mg.kg^{-1})ranges 1000-50000 while it is 13700 (Earth soil)-53800 (Urban soil) in soil (Yalcin et al., 2020b). So, in black poplar, Ca levels were found to be lower than normal limits in u/w leaves (except st1 and st5, within normal limits), w leaves (except st2, st3 and st4, within normal limits) and roots (except st3, st4 and st5, within normal limits) at all stations whereas Ca levels were found to be within normal limits in stems (except st7 and st9, lower than normal limits) at all stations. In crack willow, Ca levels were found to be lower than normal limits in u/w leaves (except st6 and st9-10, within or close to normal limits) and w leaves (except st6 and st9, within or close to normal limits) at all stations while Ca levels were found to be within normal limits in stems and roots (except st4, lower than normal limits) at all stations. According to given information above, the soil concentrations were found be close to normal limits at all stations for Ca except st10, which was found to be lower than normal limits (stations 1, 2, 3, 4, 5, and 6 were evaluated as earth soil while stations 7, 8, 9, and 10 were evaluated as urban soil).

Fe levels in plants are reported to be 50-200 mg.kg^{-1} (>500 toxic) while it is 5000-50000 with average 38000 mg.kg^{-1} in soil (Blum et al., 2004). In black poplar, the Fe concentrations were determined as within the allowable range in u/w (except st2-3, st5 and st9, lower than normal limits whereas st8 and st10, higher than normal limits) and w (except 2-3, st5-7 and st9, lower than normal limits) leaves, and stems (except st1, st3-4 and st10, higher than normal limits) at all stations. Its levels were exceeded the allowable limits in roots at st2-3, and st5 (except st1, lower than normal limits) and even were toxic range at st4, 6-10. The Fe concentrations in crack willow were determined as within the allowable range in u/w leaves (except st8, higher than normal limits), w leaves (except st4 and st9, lower than normal limits), stems (except st1, st6 and st8, higher than normal limits) and roots (except st1, lower than normal limits) at all stations. Soil concentrations for Fe were found to be within normal limits.

Normal K range is demonstrated 1000-50000 mg.kg^{-1} in plants and in soil,it is 5000-25000 with an average 12000 mg.kg^{-1} (Ozyigit et al., 2018; Dogan et al., 2021). Herein, in black poplar, K levels were found to be lower than the normal limits in u/w leaves (except st4, within normal limits), w leaves, stems and roots at all stations. In crack willow, K levels were found to be lower than the normal limits in u/w leaves (except st5, within normal limits), w leaves, stems and roots at all stations. Soil concentrations were found be within normal limits at all stations.

Plant Mg levels are given 100-1000 mg.kg^{-1} while it is 300-8400 with average 5000 mg.kg^{-1} in soil (Barker and Pilbeam, 2015; Ozyigit et al., 2018). In this work, in black poplar, Mg levels were determined as higher than acceptable limits in u/w leaves (except st1 and st5, within normal limits), w leaves (except st1, st5 and st10, within normal limits) and roots (except st1-3, st5 and st10, within normal range) at all stations. Mg levels were found to be within normal limits in stems (except st7 and st8, higher than normal limits) at all stations. In crack willow, Mg levels were determined as higher than acceptable limits in u/w leaves (except st5, within normal limits), w leaves (except st3, st5, st8 and st10, within normal limits) and roots (except st1 and st7, within normal range) at all stations. Its levels were found to be within normal limits in stems at all stations. Pb levels in the soil samples were found to be higher than normal range at all stations.

Al plant concentrations are reported to be 40-500 mg.kg^{-1} while its soil levels range 10000-40000 mg.kg^{-1} (Barker and Pilbeam, 2015). In black poplar, Al levels in u/w and w leaves were found to be lower than the acceptable limits at all stations while its levels were within ranges in stems (except st1-3 and 10, lower than normal limits) and roots (except st4-8, slightly higher than normal limits) at all stations. In crack willow, Al levels were found to be lower than the acceptable limits in u/w leaves (except st1-3, st5, st8 and st10, within normal range) and w leaves (except st5, within normal range) and stems (except st6, within normal range) at all stations while its levels were within range in roots (except st5 and 9, higher than normal limits) at all stations. Soil concentrations for Al were found to be within normal limits (except st5 and st8, higher than upper limits in close range) at all stations.

Cr concentrations in plants are demonstrated to be 0.1-0.5 mg.kg^{-1} (5-30 toxic) while in soil it is up to 54 mg.kg^{-1} (> 64 toxic) (Blum et al. 2004). In this study, in black poplar, Cr levels were found to be exceeded or close to the upper acceptable limits in u/w leaves (even in toxic level at st3, st6, st7 and st10), w leaves (even close to toxic level at st3 and st7), stems (except st4, within normal limits), and roots (except st1, st5 and st7, within normal limits) at all stations. Cr levels in crack willow were found to be exceeded the upper acceptable limits in u/w leaves (even in toxic level at st8), w leaves, stems (except st1, st3 and st4, within normal limits), and roots (except st1, st3 and st4, within normal limits) at all stations. The soil concentrations for Cr were found to be in toxic range at all stations.

In plants acceptable ranges for Cu are reported to be 5-30 mg.kg^{-1} (>30 toxic) and in soil it is given 8-80 with average 13-24 mg.kg^{-1} (Blum et al. 2004). In black poplar, Cu levels were determined as within normal range in u/w and w leaves but its levels were found to be lower than the normal limits in stems (except st7 and 9, within normal limits) and roots at all stations. In crack willow, Cu levels were determined as within normal range in u/w (except st8 and st10, lower than normal limits), w leaves (except st8 and st10, lower than normal limits), stems (except st8, lower than normal limits and roots at all stations. Besides, in soil samples Cu levels were found to be above the specified range at st5-8 and 10 while its levels were found to be within normal range at st1-4 and st9.

Acceptable Ni limits are reported to be 0.5-5 mg.kg^{-1} in plants and 0.2-450 with average 12-34 mg.kg^{-1} in soil (Barker and Pilbeam, 2015). So, in black poplar, Ni concentrations in were being in normal range in u/w (except st1, lower than normal limits) and w leaves (except st1, st3, st5-6, lower than normal limits), and roots at all stations while its concentrations were detected as higher than the normal range in stems (except st1, st7 and st9, within normal range) at all stations. Ni concentrations in crack willow in were being in normal range in u/w and w leaves, stems (except st57 and st9, higher than the acceptable limits) and roots at all stations. Ni concentrations in the soil samples were noted within normal range at all stations.

Reported Pb range in plants is 0.1-10 mg.kg^{-1} (>30 toxic) and in soil it is 10-40 with average 25 mg.kg^{-1} (Kabata-Pendias and Pendias, 2001; Yalcin et al., 2020a). In black poplar, Pb levels in w leaves (except st6 and 8, higher than the normal limits and st7, in toxic range) and roots were detected within allowable limits at all stations but its levels were found to be in ranges, higher than the normal limits in u/w leaves (except st1-4, within normal limits) and stems (except st1-4, within normal limits) at all stations. Even toxic levels were also noted in u/w leaves at st6-8 and w leaves at st7, and stems at st7, 8 and 10. In crack willow, Pb levels were found to be higher or close to the allowable limits in u/w leaves (even in toxic range at st4-8), w leaves (even in toxic range at st3-8), stems (except st1-5, and st10, within normal range) at all stations but its levels were found to be in ranges in roots (except st7-8, in toxic range) at all stations. Besides, Pb levels in the soil samples were also found to be higher than normal range at all stations.

Acceptable limits for Zn are reported to be 27-150 mg.kg^{-1} in plants and 3-370 with average 45-100 mg.kg^{-1} in soil (Barker and Pilbeam, 2015; Dogan et al., 2021). In black poplar, Zn levels were found to be within or close to acceptable limits in u/w leaves, w leaves (except st7 and st10, lower than normal limits) and stems (except st2, st3 and st7, lower than normal limits) at all stations whereas Ca levels were found to be lower than normal limits in roots (except st1 and st10, within or close to normal range) at all stations. Zn levels in crack willow were found to be within or close to acceptable limits in u/w leaves (except st1 and st7-8, lower than the normal limits and except st10, higher than normal limits) and stems (except st7, lower than normal limits) at all stations while its levels were found to be lower than normal limits in w leaves (except st4 and st6, within normal limits and st10, higher than normal limits) and roots (except st4, st6 and st10, within normal limits) at all stations. Zn concentrations in the soil samples were noted within normal range at all stations.

The correlation readings between the element concentrations of the soil samples and the plant parts of two different species as a whole were given in Table 5. For *P. nigra* in this table: between Al, and Cr, Fe, Mg and Zn; between Ca, and Cr, K, Mg and Ni; between Cr, and K, Mg and Zn; between Fe, and K, Mg and Ni; between K and Mg; and between Mg and Ni, and Zn, there were high positive correlations (>0.76, >0.91). Also, for *S. fragilis*: between Al, and Cr, Mg and Zn; between Ca, and Cr, Fe, K, Mg and Ni; between Cr, and K and Mg; between Cu and Zn; between Fe, and K, Mg, Ni and Zn; between K and Mg; and between Mg and Ni, and Zn, there were high positive correlations (>0.75, >0.91).

<< Table 5 >>

The current work demonstrated that levels of certain heavy metals at some stations especially in the city sites were above the acceptable limits and even at toxic levels. Besides, the concentrations of mineral elements exceeded the natural limits at some stations while they were below the limits at some others. This tempted to speculate that mineral element metabolism is affected by the presence of heavy metals. Overall, it was revealed that pollution levels along the Alamedin River site in Bishkek/Kyrgyzstan reached a threatening level for some heavy metals. So, biomonitoring activities for those heavy metals should be intensified and pollution source/s must be immediately identified in order for implementation of more consistent and coherent policies.

According to our data, the levels of Cu (lower than normal range at some stations), Fe (exceeded or lower than normal range at some stations), Ni (exceeded or lower than normal range at some stations) and Zn (exceeded or lower than normal range at some stations) in the plant samples at all stations in which research conducted were found to be within the normal ranges in comparison with literature. The normal ranges were exceeded at all or some stations for Cr, Mg (within normal range at some stations), and Pb (in toxic or close to toxic range) whereas the levels of Al (within or exceeded normal range at some stations), Ca (within normal range at some stations) and K were found to be lower than normal ranges. Our data showed that the level of environmental pollution in Bishkek, especially at stations where are located in the city, is getting for being a problem in terms of accumulations for at least some heavy metals.

Declarations

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Declaration of conflicting interests

The authors declare that they have no conflict of interests.

Informed consent

This manuscript did not involve human or animal participants; therefore informed consent was not collected.

Data availability statements

The authors can confirm that all data generated or analyzed are included in the article.

Authors'contributions

"All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Tamara Abdikaimova and Ilhan Dogan. The first draft of the manuscript was written by Ilhan Dogan and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript."

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Tables

Table 1
Sampling stations, sample type and geographical data in *P. nigra* and *S. fragilis* trees.

			Populus nigra (black poplar)					***Salix fragilis (crack willow)***				
			Root	**Stem**	**Leaf***		**Soil**	**Root**	**Stem**	**Leaf***		**Soil**
Sampling stations	**GPS coordinates**	**Altitude**			**WL**	**UWL**				**WL**	**UWL**	
1 Jiluu Bulak (Tepliye, Kluci)	N: 42.61570 E: 074.66459	1696 m	+	+	+	+	+	+	+	+	+	+
2 Arasan	N: 42.63340 E: 074.67370	1610 m	+	+	+	+	+	-	-	-	-	+
3 Tas- Moynok	N: 42.633661 E: 074.67351	1602 m	+	+	+	+	+	+	+	+	+	+
4 Bes-Kyngoy	N: 42.70465 E: 074.65899	1284 m	+	+	+	+	+	+	+	+	+	+
5 Kok-Jar	N: 42.77499 E: 074.64185	1042 m	+	+	+	+	+	+	+	+	+	+
6 Tustuk Magistral	N: 42.81267 E: 074.64236	939 m	+	+	+	+	+	+	+	+	+	+
7 Ahunbaeva Jaddesi	N: 42.84115 E: 074.63109	851 m	+	+	+	+	+	+	+	+	+	+
8 Cuy Jaddesi	N:42.8562 E:074.62813	794 m	+	+	+	+	+	+	+	+	+	+
9 Cigis Avtovokzal	N: 42.86011 E: 074.62686	786 m	+	+	+	+	+	+	+	+	+	+
10 Alamudun Kici Rayonu	N: 42.89053 E: 074.63147	722 m	+	+	+	+	+	+	+	+	+	+

*WL stands for washed leaf; UWL stands for unwashed leaf. “+” and “-”signs respectively show presence and absence of samplings for given plant tissues.

Table 2

Heavy metal and mineral element concentrations (mg kg^{-1} DW) in *P. nigra* plants samples from 10 different stations.

	Stations	Al	Ca	Cr	Cu	Fe	K	Mg	Ni	Pb	Zn
UWL	1	19.804 ± 0.38	854.021 ± 4.494	1.23 ± 0.008	7.831 ± 0.228	75.278 ± 1.164	709.406 ± 5.081	980.162 ± 11.05	0.209 ± 0.007	7.34 ± 0.098	28.988 ± 0.234
	2	10.408 ± 0.245	1354.642 ± 15.637	1.135 ± 0.017	6.661 ± 0.188	37.347 ± 0.89	572.176 ± 10.324	3379.802 ± 7.453	0.61 ± 0.01	4.226 ± 0.105	50.464 ± 1.581
	3	6.513 ± 0.073	1531.217 ± 23.766	5.54 ± 0.132	7.153 ± 0.071	31.683 ± 0.4	681.767 ± 2.047	2026.234 ± 32.544	0.513 ± 0.005	6.768 ± 0.077	42.09 ± 1.329
	4	21.871 ± 0.153	1271.188 ± 11.234	2.242 ± 0.015	6.882 ± 0.214	79.111 ± 0.458	1079.968 ± 8.652	1462.917 ± 24.783	0.66 ± 0.008	6.302 ± 0.044	38.34 ± 0.427
	5	11.927 ± 0.219	552.669 ± 9.609	3.842 ± 0.012	9.451 ± 0.117	27.166 ± 0.775	386.164 ± 8.62	987.314 ± 25.686	0.595 ± 0.015	11.212 ± 0.248	65.434 ± 1.851
	6	10.865 ± 0.3	1267.573 ± 17.383	5.78 ± 0.032	14.511 ± 0.281	51.134 ± 1.161	438.106 ± 11.233	1620.07 ± 44.214	0.633 ± 0.006	43.558 ± 1.026	74.555 ± 0.199
	7	10.509 ± 0.217	414.242 ± 9.981	16.51 ± 0.247	7.417 ± 0.151	59.426 ± 0.93	475.487 ± 7.728	1725.045 ± 26.14	1.911 ± 0.051	32.78 ± 0.091	24.096 ± 0.364
	8	39.466 ± 0.181	893.808 ± 18.227	1.314 ± 0.041	9.15 ± 0.028	227.252 ± 5.799	710.763 ± 8.846	1167.252 ± 17.211	0.922 ± 0.01	41.027 ± 0.41	67.536 ± 0.495
	9	13.959 ± 0.045	509.528 ± 13.516	1.926 ± 0.006	5.669 ± 0.158	41.783 ± 0.496	794.206 ± 22.181	1356.115 ± 6.137	0.654 ± 0.019	15.36 ± 0.281	68.802 ± 1.651
	10	22.236 ± 0.671	752.549 ± 14.85	5.396 ± 0.145	9.99 ± 0.169	225.461 ± 1.758	724.847 ± 21.123	2064.373 ± 13.242	1.324 ± 0.017	26.548 ± 0.181	91.594 ± 2.259
WL	1	19.601 ± 0.505	784.539 ± 18.484	1.029 ± 0.022	6.847 ± 0.13	61.032 ± 0.57	707.846 ± 19.182	967.372 ± 30.054	0.19 ± 0.005	4.487 ± 0.028	26.415 ± 0.584
	2	4.281 ± 0.116	1242.999 ± 18.763	0.945 ± 0.008	6.455 ± 0.159	25.229 ± 0.06	387.101 ± 12.328	2053.71 ± 7.2	0.589 ± 0.008	1.615 ± 0.033	35.466 ± 0.611
	3	6.001 ± 0.084	1319.121 ± 4.098	4.891 ± 0.037	6.43 ± 0.035	25.952 ± 0.106	578.959 ± 3.37	1985.947 ± 57.104	0.401 ± 0.008	5.493 ± 0.069	26.48 ± 0.249
	4	11.514 ± 0.123	1092.9 ± 15.746	1.156 ± 0.012	6.669 ± 0.199	55.654 ± 1.508	845.572 ± 10.1	1236.605 ± 36.281	0.61 ± 0.014	4.088 ± 0.07	36.938 ± 0.914
	5	9.986 ± 0.169	393.71 ± 11.58	2.965 ± 0.039	7.121 ± 0.136	25.862 ± 0.32	319.908 ± 2.043	834.446 ± 13.044	0.383 ± 0.004	9.053 ± 0.17	57.853 ± 0.285
	6	8.939 ± 0.241	663.136 ± 3	3.363 ± 0.098	9.337 ± 0.044	34.544 ± 0.483	368.245 ± 3.241	1557.137 ± 12.693	0.48 ± 0.009	17.951 ± 0.301	50.723 ± 0.925
	7	9.207 ± 0.149	393.44 ± 6.673	4.862 ± 0.086	7.301 ± 0.068	49.482 ± 0.498	443.265 ± 10.203	1256.547 ± 10.209	1.217 ± 0.024	31.669 ± 0.347	19.304 ± 0.13
	8	30.546 ± 0.36	879.242 ± 7.764	1.222 ± 0.009	7.169 ± 0.192	145.273 ± 3.665	664.826 ± 6.53	1144.052 ± 16.481	0.836 ± 0.006	17.471 ± 0.116	57.026 ± 0.217
	9	10.908 ± 0.158	479.95 ± 11.334	1.249 ± 0.035	5.471 ± 0.144	38.87 ± 1.039	638.897 ± 15.881	1257.396 ± 19.285	0.6 ± 0.013	4.057 ± 0.089	51.345 ± 0.25
	10	17.261 ± 0.323	694.158 ± 18.368	1.212 ± 0.008	5.484 ± 0.023	58.666 ± 1.738	682.364 ± 9.565	253.718 ± 8.062	0.726 ± 0.01	6.458 ± 0.039	18.651 ± 0.386
Stem	1	8.105 ± 0.131	1797.386 ± 50.841	0.556 ± 0.002	0.383 ± 0.006	264.146 ± 4.273	576.023 ± 10.656	383.193 ± 7.433	3.349 ± 0.042	0.321 ± 0.001	27.987 ± 0.852
	2	23.645 ± 0.05	1215.465 ± 7.816	0.435 ± 0.011	4.332 ± 0.116	94.615 ± 0.465	301.679 ± 0.823	498.007 ± 11.708	5.09 ± 0.125	7.31 ± 0.049	22.604 ± 0.431
	3	18.786 ± 0.11	2047.582 ± 12.622	0.727 ± 0.004	3.094 ± 0.057	237.473 ± 4.926	436.173 ± 13.101	379.596 ± 10.722	8.442 ± 0.13	9.7 ± 0.205	22.186 ± 0.397
	4	45.821 ± 0.873	3069.256 ± 17.366	0.302 ± 0.001	2.215 ± 0.011	349.379 ± 8.078	502.449 ± 11.495	976.976 ± 26.396	4.837 ± 0.033	4.679 ± 0.047	36.764 ± 0.227
	5	55.177 ± 1.043	1524.735 ± 23.84	0.562 ± 0.018	2.164 ± 0.037	70.411 ± 1.599	230.2 ± 5.019	549.422 ± 4.688	12.683 ± 0.229	14.642 ± 0.282	38.399 ± 0.98

	Stations	Al	Ca	Cr	Cu	Fe	K	Mg	Ni	Pb	Zn
	6	58.421 ± 1.789	2771.628 ± 53.974	0.601 ± 0.01	3.695 ± 0.067	75.323 ± 1.932	328.136 ± 10.088	642.015 ± 19.828	4.984 ± 0.108	12.584 ± 0.366	36.417 ± 0.455
	7	46.628 ± 0.907	673.521 ± 19.684	0.626 ± 0.017	14.134 ± 0.227	69.567 ± 1.753	299.827 ± 7.246	1196.398 ± 7.886	3.719 ± 0.037	49.466 ± 0.27	17.694 ± 0.378
	8	58.774 ± 0.684	1882.101 ± 56.528	0.761 ± 0.009	4.471 ± 0.024	158.301 ± 0.387	474.738 ± 10.874	1153.223 ± 8.914	5.327 ± 0.076	37.56 ± 0.759	29.215 ± 0.439
	9	39.74 ± 1.078	792.032 ± 5.854	0.888 ± 0.005	10.372 ± 0.108	90.925 ± 1.628	397.536 ± 1.474	511.972 ± 1.53	3.094 ± 0.081	23.277 ± 0.287	29.816 ± 0.837
	10	22.625 ± 0.157	1962.163 ± 49.292	0.974 ± 0.009	3.384 ± 0.087	238.098 ± 0.793	464.419 ± 6.816	750.952 ± 23.619	11.068 ± 0.088	36.246 ± 1.158	27.367 ± 0.594
Root	1	62.202 ± 0.577	2259.512 ± 43.288	0.441 ± 0.006	0.942 ± 0.022	3.551 ± 0.062	615.473 ± 6.637	636.558 ± 18.964	0.746 ± 0.014	0.335 ± 0.011	26.766 ± 0.675
	2	269.757 ± 3.362	1818.302 ± 31.189	0.545 ± 0.005	1.817 ± 0.025	399.014 ± 8.908	222.644 ± 0.793	878.983 ± 18.807	1.792 ± 0.008	6.023 ± 0.143	21.546 ± 0.315
	3	173.684 ± 1.536	627.755 ± 9.876	0.542 ± 0.013	3.105 ± 0.013	283.168 ± 7.816	496.38 ± 14.888	880.57 ± 25.226	2.455 ± 0.056	2.425 ± 0.059	19.937 ± 0.424
	4	513.63 ± 11.285	796.048 ± 23.496	0.595 ± 0.002	2.084 ± 0.057	686.986 ± 21.944	462.474 ± 9.63	1730.561 ± 52.588	2.504 ± 0.016	2.908 ± 0.059	17.142 ± 0.234
	5	535.308 ± 15.995	628.8 ± 12.001	0.451 ± 0.011	3.975 ± 0.117	312.104 ± 8.991	115.617 ± 2.297	904.453 ± 8.809	2.032 ± 0.015	9.189 ± 0.04	7.95 ± 0.031
	6	544.828 ± 7.298	1148.272 ± 4.576	0.543 ± 0.01	1.807 ± 0.044	1133.774 ± 2.359	317.009 ± 6.316	1481.335 ± 38.081	1.274 ± 0.007	7.818 ± 0.226	17.436 ± 0.175
	7	486.621 ± 8.881	955.227 ± 21.425	0.409 ± 0.01	3.007 ± 0.063	776.317 ± 22.478	395.874 ± 5.575	1563.314 ± 27.543	1.185 ± 0.036	8.123 ± 0.223	13.556 ± 0.247
	8	482.809 ± 5.814	1371.036 ± 32.451	0.645 ± 0.009	2.465 ± 0.066	1172.044 ± 33.813	236.125 ± 3.938	1512.506 ± 14.334	1.235 ± 0.039	8.687 ± 0.222	10.52 ± 0.184
	9	392.888 ± 6.091	1452.046 ± 23.846	0.822 ± 0.015	2.209 ± 0.019	1679.544 ± 27.231	327.536 ± 2.038	708.8 ± 8.386	1.538 ± 0.046	6.057 ± 0.129	19.574 ± 0.411
	10	53.863 ± 1.701	2765.57 ± 70.742	1.729 ± 0.014	4.892 ± 0.064	817.593 ± 5.821	547.398 ± 15.873	1148.834 ± 4.246	4.86 ± 0.121	6.519 ± 0.038	28.939 ± 0.877

WL stands for washed leaf; UWL stands for unwashed leaf. (1) Jiluu Bulak (Tepliye, Kluci), (2) Arasan, (3) Tas-Moynok, (4) Bes-Kyngoy, (5) Kok-Jar, (6) Tustuk Magistral, (7) Ahunbaeva Jaddesi, (8) Cuy Jaddesi, (9) Cigis Avtovokzal and (10) Alamudun Kici Rayonu.

Table 3
Heavy metal and mineral element concentrations (mg kg^{-1} DW) in *S. fragilis* plants samples from 10 different stations.

	Stations	Al	Ca	Cr	Cu	Fe	K	Mg	Ni	Pb	Zn
UWL	1	29.159 ± 0.844	698.919 ± 8.827	1.42 ± 0.026	8.507 ± 0.184	167.662 ± 3.722	342.545 ± 9.856	1740.954 ± 21.461	0.741 ± 0.012	10.518 ± 0.193	21.821 ± 0.103
	3	42.51 ± 0.317	773.712 ± 9.734	2.091 ± 0.018	6.328 ± 0.109	132.881 ± 3.688	674.082 ± 16.65	1028.498 ± 20.848	1.01 ± 0.023	30.638 ± 0.075	29.244 ± 0.888
	4	33.598 ± 0.244	798.639 ± 8.716	2.515 ± 0.068	10.551 ± 0.104	85.138 ± 2.429	307.31 ± 8.638	1283.174 ± 29.06	1.034 ± 0.031	196.799 ± 3.657	139.272 ± 0.417
	5	101.857 ± 2.616	376.778 ± 10.06	1.261 ± 0.018	6.435 ± 0.116	64.672 ± 0.411	1124.268 ± 28.245	395.495 ± 10.708	1.323 ± 0.014	117.185 ± 3.447	34.397 ± 0.788
	6	22.821 ± 0.432	1144.212 ± 34.46	1.731 ± 0.011	7.251 ± 0.181	161.422 ± 4.283	589.221 ± 3.774	1869.036 ± 39.719	0.971 ± 0.03	75.155 ± 0.52	45.732 ± 0.663
	7	25.033 ± 0.127	842.975 ± 7.249	1.135 ± 0.021	10.27 ± 0.181	168.048 ± 4.624	405.911 ± 10.676	2628.437 ± 33.277	1.066 ± 0.023	71.238 ± 1.323	18.017 ± 0.531
	8	40.895 ± 0.807	459.299 ± 3.288	9.653 ± 0.165	2.133 ± 0.058	282.144 ± 7.092	621.906 ± 12.99	1130.8 ± 7.527	1.61 ± 0.046	41.63 ± 0.842	17.395 ± 0.237
	9	16.256 ± 0.23	2011.369 ± 35.157	2.185 ± 0.025	6.168 ± 0.054	92.855 ± 1.004	272.455 ± 7.163	2654.158 ± 67.87	1.542 ± 0.013	20.318 ± 0.28	25.17 ± 0.271
	10	76.588 ± 0.451	995.994 ± 15.773	2.284 ± 0.049	3.971 ± 0.011	122.544 ± 2.387	332.378 ± 1.789	1284.946 ± 25.262	1.951 ± 0.016	22.46 ± 0.117	218.522 ± 1.392
WL	1	17.265 ± 0.298	656.918 ± 20.953	0.902 ± 0.009	5.328 ± 0.099	167.557 ± 1.493	295.739 ± 8.166	1462.458 ± 23.852	0.677 ± 0.016	9.429 ± 0.038	19.264 ± 0.315
	3	28.586 ± 0.768	764.715 ± 11.322	1.54 ± 0.02	4.635 ± 0.062	98.716 ± 2.829	636.877 ± 1.663	568.927 ± 1.495	0.854 ± 0.02	16.688 ± 0.129	20.147 ± 0.195
	4	11.724 ± 0.357	569.482 ± 14.986	0.554 ± 0.006	4.567 ± 0.118	21.045 ± 0.614	302.338 ± 5.531	1062.51 ± 22.122	0.477 ± 0.013	41.12 ± 0.446	95.363 ± 1.947
	5	79.013 ± 0.649	305.539 ± 4.938	1.198 ± 0.005	5.914 ± 0.049	54.085 ± 1.433	933.35 ± 20.181	381.606 ± 9.65	0.939 ± 0.014	50.333 ± 1.443	25.405 ± 0.368
	6	15.821 ± 0.052	987.788 ± 13.881	1.406 ± 0.032	5.314 ± 0.119	112.86 ± 1.089	325.974 ± 8.845	1264.527 ± 10.626	0.907 ± 0.011	36.007 ± 0.121	27.363 ± 0.825
	7	22.592 ± 0.471	817.74 ± 25.633	1.034 ± 0.014	7.211 ± 0.214	138.596 ± 4.393	386.465 ± 8.428	2160.486 ± 9.756	0.664 ± 0.012	68.81 ± 0.643	16.285 ± 0.04
	8	15.323 ± 0.375	457.454 ± 11.036	1.135 ± 0.027	1.795 ± 0.046	137.629 ± 1.693	588.165 ± 6.649	985.676 ± 30.844	1.403 ± 0.038	37.783 ± 0.545	16.194 ± 0.457
	9	6.526 ± 0.08	1223.98 ± 33.534	1.11 ± 0.008	4.598 ± 0.095	30.433 ± 0.531	193.779 ± 6.106	1996.579 ± 46.736	0.866 ± 0.026	10.343 ± 0.275	17.713 ± 0.264
	10	18.533 ± 0.118	803.286 ± 9.364	0.836 ± 0.02	3.521 ± 0.015	57.708 ± 1.31	324.617 ± 8.516	777.323 ± 5.588	1.561 ± 0.039	12.612 ± 0.121	216.485 ± 6.681
Stem	1	21.649 ± 0.073	1272 ± 21.8	0.212 ± 0.001	13.251 ± 0.272	205.237 ± 6.45	172.598 ± 2.429	576.989 ± 12.431	1.641 ± 0.006	3.379 ± 0.105	26.738 ± 0.395
	3	16.68 ± 0.291	1944.552 ± 60.966	0.127 ± 0.003	6.721 ± 0.078	73.947 ± 2.355	276.715 ± 0.629	487.797 ± 10.929	3.08 ± 0.094	5.802 ± 0.069	38.738 ± 0.385

	Stations	Al	Ca	Cr	Cu	Fe	K	Mg	Ni	Pb	Zn
	4	12.301 ± 0.21	1099.889 ± 4.752	0.078 ± 0.001	8.93 ± 0.131	68.414 ± 0.559	132.836 ± 3.421	543.741 ± 12.65	3.407 ± 0.053	3.562 ± 0.012	57.833 ± 1.137
	5	35.764 ± 0.257	1135.085 ± 14.849	0.604 ± 0.006	6.855 ± 0.192	66.54 ± 1.128	394.687 ± 5.432	538.007 ± 3.519	9.895 ± 0.072	4.191 ± 0.073	31.897 ± 0.071
	6	88.072 ± 2.064	2511.852 ± 52.959	0.781 ± 0.018	6.061 ± 0.052	245.387 ± 6.977	252.786 ± 1.235	339.606 ± 4.841	15.647 ± 0.463	23.262 ± 0.242	32.276 ± 0.391
	7	20.941 ± 0.148	2307.581 ± 37.782	0.908 ± 0.008	8.883 ± 0.018	112.528 ± 3.405	425.11 ± 5.287	414.777 ± 1.822	7.73 ± 0.038	25.519 ± 0.793	20.845 ± 0.27
	8	25.269 ± 0.669	1729.72 ± 37.939	0.864 ± 0.013	3.835 ± 0.054	327.21 ± 7.843	323.113 ± 8.891	418.246 ± 8.813	3.338 ± 0.042	22.492 ± 0.181	26.213 ± 0.144
	9	14.201 ± 0.398	1883.094 ± 15.388	0.589 ± 0.014	7.325 ± 0.225	58.779 ± 1.143	138.37 ± 2.877	733.232 ± 12.663	14.077 ± 0.234	17.562 ± 0.525	26.02 ± 0.796
	10	15.22 ± 0.354	2187.154 ± 53.248	0.966 ± 0.027	8.012 ± 0.164	80.3 ± 0.588	134.031 ± 1.671	587.72 ± 15.391	3.891 ± 0.114	5.45 ± 0.019	81.124 ± 1.544
Root	1	288.607 ± 1.399	1786.87 ± 48.987	0.316 ± 0.009	10.954 ± 0.298	39.868 ± 0.951	182.55 ± 3.649	660.051 ± 18.653	2.509 ± 0.077	4.024 ± 0.047	18.715 ± 0.233
	3	437.38 ± 7.595	1117.195 ± 18.884	0.296 ± 0.007	6.475 ± 0.069	113.637 ± 2.752	395.93 ± 1.524	1059.424 ± 31.625	0.941 ± 0.024	7.973 ± 0.222	6.63 ± 0.151
	4	343.555 ± 10.174	870.042 ± 10.377	0.17 ± 0.002	10.809 ± 0.161	90.811 ± 2.549	161.96 ± 4.82	1689.781 ± 50.642	1.598 ± 0.033	5.478 ± 0.07	34.118 ± 0.748
	5	597.505 ± 13.761	1914.593 ± 22.026	0.769 ± 0.016	6.712 ± 0.037	89.257 ± 1.511	617.182 ± 7.916	1468.936 ± 7.678	1.15 ± 0.03	8.286 ± 0.067	13.858 ± 0.384
	6	351.484 ± 3.49	1784.158 ± 21.29	0.847 ± 0.012	7.392 ± 0.073	99.386 ± 1.215	584.853 ± 15.508	1179.487 ± 19.132	1.945 ± 0.045	6.333 ± 0.036	36.902 ± 1.061
	7	396.294 ± 7.281	1334.515 ± 17.873	1.13 ± 0.024	14.167 ± 0.28	131.963 ± 4.204	659.512 ± 11.125	984.67 ± 3.008	1.403 ± 0.038	35.519 ± 0.816	16.105 ± 0.407
	8	319.536 ± 6.7	1986.633 ± 55.269	0.511 ± 0.015	10.157 ± 0.105	142.098 ± 0.524	248.469 ± 1.405	1573.547 ± 29.683	1.362 ± 0.044	77.991 ± 2.397	8.344 ± 0.056
	9	588.738 ± 10.328	1296.903 ± 31.813	0.661 ± 0.01	6.246 ± 0.153	114.314 ± 1.998	317.805 ± 6.613	2032.209 ± 64.871	1.246 ± 0.006	7.342 ± 0.08	13.199 ± 0.237
	10	162.439 ± 3.222	1368.374 ± 27.259	1.054 ± 0.012	6.369 ± 0.176	52.585 ± 0.291	306.879 ± 3.705	1617.517 ± 18.874	0.954 ± 0.003	5.651 ± 0.122	92.979 ± 1.833

WL stands for washed leaf; UWL stands for unwashed leaf. (1) Jiluu Bulak (Tepliye, Kluci), (3) Tas-Moynok, (4) Bes-Kyngoy, (5) Kok-Jar, (6) Tustuk Magistral, (7) Ahunbaeva Jaddesi, (8) Cuy Jaddesi, (9) Cigis Avtovokzal and (10) Alamudun Kici Rayonu.

Table 4

Heavy metal and mineral element concentrations (mg kg^{-1} DW) in co-located soil samples from 10 different stations.

Stations	Al	Ca	Cr	Cu	Fe	K	Mg	Ni	Pb	Zn
1	22491.421 ± 526.995	20674.574 ± 516.696	78.207 ± 1.422	58.445 ± 0.595	6084.031 ± 112.951	9393.729 ± 168.646	17838.44 ± 453.213	51.153 ± 1.021	56.649 ± 0.854	178.945 ± 1.185
2	23280.274 ± 293.509	17437.008 ± 432.372	75.083 ± 1.941	75.625 ± 1.358	5986.692 ± 147.311	5061.135 ± 62.933	16348.965 ± 145.513	55.541 ± 0.381	72.008 ± 2.099	267.707 ± 8.054
3	36542.571 ± 876.468	10212.419 ± 21.392	71.934 ± 1.333	47.136 ± 1.395	7306.013 ± 14.715	7313.939 ± 17.077	21349.431 ± 196.278	48.164 ± 0.869	40.66 ± 0.641	177.298 ± 3.847
4	36456.758 ± 422.999	19289.897 ± 391.766	100.187 ± 2.94	79.582 ± 2.142	7331.588 ± 163.322	9406.153 ± 236.409	24003.848 ± 305.796	79.664 ± 2.313	69.037 ± 1.728	287.557 ± 5.689
5	40634.066 ± 219.309	15063.868 ± 250.982	98.903 ± 0.962	98.618 ± 1.35	8008.475 ± 184.897	7872.322 ± 149.811	23068.719 ± 354.007	74.468 ± 0.501	77.345 ± 0.817	275.053 ± 4.915
6	24623.542 ± 406.401	29799.869 ± 700.063	83.749 ± 2.206	84.699 ± 2.541	6197.89 ± 96.666	5866.026 ± 160.843	18220.799 ± 233.472	68.041 ± 1.839	64.754 ± 1.584	251.418 ± 2.254
7	31873.15 ± 314.804	40082.154 ± 294.512	68.962 ± 1.032	107.381 ± 0.567	6462.81 ± 70.31	8869.138 ± 57.662	21490.409 ± 437.686	68.662 ± 2.113	414.466 ± 7.804	201.777 ± 4.204
8	43207.508 ± 1314.916	45283.587 ± 463.347	85.192 ± 2.283	94.183 ± 0.68	8281.466 ± 63.051	13645.647 ± 431.881	26718.447 ± 345.743	66.002 ± 0.749	100.157 ± 0.902	311.843 ± 9.404
9	29450.932 ± 186.304	46465.531 ± 1124.703	103.309 ± 0.343	74.443 ± 1.903	6948.365 ± 95.143	7524.759 ± 62.805	19652.093 ± 289.653	84.241 ± 1.913	50.804 ± 1.412	215.878 ± 5.062
10	29906.66 ± 438.228	27524.37 ± 476.422	126.955 ± 2.804	324.366 ± 3.092	7756.801 ± 221.746	6355.354 ± 27.942	21387.907 ± 80.016	66.72 ± 1.645	105.666 ± 0.439	345.098 ± 6.473

(1) Jiluu Bulak (Tepliye, Kluci), (2) Arasan, (3) Tas-Moynok, (4) Bes-Kyngoy, (5) Kok-Jar, (6) Tustuk Magistral, (7) Ahunbaeva Jaddesi, (8) Cuy Jaddesi, (9) Cigis Avtovokzal and (10) Alamudun Kici Rayonu.

Table 5

Pearson correlation coefficients between the elements of *P. nigra* (in **bold**) and *S. fragilis* species analyzed in this study.

	Al	Ca	Cr	Cu	Fe	K	Mg	Ni	Pb	Zn
Al	1	**.666****	**.854****	**.436***	**.885****	**.666****	**.893****	**.562****	**.696***	**.838****
Ca	.634**	1	**.870****	**.506***	**.676****	**.898****	**.887****	**.909****	**.474***	**.649****
Cr	.835**	.871**	1	**.445****	**.672****	**.815****	**.869****	**.673****	**.443***	**.764****
Cu	.428*	.601*	.538**	1	**.574***	**.480***	**.663***	**.558****	**.438***	**.638****
Fe	.690**	.779**	.683**	.575*	1	**.850****	**.887****	**.870****	**.475***	**.742****
K	.646**	.896**	.816**	.471*	.758**	1	**.872****	**.629****	**.408***	**.707****
Mg	.863**	.885**	.869**	.655*	.894**	.870**	1	**.570****	**.312***	**.854****
Ni	.459**	.906**	.674**	.651*	.874**	.727**	.667**	1	**.509***	**.839****
Pb	.650	.330*	.401	.415	.437	.476*	.468	.447	1	**.452****
Zn	.852**	.668*	.676**	.753*	.768**	.715**	.860**	.851**	.399	1

**.Correlation is significant at the 0.01 level (2-tailed). *.Correlation is significant at the 0.05 level (2-tailed).

Figures

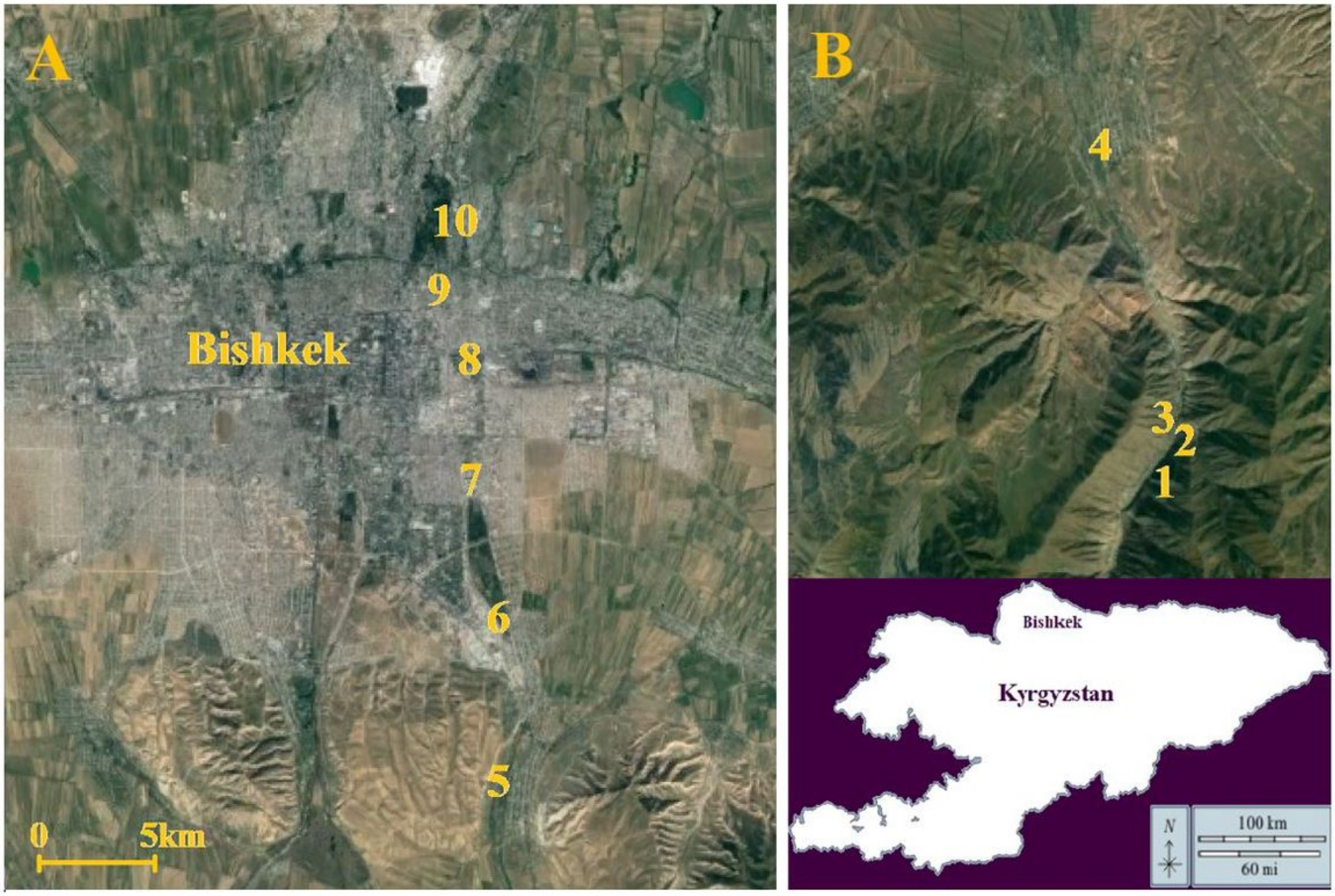

Figure 1

The satellite images (A and B) showing sampling stations in research area. A: Jiluu Bulak (Tepliye, Kluci) (1), Arasan (2), Tas-Moynok (3), Bes-Kyngoy (4), Kok-Jar (5) B: Tustuk Magistral (6), Ahunbaeva Jaddesi (7), Cuy Jaddesi (8), Cigis Avtovokzal (9) and Alamudun Kici Rayonu (10).