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RESEARCH

Effect of drought and soil heavy metal contamination on three maple species: a case study of Kastamonu University campus in Türkiye

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Abstract This study investigated the effects of heavy metals and drought on tree drying in three maple species located in the Kastamonu Campus in northwestern Türkiye. Soil samples were taken from 0–30 cm depth under maple species, and some soil properties were analyzed. The standardized precipitation evapotranspiration index was calculated for the drought impression using 71 years of climate data. The severe drought has had its effect (1.516) since August 2020. There was an extreme drought in January and February 2021 (-2.032 and -2.076, respectively), and this drought effect lasted until August as a severe drought. Chromium concentration at maple species was almost twice higher than the Maximum Allowable Limit for Türkiye (>100 mg kg^{-1}). The highest nickel concentration was found under *Acer pseudoplatanus* (97.25 mg kg^{-1}) and *Acer negundo* (108.13 mg kg^{-1}). The sampling sites were nonsignificant for copper ($p=0.806$), lead ($p=0.916$), and zinc ($p=0.866$) heavy metals. *Phyllosticta minima* and *Phyllactinia marissallii* were detected in maple trees. In conclusion, it is understood that drought and heavy metal accumulation (chromium, nickel) in the soil affect tree drying. Physiological drought was first seen in trees due to the lack of rainfall in 2020. Soils were contaminated with heavy metals, and finally, diseases were seen. These results show that adverse climate events due to global climate change will have a negative impact on the growth and development of maple species, as their severity is expected to increase in the next few years.

Highlights
- Drought in 2020 was one of the most severe droughts of the last 70 years.
- Heavy metal accumulation (chromium and nickel) was observed in the soil of maple species.
- *Phyllosticta minima* and *Phyllactinia marissallii* diseases were seen in maple species.
- Drying in maple species has been observed after drought, heavy metal accumulation, and disease.

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Introduction

Plants are exposed to many environmental conditions, such as biotic and abiotic stress (Mansoor et al., 2021). Drought and heavy metals, which are abiotic stress, negatively affect soil fertility and plant development. Thus, they are considered two crucial environmental (abiotic) factors attracting increasing attention due to their effects on plants (Islam & Sandhi, 2023). Forest ecosystems are affected by global climate change depending on factors such as an increase in annual temperature, a decrease in precipitation, and the severity and frequency of extreme climate events. Hot weather occurring in many regions for the first time with global warming has shown that drought has become a widespread environmental stress that significantly affects plant growth and development (Diatta et al., 2020). Such climate changes have a negative impact on plant growth and physiology by triggering multiple abiotic stresses and consequently limiting their productivity.

The frequency and severity of drought periods worldwide are increasing due to climate change (Fischer & Ashnaei, 2019). Climate changes worldwide negatively affect the earth's crust, leading to erratic rainfall, increased temperatures, and drought-prone soils (Rummukainen, 2012). Climatic prediction models explain that temperature increases due to climate changes are synergistically accompanied by drought stress resulting from plants' demand for soil moisture, reducing plant productivity (Suzuki, 2016). Over the last two decades, the forests of Central Europe have been affected by several heat waves with very dry summers, resulting in exceptionally high tree mortality due to these extreme events (Flach et al., 2021; Kunert & Hajek, 2022). The average temperature in Türkiye (Düzce) may increase significantly, the precipitation regime may change, and the climate types may shift towards arid climate types in the coming years (Koç, 2021). In one of the studies, Koç (2022) stated that today's mean minimum and maximum temperature at Samsun changes around 7–24 °C and future temperature changes between 13–19 °C from 2040 to 2080, and it will increase up to 19–25 °C in the second scenario during 2080–2100 and emphasized that the area will be much warmer in 2100.

Plants are exposed to high drought or salt stress levels, especially during summer (Ma et al., 2016). Drought symptoms manifest in many different ways according to tree species or variety and the severity of the water deficit (Preece & Penuelas, 2016). Horsley et al. (2002) stated that *Acer saccharum* was affected by many abiotic and biotic stress-induced stem, root, crown damage, or tree mortality regarding economic loss. While some stressors cause many diseases over a wider area, most usually have a limited effect on individual trees (Horsley et al., 2002). The severity of drought causes higher plant mortality due to reduced C uptake (reduced photosynthesis and increased autotrophic respiration) (Brando et al., 2019; Xiao et al., 2021). Therefore, plant mortality observed during more frequent and intense drought periods may change the phytosociological structure of entire plant communities over time (Santos et al., 2022). Many plant species in areas where drought has not been seen before face drought stress, and the plant has to develop avoidance mechanisms against drought (Islam & Sandhi, 2023).

Drought and heavy metal contamination, such as cobalt (Co), nickel (Ni), chromium (Cr), lead (Pb), zinc (Zn), copper (Cu), manganese (Mn), molybdenum (Mo) etc., are significant and influential environmental factors for plants. Each heavy metal creates various harmful effects on plants (Rehman et al., 2021; Yaashikaa et al., 2022). Exposure of plants to high heavy metals in the soil negatively affects many biochemical and physiological activities, causing plant growth to stop and low productivity (Bilal et al., 2020). The levels of some heavy metals, such as high concentrations of Cu, Zn, Co, Ni, Mn, and Mo in the soil adversely affect the biochemical processes that lead to a decrease in plant physiology, metabolism, biomass, yield, and growth (Islam & Sandhi, 2023; Thijs et al., 2017). Negative results include regression in plant growth and development, necrosis, chlorosis, and decreased germination rate (Khan et al., 2021; Yaashikaa et al., 2022). Cr toxicity causes restriction of plant growth, imbalance in nutrient uptake, yellowing of leaves, and damage to root tips (Ertani et al., 2017; Yaashikaa et al., 2022). Detrimental effects of Cr on plant growth include changes in the germination cycle and the development of leaves, stems, and roots. Likewise, Cr causes adverse consequences on the physiological cycles of the plant, such as mineral supplementation for photosynthesis and nutrition (Cai et al., 2019). Cr excess causes plant growth restriction, leaf yellowing, nutrient uptake imbalance, and root tip damage (Ertani et al., 2017).

As a result, excessive exposure to Cr concentration affects total dry matter production and yield efficiency. Ni toxicity in plants causes decreased water content in monocot and dicot plants. Therefore, Ni toxicity in plants is attributed to reduced water content. Ni toxicity is closely related to the inhibition of protein and chlorophyll processes. Water holding capacity is relatively poor in metal-contaminated soils, and evaporation rates are high (de Silva et al., 2012). Cu toxicity in the soil causes stress in the soil, causing regression in plant development and chlorosis

(Bae et al., 2022). Pb toxicity is a symptom of rapid inhibition of stunted growth, root growth, and chlorosis (Sharma & Dubey, 2005). Zn toxicity causes a decrease in the germination and biomass of plants and a decrease in yield and quality (Kaur & Garg, 2021).

Our country has 12 taxa of maple, with 11 taxa natural and one taxon naturalized. This study was conducted on *A. pseudoplatanus*, *A. negundo* L., and *A. platanoides* L. species. *A. negundo* L. taxon has become naturalized, although it is not natural (Urziceanu et al., 2020). *A. platanoides* trees have variable climatic demands and are resistant to cold climatic conditions (Lestrade et al., 2013). However, they do not like very arid and hot climates but will endure to some extent (Öztürk, 2016). *A. pseudoplatanus* L. trees are resistant to cold weather and remarkable climate species that can withstand hot but not extreme heat (Feliksik et al., 2000). They are more drought-more sensitive than the *A. platanoides* L. and *A. negundo* L. prefers to grow in moist soils with deep roots (Straigyte et al., 2015).

Many studies have been conducted on heavy metals in the soil and leaves of many tree species due to drought in different land environments worldwide (Hrotkó et al., 2021; Savacı & Öksüz, 2020; Sitko et al., 2021). As far as we know, there is very limited information about how different maple species on campus are affected by drought and metal-contaminated soils. Maple drying has been observed on the university campus; to our knowledge, this is the first study to be done there. We hypothesized that maple species that eventually died during drought events (in the future referred to as dead trees) were already less resistant to droughts that occurred five years before their death. Finally, the relationship between drought tolerance and future mortality risk is characterized by (i) the drought index calculated as the ratio between each region's long-term water availability (potential evapotranspiration (PET) and precipitation, (ii) the intensity of the drought event considered, and (iii) we evaluated how soil properties had an effect.

Materials and methods

General characteristics of the study area

The study was conducted in *Acer negundo* L. (also known as boxelder maple), *Acer platanoides* L. (also known as Norway maple), and *Acer pseudoplatanus* L. (also known as sycamore maple) in Kastamonu University Campus, northwest Türkiye (41°25ʹ31"N, -33°46ʹ20" E) (Fig. 1). The total area is 3.929 m^2. The mean elevation of the study site was 843 m a.s.l., and the aspect was northwest (NW) with a slope of 18%.

This study area is generally in the post-Black Sea climate zone, or the transition climate zone, with hot and dry summers and cold and snowy winters (Abacıoğlu & Palta, 2021). Bedrock type was lacustrine limestone, marl, and shale, belonging to the Miocene geological period (Akbaş et al., 2011). Regarding geological structure, the study area consists of the Schist and Limestone Schist layers of marl and shale (FAO-Unesco, 1981).

Determination of silvicultural characteristics

The study area of three different maples; diameter at breast height (1.30 m above ground) was measured to 0.1 cm precision using calipers on every living tree. Total tree height (TTH) was measured with Vertex IV or Blume-Leiss Altimeter (0.1 m precision). The age of trees was determined with an increment borer. Summaries of silvicultural characteristics are given in Table 1.

Soil and leaf sampling and analysis

There are tree dryings seen in maple species in the study areas. In June 2022, thirty-three soil samples (at 0–30 cm depth) were taken randomly from 11 points in 3 replicates within different maples in Kastamonu Campus, and the spatial distribution and contamination levels of heavy metals were determined. The 11 points in the study area are abbreviated as L1, L2, L3,…, and L11 from Location 1 to 11. Soil samples were oven-dried at 105°C for 24 h. Soil pH was measured using a pH meter (Enez et al., 2022). The salt values of the soils were measured with the help of a conductivity measuring device (Richards, 1954). Organic matter was analyzed using the loss on ignition method (Hoogsteen et al., 2018). In determining the soil type, 100 g of each sample was weighed, and their saturation with water was checked (Richards, 1954). The carbonate contents of the samples were determined by a Scheibler calcimeter (Szőőr et al., 2008). Soil nitrogen (N) was determined by using the Kjeldahl method.

At least twenty-five trees of each maple species were randomly identified, and their upper canopy leaves were sampled in May 2022. Leaves were obtained by rope climbing trees and using a pole

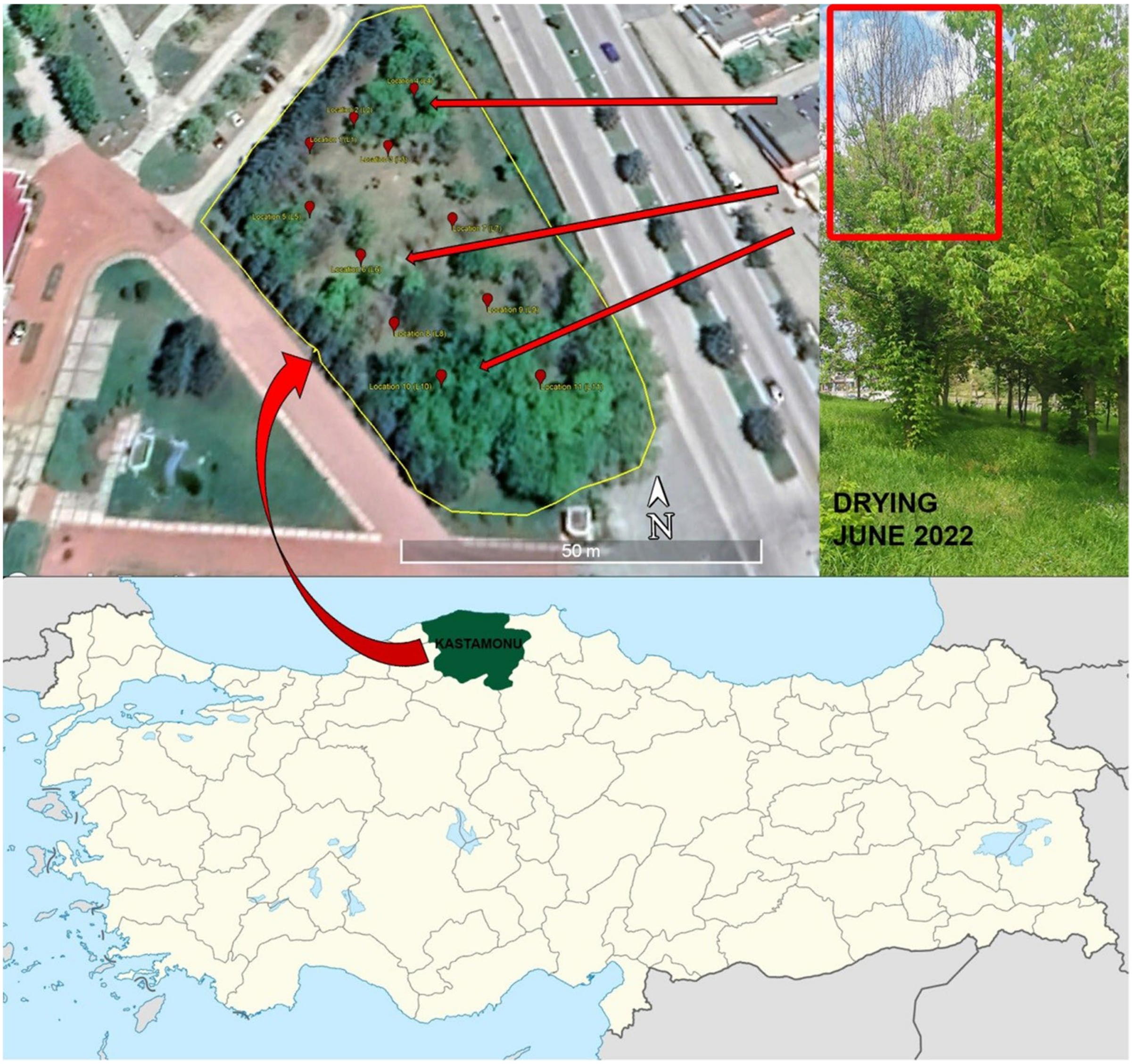


Fig. 1 Map showing the sampling location

Table 1 Silvicultural characteristics of the study area of three different maple trees

Silvicultural Characteristics	*Acer negundo* L	*Acer pseudoplatanus* L	*Acer platanoides* L
Mean tree age (year)	47	46	40
Mean diameter at breast height ($d_{1.30}$)	7.9	7.5	6.9
Mean tree height (m)	10	11	8
The number of healthy trees	39	36	15
The number of peak dry trees	7	1	2
The number of dead trees	18	4	24
The number of trees cut	13	9	22

cutter to remove a section of the tree branch. The fresh leaf samples were air-dried and then oven-dried at 65 ºC for 48 h (Ojo et al., 2023). Dried leaves were powdered using a coffee grinder. A leaf digestion method modified from Dospatliev & Ivanova (2022) was utilized, where 10 mL HNO_3 (65%) was added in 0.5 g of powdered leaf weighed inside a Teflon reaction vessel. Macro (phosphorous, potassium, calcium, and magnesium) and trace (nickel, zinc, lead, copper, and chromium) elements in maple leaf and soil samples were measured using an inductively coupled plasma mass spectrometer (ICP-OES Spectroblue, Spectro Ametek, Berwyn, USA). All analyses were performed with three repetitions.

Disease and insect detection in maple trees

In the examinations made on the maple species in the area regarding pests and diseases, no insect species that effectively damage the trees were found. An abundance of *Corythucha arcuata* (Say) (Heteroptera: Tingidae) (oak lace bug) was encountered in maple leaves (Fig. 2 a). Symptoms of powdery mildew disease (*Phyllactinia marissallii*) and purple-bordered leaf spot (*Phyllosticta minima*) were also observed in the same trees (Fig. 2 b). Nutritional disorders reduce the yield and the resistance of trees to diseases, cold, and thirst. Trees that cannot be fed adequately and in a balanced way become much more susceptible to viral, bacterial, and fungal diseases. It is easier to catch diseases and get more damage from diseases (Tripathi et al., 2022). It is thought that the excess Cr, Mg, Ca, and K in the soil and the Mg, Ca, and Cu concentrations in the leaves in our research area cause the maple trees to be susceptible to fungal diseases (Fig. 2 c).

Statistical data, mapping, and climate data

All statistical analyses were first prepared in the Microsoft Excel 2013 program. In this study, the effects of healthy, little-drying, and very-drying *A. negundo, A. pseudoplatanus,* and *A. platanoides* on the changes in soil and leaf nutrient element concentrations were tested by analysis of variance (ANOVA). A comparison of means was made with Duncan's test. Statistical analyses were performed on a computer using the SPSS statistical package program (IBM SPSS Statistics 22.0 version). The Pearson correlation coefficients examined the relationship between foliar and soil nutrients.

The spatial distribution of heavy metal maps was generated by Kriging interpolating from soil samples using Spatial Analysis Tools. The spatial distribution maps of Ca, Mg, K, Cr, Pb, Cu, Zn, and Ni under soil samples in Kastamonu University Campus were obtained based on their concentrations using ArcGIS software (Version 10.8, Esri, California, USA) by ordinary Kriging and the quantile classification method (Turhan et al., 2020).

To determine better the effect of this drought on plants, researchers have put forward many indices

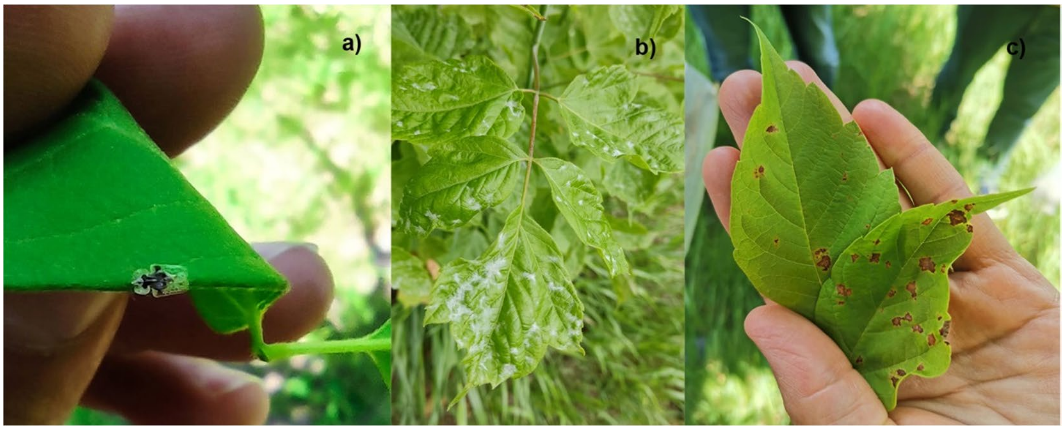


Fig. 2 **a)** *Corythucha arcuata* determined on *Acer pseudoplatonis* leaf **b)** Symptoms of powdery mildew (*Phyllactinia marissallii*) disease on *Acer negundo* leaf **c)** *Phyllosticta minima* disease symptom associated with Cu toxicity on *Acer negundo* leaf

to measure long-term meteorological drought severity from past to present (Savacı & Sarıyıldız, 2019). Some of the popular standard drought indices are the Palmer Drought Severity Index (PDSI; Wang et al., 2022), Standardized Precipitation Index (SPI; Zuo et al., 2021), Reclamation Drought Index (RDI; Gonçalves et al., 2023), Standardized Precipitation Evapotranspiration Index (SPEI; Isia et al., 2022), and Regional Drought Area Index (RDAI; Chang et al., 2021). Among all drought indices, the SPEI index is the most preferred and widely used for drought analysis worldwide (Dikshit et al., 2021). Vicente-Serrano et al. (2010) proposed the SPEI index, which considers the two most essential factors affecting drought: evaporation and precipitation, and could reflect the change in water balance. For this reason, the drought index was calculated using the SPEI index in this study. The climate data in this study are from the Standardized Precipitation Evapotranspiration Index (SPEI), Global Drought Monitor Service System (URL-1, 2022), and long-term monthly precipitation (mm) data from 1951 to 2022. Twelve months of SPEI and the diagram were generated by Excel 2013 software. The following Eq. 1 expresses the probability density function to calculate the value of SPEI:

$$f(x) = \frac{\beta}{\alpha}\left(\frac{x-y}{\alpha}\right)^{\beta-1}\left(1+\left(\frac{x-y}{\alpha}\right)^{\beta}\right)^{-2} \quad (1)$$

where α, β, and γ represent scale, shape, and origin, respectively. Thus, the probability distribution function can be expressed as Eq. 2:

$$F(x) = \left[1+\left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1} \quad (2)$$

The SPEI was calculated as follows: Eq. 3 (Vicente-Serrano et al., 2010):

$$SPEI = \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \quad (3)$$

when.

P≤0.5, $W = \sqrt{-2In(P)}$, and when P>0.5, $W = \sqrt{(-2In(1-P)}$, C_0 =2.5155, C_1 =0.8028, C_2=0.0103, d_1=1.4327, d_2=0.1892, d_3=0.0013. The categorization of drought classified by the SPEI is given in Table 2.

Results and discussion

Climate data of study area

The temporal variation of 12-month SPEI (SPEI_12) values in the study area from 1951 to 2022 is shown in Fig. 3. Extreme drought events were determined by combining the information from the growth and SPEI time series (Fig. 3). As it is known, the most severe drought was experienced in 2020 on a global scale. In Poland, there was an extreme drought in the dry spring of 2020 (especially in April), and the SPEI graph showed decreasing trends (Pińskwar et al., 2020). Rakovec et al. (2022) reported that the recent 2018–2020 drought event was exceptional due to its significantly higher intensity than past events and its rapid development from its onset in Europe. South China experienced an extreme drought from October 2020 to March 2021 (Feng et al., 2022). Dursun & Babalık (2021) stated that, according to the 12-month drought occurrence percentages (SPI_12), the probability of drought was more than 50% in Isparta and Senirkent town of Türkiye, and it was close to 50% in other towns. Dikici & Aksel (2019) reported the drought periods for Türkiye's Seyhan basin as 1973–1974, 1989, 2001, 2007–2008, 2014, and 2016. Güner Bacanlı & Akşan (2019) reported that when SPEI drought indices were examined for Osmaniye of Türkiye between 1970 and 2018, the highest value in the near-normal drought class was 12 months frequency (68.06%), and it was the highest among all frequencies in the drought class. Kumanlioglu (2020) revealed that wet periods were dominant in the Gediz basin before 1984, and dry periods occurred more frequently and lasted longer after this year. It was determined that the effect of possible evapotranspiration

Table 2 The standardized precipitation evapotranspiration index (SPEI) drought analysis ranges

Climatic moisture categories	SPEI Value
Extremely wet	≥ 2.0
Severely wet	1.5 to 1.99
Moderately wet	1.0 to 1.49
Normal	0.99 to − 0.99
Moderate drought	− 1.0 to − 1.49
Severe drought	− 1.5 to − 1.99
Extreme drought	≤ − 2.0

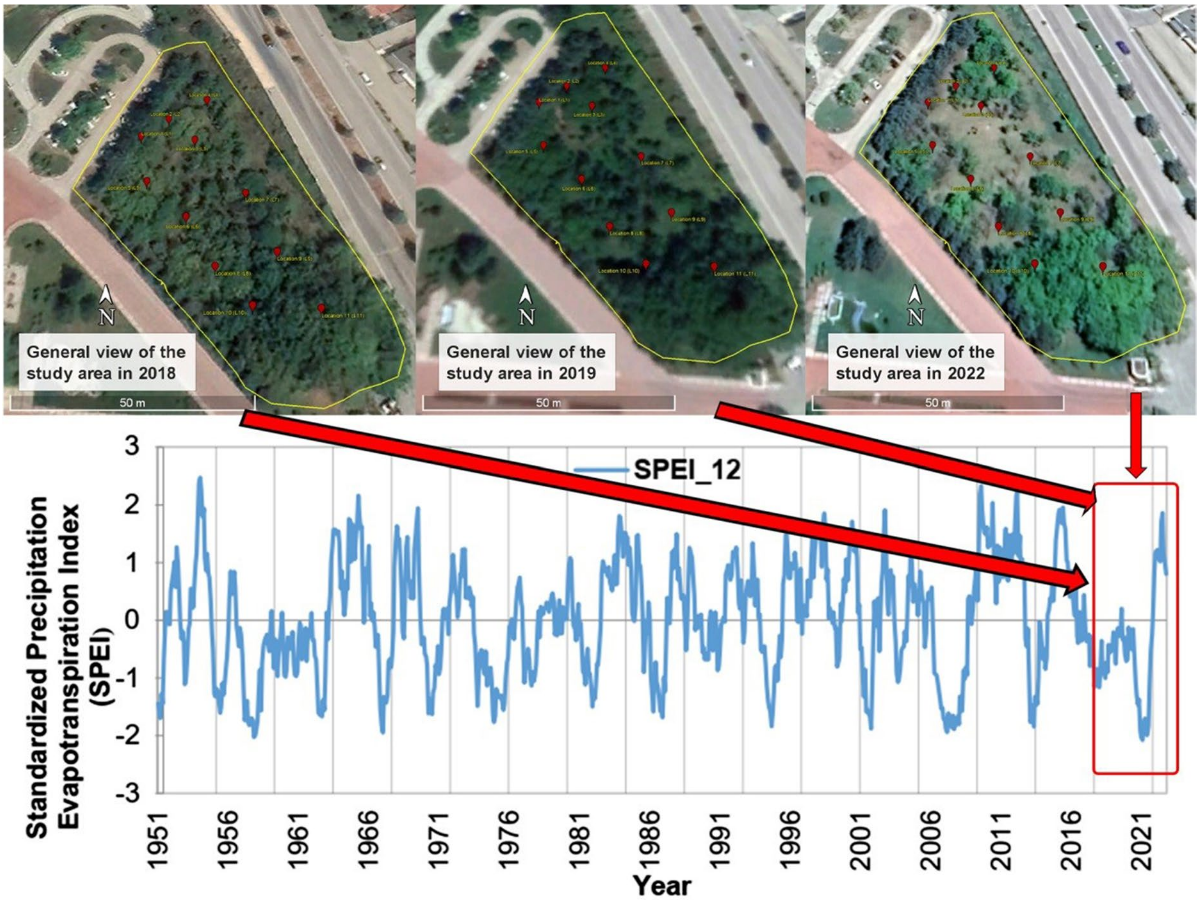


Fig. 3 The SPEI at 12 months for the study area in Kastamonu Province from 1951 to 2022. General views of the study area in 2018, 2019, and 2022

losses due to temperature increase on drought events increased after 2000, and the droughts that occurred after this year were experienced more intensely in the basin. Eris et al. (2020) stated that the most severe month in Türkiye's Küçük Menderes River basin was SPEI = -3.05 (extreme drought) in September 1994 and extreme droughts in July 1988, 2007, 2012, June 2016, and April 2018. Considering the climate data area where maple trees drying was observed in the study areas, the lowest precipitation was observed in July (8.7 mm), August (4.2 mm), and November (1.0 mm) of 2020. However, it was observed that the temperature values did not change much between the years. The annual total precipitation in July, August, and November of 2019 decreased by 18.3%, 4.2%, and 7.2% in 2022, respectively (Fig. 3). Table 2 shows a wet event when the SPEI value is more significant than zero and a drought with negative values. Figure 3 shows that the SPEI value changed frequently between drought and precipitation as it was vulnerable to short-term climatic conditions. The most severe drought has occurred in the last 3 years, from August 2020 to August 2021. From November 2021 (0.143) to the present, SPEI values have shown an increasing trend, meaning the study area has become a wet event in recent years (Fig. 3).

The severity of 2020 spring and summer droughts increased with the scale in the SPEI. SPEI 12 showed extreme drought at only a few stations (values above -1.5) from December 2020 to July 2021 (Fig. 3). Similarly, Pińskwar et al. (2020) stated in their study that two consecutive dry years, 2018 and 2019, a mild winter in 2019/20, and an arid spring in 2020 led to severe drought in Poland. The Standard Precipitation

Index (SPI) is the most commonly used index to evaluate the total precipitation change over time in drought. SPI-1 to SPI-6 are agricultural droughts, and SPI-7 to SPI-24 are hydrological droughts (Islam & Sandhi, 2023). In this study, it has been shown that 2020 spring and summer droughts were one of the most severe droughts of the last 70 years. Cumulative year-on-year water scarcity and lack of precipitation, reflected in very low SPEI values, led to the development of severe drought. Ojha et al. (2021) stated that 3-month SPI and 12-month SPI values in the Punpun River basin showed an increasing trend, and drought severity showed a decreasing trend from seasonal to annual time scale.

Some soil properties of the study area

The average of three repetitions samples taken from each point and some physical and chemical properties of soils are given in Table 3. Soil pH ranged from 7.85 to 8.21, and soils generally had slightly alkaline reactions. However, Straigytė et al. (2019) reported that the most acidic soil (5.9–6.1) was found with *A. platanoides* in Lithuania. Reich et al. (2005) found that the soils beneath different species varied in mineral soil acidity from 4.36 to 4.50 for *A. pseudoplatanus* and 4.89 to 4.99 for *A. platanoides*. *A. saccharum* L. can grow successfully in a wide range of soils, exhibiting a large pH tolerance by growing in soils with a pH of 3.7—7.3 (West et al., 2023). As a result of the soil analysis, the salinity of soils is unsalted (between 0.13–0.25 dS m^{-1}). It can be seen that all of the soils are in the salinity class (Table 3), so the soils do not have any problems regarding salinity (Table 3). Özyazıcı et al. (2013) emphasized that EC values of the Eastern Black Sea Region soils varied between 0.022 and 1.956 dS m^{-1} and were salt-free. Similar findings were obtained in the study conducted by Özyazıcı et al. (2010) in the same region. Salinity stress is relatively low in our region (Table 3) and has little effect on the water potential of leaves (Wang et al., 2020). The soils of the study area are very calcareous, with an average of 28%. The organic matter content of soils is medium–high humus soils (Table 3). Nitrogen content is between 0.093% and 0.320%, and the soil type in this area varies between clayey loam and loam. When soil properties determined above are examined in terms of soil requirements of 3 different maple species (*A. negundo*, *A. pseudoplatanus*, and *A. platanoides*) found in the site, *A. negundo* adapts to various soil types. Although moist, loose soils are ideal for plants, they can grow in deep, well-drained, or sandy mud soils but tolerate sun or partial shade, cold, and drought (DeGraaf, 2002). *A. platanoides* species can grow in soils with low sand content, salty, heavy clay, and calcareous soils (Simkovic, 2020). *A. pseudoplatanus* species usually grow in deep and moist soils (Straigyte & Baliuckas, 2015). It can grow in any soil except very alkaline or saline soil. *A. pseudoplatanus* species tolerate clayey and heavy metals (Lestrade et al., 2013). The impact of a tree species on soil fertility varies depending on climate, bedrock type, and forest management (Krajnc et al., 2021). Ca-rich tree species are associated with increased soil pH (Reich et al., 2005). In our study, the soil under the *Acer* subsp. trees were

Table 3 Some physical and chemical properties of soils under maple species (0–30 cm)

No	pH	EC (dS m-1)	Lime (%)	Organic matter (%)	N (%)	Soil Type
1	8.14	0.200	35.72	5.10	0.127	CL
2	8.19	0.159	28.45	5.00	0.096	CL
3	8.16	0.153	28.45	4.16	0.078	CL
4	8.07	0.250	30.05	2.91	0.120	CL
5	8.13	0.131	23.27	3.83	0.082	L
6	7.85	0.191	23.10	3.40	0.133	CL
7	8.04	0.151	22.13	4.46	0.093	L
8	8.21	0.132	30.53	2.87	0.320	L
9	8.01	0.170	27.63	3.58	0.270	CL
10	8.05	0.250	24.09	3.45	0.127	CL
11	8.08	0.180	27.35	3.89	0.145	CL

quite calcareous, which may have caused the pH to increase. Soil pH levels fluctuate both temporally and spatially (Guo et al., 2018). Spatial pH variation is more significant than seasonal variation (Straigytė et al., 2019). Seasonal pH fluctuations are mostly related to temperature, microbial activity, and soil moisture. For example, spring snowmelt can saturate the soil and cause nutrients to leach out, which can cause changes in soil pH (Straigytė et al., 2019).

As a result, although soils in the study area are rich in organic matter, have clayey-loam soil characteristics, are moderately calcareous, salt-free, and have a slightly primary reaction, there is no negative effect on the growth of maple species. It was determined that better development was achieved in the soil properties of species.

Foliar nutrients and heavy metals

Foliar concentrations of Cr, P, Ni, K, Cu, Pb, and Zn were significantly higher ($p < 0.001$, but Ca and Mg were significantly lower in different maple species in Kastamonu University Campus ($p < 0.05$; Table 4). The concentrations of Ca and Ni in *A. negundo* leaves did not significantly affect the degree of disease. Also, the concentrations of Ni and Mg in *A. pseudoplatanus* leaves had nonsignificant differences according to the degree of disease. At the same time, there were significant differences in nutrient concentrations among all maple species (Table 4). Ca concentration was the same value in all maple species. Among the macronutrients necessary for tree nutrition, Ca concentration is the main factor limiting *A. rubrum* growth in acidic soils (Arseneau et al., 2021). Mg concentration ranged from 32.7 mg kg^{-1} to 121.9 mg kg^{-1}, the highest in little-dried and very-dried maple trees, respectively. P, K, and Cu concentrations were very low in the very-dried *A. pseudoplatanus* trees (3.03 mg kg^{-1}, 45.5 mg kg^{-1}, and 41.5 mg kg^{-1}, respectively). Ateya et al. (2023) reported that Ca and Mg concentrations in *Picea pungens* needles ranged between 3248.4 mg kg^{-1}—3259.6 mg kg^{-1} and 497.3 mg kg^{-1}—867.9 mg kg^{-1}, respectively. Mg can change depending on soil pH, microbial activity in the rhizosphere, and ratios, especially Ca, K, and Mn nutrients (Huber & Jones, 2013). The mean pH of our study soils was 8.09, which may have been affected by highly alkaline soil, but no correlation was found between Mg in soil and Mg in leaves. Therefore, Mg may indirectly affect overall plant health or directly affect a specific physiological function of Mg (Huber & Jones, 2013). The symptom of the disease is nutrient alteration. Determining which biotic and abiotic factors cause nutrient deficiency or excess effects is often complex (Huber & Jones, 2013).

Available K and P concentrations were also significantly higher in little-dried and very-dried *A. negundo* L. compared to *A. pseudoplatanus* L. and *A. platanoides* L. trees ($p < 0.05$, Table 4). Trees grown in P-rich soil can solubilize the excess P in the body and allocate it to the leaf's epidermis cells, which may be excessive in aged leaves (Guilherme Pereira et al., 2019; Suriyagoda et al., 2023). Cr concentration for *A. pseudoplatanus* leaves varied between 7.1 mg kg^{-1} (healthy) and 11.6 mg kg^{-1} (very-dried), for *A. negundo* varied between 5.5 mg kg^{-1} (very-dried) and 6.5 mg kg^{-1} (healthy), and for *A. platanoides* leaves varied between 7.7 mg kg^{-1} (little-dried) and 8.9 mg kg^{-1} (very-dried). Soba et al. (2021) found that the concentration of Cr in the *Tilia cordata* leaf was 7.65 ± 0.43 mg kg^{-1} in Spain. The highest concentration of Ni was in healthy *A. platanoides* (19.3 mg kg^{-1}), followed by very-dried (9.8 mg kg^{-1}) and little-dried (9.3 mg kg^{-1}), respectively.

Cu concentration was higher in the very-dried *A. negundo* (77.2 mg kg^{-1}) and *A. platanoides* (89.2 mg kg^{-1}) trees (Table 4). Heavy metal toxicity slows down the plant's physiological change, namely the plant's growth, depending on oxidative stress. Since Cu toxicity causes ultrastructural damage, it affects some biochemical processes of the plant (Rajput et al., 2019). All maple species had significantly greater foliar Pb and Zn concentrations in Kastamonu University Campus (Table 4). Alam et al. (2020) stated that the concentration ranges were 29.62–64.81 mg kg^{-1} for Zn and 0.2–1 mg kg^{-1} for Pb for foliar samples. Turan et al. (2020) observed that the highest concentration of Zn was obtained in pine samples, such as 82.06 mg kg^{-1} in Istanbul, Anatolia. Some studies suggest a warming climate contributing to declines in *A. saccharum* Marsh growth (Boakye et al., 2023; Wang & Ibáñez, 2022), although nutrient degradation and drought also likely play a role (Raczka et al., 2023). Mleczek et al. (2023) reported that Cu, Pb, and Zn concentrations were ranging from 20.2 mg kg^{-1} to 52.7 mg kg^{-1}, 9.52 mg kg^{-1} to 23.6 mg kg^{-1}, and 475 to 1070 mg kg^{-1} for *A. platanoides*, respectively.

Table 4 Some nutrients of soils and leaves under three different maple trees

Nutrient (mg kg^{-1})	Tree Species										
	Acer negunda			*Acer pseudoplatanus*			*Acer platanoides*				
	Healthy	Little drying	Very drying	Healthy	Little drying	Very drying	Healthy	Little drying	Very drying	F	Sig
Ca_soil	122264^{a} ± 5438	125659^{a} ± 4882	125193^{a} ± 6310	127765^{a} ± 6265	108546^{a} ± 6572	124353^{a} ± 19,324	116445^{a} ± 10,771	134316^{a} ± 5094	118656^{a} ± 6993	.720	NS
Mg_soil	7087^{a} ± 246.9	6993^{a} ± 231.4	7591^{a} ± 341.8	7068^{a} ± 308.9	7193^{a} ± 283.0	6805^{a} ± 783.2	7033^{a} ± 429.6	7392^{a} ± 501.1	7968^{a} ± 273.8	.776	NS
P_soil	690^{a} ± 61.4	774^{a} ± 55.8	634^{a} ± 62.7	700^{a} ± 59.3	543^{a} ± 63.6	844^{a} ± 220.2	720^{a} ± 129.4	645^{a} ± 64.9	649^{a} ± 93.6	.849	NS
K_soil	8055^{a} ± 298	7874^{a} ± 286	8636^{a} ± 335	7956^{a} ± 348	8216^{a} ± 424	7835^{a} ± 887	7937^{a} ± 570	8382^{a} ± 502	9036^{a} ± 149	.804	NS
Cr_soil	131.9^{abc} ± 4.3	130.1^{abc} ± 3.9	145.4^{abc} ± 6.8	135.4^{abc} ± 5.2	124.4^{ab} ± 4.9	129.8^{abc} ± 9.2	123.8^{a} ± 4.1	152^{c} ± 6.6	146.5^{bc} ± 9.2	2.112	*
Ni_soil	96.2^{a} ± 2.2	94.8^{a} ± 2.0	102.9^{ab} ± 2.8	98.2^{ab} ± 2.2	93.4^{a} ± 2.5	94.6^{a} ± 6.2	92.9^{a} ± 2.7	106.9^{b} ± 3.1	102^{ab} ± 3.5	2.165	*
Cu_soil	37.1^{a} ± 9.7	43.3^{a} ± 9.9	23.6^{a} ± 1.1	32.2^{a} ± 8.5	26.2^{a} ± 1.8	63.6^{a} ± 43.4	45.6^{a} ± 21.1	21.8^{a} ± 0.7	25.3^{a} ± 1.3	.692	NS
Pb_soil	14.5^{a} ± 1.97	15.9^{a} ± 1.98	12.4^{a} ± 0.3	14.2^{a} ± 1.72	12.1^{a} ± 0.15	19.7^{a} ± 8.83	16.7^{a} ± 4.27	12.3^{a} ± 0.31	12.9^{a} ± 0.39	.595	NS
Zn_soil	71.7^{a} ± 1.3	73.4^{a} ± 1.08	72.4^{a} ± 2.3	73.1^{a} ± 1.5	67.8^{a} ± 1.6	74.3^{a} ± 2.8	71.5^{a} ± 2.4	73.9^{a} ± 1.8	72.8^{a} ± 3.5	.776	NS
Ca_plant	40.3^{ab} ± 0.05	40.4^{ab} ± 0.06	40.3^{ab} ± 0.11	40.6^{b} ± 0.12	40.1^{a} ± 0.05	40.1^{a} ± 0.0	40.6^{b} ± 0.07	40.6^{b} ± 0.16	40.4^{ab} ± 0.22	2.682	*
Mg_plant	95.3^{bc} ± 11.3	110.6^{bc} ± 7.6	121.9^{c} ± 6.2	97.4^{bc} ± 10.1	105.9^{bc} ± 0.6	99.9^{bc} ± 0.6	32.7^{a} ± 0.9	77.3^{bc} ± 26.7	71.7^{ab} ± 17.9	3.458	**
P_ plant	9.6^{bcd} ± 1.6	11.3^{cd} ± 0.6	21.6^{e} ± 2.1	8.9^{bc} ± 0.9	16.6^{de} ± 2.1	3.03^{ab} ± 0.03	-	5.8^{abc} ± 0.04	9.3^{bc} ± 0.04	9.691	***
K_ plant	174.8^{c} ± 5.1	185.6^{c} ± 3.7	232.8^{d} ± 9.6	154.3^{bc} ± 11.5	162.0^{bc} ± 20.3	45.5^{a} ± 0.1	135.8^{b} ± 6.5	134.8^{b} ± 16.5	177.9^{c} ± 25.4	12.317	***
Cr_ plant	6.5^{ab} ± 0.3	5.5^{a} ± 0.3	5.5^{a} ± 0.1	7.1^{abc} ± 0.2	7.4^{bcd} ± 1.4	11.6^{e} ± 0.1	8.7^{cd} ± 0.2	7.7^{bcd} ± 0.9	8.9^{d} ± 0.4	9.989	***
Ni_ plant	8.6^{a} ± 1.7	5.6^{a} ± 1.0	4.3^{a} ± 0.1	6.7^{a} ± 1.0	5.0^{a} ± 0.5	5.5^{a} ± 0.2	19.3^{b} ± 2.5	9.5^{a} ± 1.9	9.8^{a} ± 1.7	6.222	***
Cu_ plant	69.3^{bc} ± 4.9	55.9^{ab} ± 2.8	77.2^{bcd} ± 5.4	55.8^{ab} ± 5.3	98.2^{d} ± 16.4	41.5^{a} ± 0.4	86.2^{cd} ± 4.5	75.2^{bc} ± 4.7	89.2^{cd} ± 1.2	6.850	***
Pb_ plant	22.2^{bc}d ± 1.0	20.6^{ab} ± 0.6	17.9^{a} ± 0.5	23.2^{bcde} ± 0.9	21.3^{bc} ± 1.2	24.2^{cdef} ± 0.2	27.5^{f} ± 0.4	25.3^{def} ± 1.0	25.9^{ef} ± 0.4	7.351	***
Zn_plant	17.7^{abc} ± 1.9	19.4^{abc} ± 1.4	29.5^{de} ± 3.2	23.1^{bcd} ± 2.7	32.6^{e} ± 3.1	15.0^{ab} ± 0.3	10.2^{a} ± 0.0	34.1^{e} ± 2.7	26.8^{cde} ± 5.2	6.830	***

It is expressed as Means ± Standard Error. Where letters in superscript differ, data are significantly different *($P < 0.05$), **($P < 0.01$), ***($P < 0.001$). *Ca* calcium, *Mg* magnesium, *P* phosphorus, *K* potassium, *Cr* chromium, *Ni* nickel, *Cu* copper, *Pb* lead, *Zn* zinc, *NS* nonsignificant

The Pearson correlation coefficients of metals in the Kastamonu University Campus are shown in Table 5. A significantly positive correlation was found between plant elemental pairs Ni–Cr (0.574), Cr-Cu (0.384), Cr-Pb (0.707), Pb-Ni (0.802), Ni-Ca (0.517), P-Cu (0.788), Zn-P (0.717), Zn-K (0.428), P-K (0.803), and K-Mg (0.500) at $p < 0.001$. In contrast, a significantly negative correlation was found between plant elemental pairs Cr-K (-0.413), Cr-Mg (-0.545), Mg-Ni (-0.859), Pb-K (-0.425), Mg-Pb (-0.729), and Mg-Ca (-0.609) at $p < 0.001$. Also, a significant correlation was found between plant and soil elemental pairs Cu_{plant}-Cr_{soil} (0.277), Cu_{plant}-Ni_{soil} (0.287), Cu_{plant}-K_{soil} (0.284), Cu_{plant}-Mg_{soil} (0.251), Zn_{plant}-Ni_{soil} (0.224), P_{plant}-Ni_{soil} (0.281), and Cu_{plant}-Cr_{soil} (0.277) at $p < 0.05$. Piczak et al. (2003) found a significant positive correlation between Mn-Zn (0.96), Cd-Cr (0.93), Mg-Zn (0.84), Pb-Cr (0.983), Ni-Ca (0.81), and Ca-Cd (0.82) at $p < 0.05$ in *A. platanoides* trees in southwest Poland. The optimal Zn content in the plant is significant, as metal is the main component of enzymes and necessary for plant protein production (Hamzah Saleem et al., 2022). P in the nutrient solution interacts with Zn, altering its availability, which can be interpreted as interaction with Cu in most cases. In this study, increasing P concentration increased Zn accumulation in plants (Zn-P, $p < 0.001$, $r = 0.717$). Contrary to our study, many studies have shown that increasing P concentration reduces Zn accumulation in plants (Mleczek et al., 2023; Saboor et al., 2021).

Soil nutrients and heavy metals

Results of the map showed that highly concentrated zones of Ca were found at sampling sites of L1, L3, L4, L8, and L10, respectively (generally under very-drying *A. negundo* trees), as shown in Fig. 4 a. This study revealed that Ca concentration was much higher than soil background values between 131.283 mg kg^{-1} and 158.096 mg kg^{-1} under *A. negundo* trees. Ca concentration in soils was moderate under *A. platanoides* and *A. pseudoplatanus* tree species. The results of the spatial distribution pattern showed that high and very high concentrated zones of Mg were found in all sampling sites (Fig. 4 b). The effect of bedrock type (limestone, marl, and shale) and medium alkalinity of soil pH (> 8.0) in study sites may have contributed to high Ca and Mg concentrations. According to SPEI data (Fig. 3), between June 2016 (-0.268) and October 2021 (-0.251), the precipitation is almost low, and soils are highly alkaline, which may cause an increase in Ca and Mg. Horuz et al. (2012) stated in their study that the region's soils receive too much precipitation, and soils with too much acid reaction may cause Ca deficiency. McDermot et al. (2020) stated that Philadelphia soils contained biogeochemically different and higher amounts of Mg, and the Ca: Mg ratio in the soil is inconsistent, making it difficult for plants to uptake Ca, Mg, and Mn. Mg toxicity in soil, an incredibly high Mg: Ca ratio, causes a toxic effect on plants (Altıoğlu, 2009). Mg redundancy prevents photosynthesis and growth, especially in physiological drought stress (Karaman et al., 2012).

In Türkiye, operative "Control of Soil Pollution" legislation (Official Gazette, 31 May 2005, 25,831) was addressed the maximum Allowable Limit (MAL) for heavy metals (Anonymous, 2023). The maximum concentration of Cr at maple species was almost twice higher than the Maximum Allowable Limit (MAL) for Türkiye values (Fig. 4 c). Similarly, Savacı & Öksüz (2020) emphasized that Cr in the soil exceeds the MAL values (= 100 mg kg^{-1}). Cr excess in the soil leads to a decrease in the uptake of plant nutrients and water from the soil solution, ultimately inhibiting plant growth and development. Therefore, a significant reduction in yield and quality is observed in plants (Saleem et al., 2022; Ugwu & Agunwamba, 2020). Cr formation in soils is generally dependent on the minerals in the bedrock. Cr concentrations in soils result from silicate alteration in minerals relative to chromite. Cr concentration is < 200 mg kg^{-1} in serpentinites and ultramafic rocks (Ertani et al., 2017). Cr at pH < 9 are Mn oxides and hydrogen peroxide (Liang et al., 2021). The average amount of Cr is between 7 and 150 mg kg^{-1} and is 30 mg kg^{-1} in sand soil, 40 mg kg^{-1} in clay soil, and 83 mg kg^{-1} in limestone soil (Barałkiewicz & Siepak, 1999).

The highest concentrated zone of Ni was found at sampling sites of L1, L2, L3, L4, and L5 under *A. platanoides* and *A. negundo* trees, as shown in Fig. 4 d. This study suggests that soils containing a high amount of clay may increase the amount of Ni concentration. Brookes (1995) stated that there was also evidence that heavy metals in sandy loam soils affected biomass at lower metal concentrations than in soils with higher clay content. Turhan et al.

Table 5 Pearson's correlation coefficient for soil and plant metals concentrations of maple trees in Kastamonu University Campus

Nutrients	Cr plant	Ni plant	Cu plant	Zn plant	Pb plant	P plant	K plant	Mg plant	Ca plant	Ca soil	Mg soil	P soil	Cr soil	Ni soil	K soil	Cu soil	Pb soil	Zn soil
Cr plant	1																	
Ni plant	.574***	1																
Cu plant	.384***	.339**	1															
Zn plant	.056	-.339**	.288**	1														
Pb plant	.707***	.802***	.333**	-.166	1													
P plant	-.070	.244*	.788***	.717***	-.113	1												
K plant	-.413***	-.321**	.174	.428***	-.425***	.803***	1											
Mg plant	-.545***	-.859***	-.327**	.338**	-.729***	.099	.500***	1										
Ca plant	.147	.517***	.107	.023	.346**	.180	-.086	-.609***	1									
Ca soil	-.093	.010	-.117	.086	-.008	.041	.069	.053	.148	1								
Mg soil	.110	-.002	.251*	.041	.045	.156	.055	.002	-.132	-.597***	1							
P soil	-.044	.058	-.253*	-.114	.037	-.158	-.041	.050	-.022	.006	.165	1						
Cr soil	.075	-.040	.277**	.186	.023	.269*	.124	.059	-.028	.144	.547***	-.129	1					
Ni soil	.077	-.048	.287**	.224*	.019	.281*	.120	.047	.013	.259*	.290**	-.484***	.870***	1				
K soil	.138	-.016	.284**	.064	.037	.171	.060	-.001	-.138	-.678***	.955***	.021	.574***	.368***	1			
Cu soil	.026	.041	-.188	-.114	.042	-.170	-.092	.017	-.076	-.545***	.371***	.738***	-.249*	-.480***	.355***	1		
Pb soil	.032	.043	-.185	-.110	.051	-.165	-.089	.022	-.079	-.502***	.392***	.774***	-.185	-.430***	.366***	.993***	1	
Zn soil	-.039	.034	-.142	-.028	.039	-.046	.008	.074	-.005	.259*	.257*	.863***	.310**	-.075	.093	.409***	.481***	1

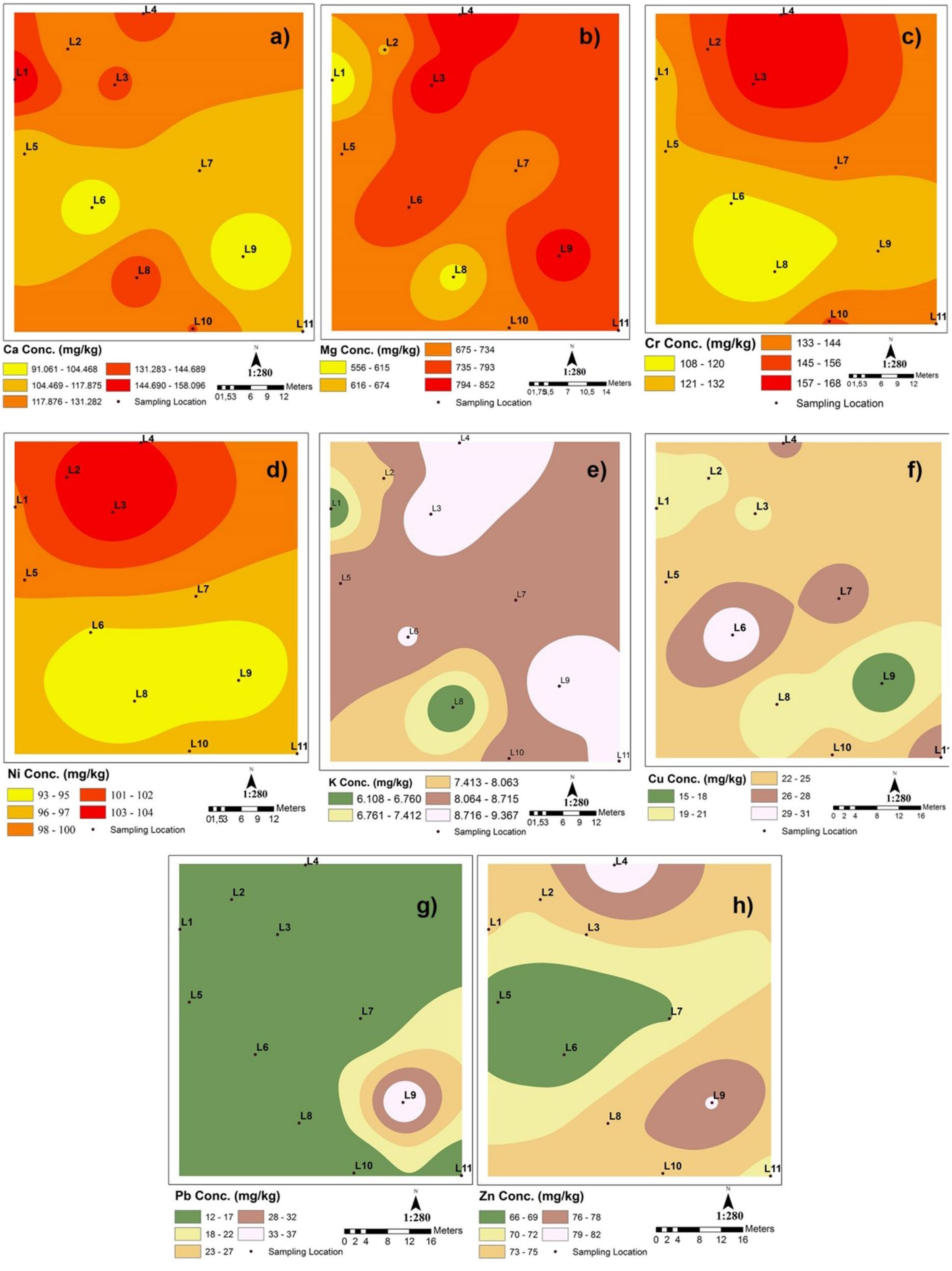
* Correlation is significant at the 0.05 level (2-tailed) ** Correlation is significant at the 0.01 level (2-tailed) *** Correlation is significant at the 0.001 level (2-tailed)

(2020) stated that Ni concentration under soils varied between 89.5 mg kg^{-1} and 971.0 mg kg^{-1} and had a mean value of 610.1 mg kg^{-1}. In this study, it is thought that bedrock is a sedimentary rock, namely limestone and shale, and is also effective in increasing Ni concentration. Ni formation is observed in silty sedimentary rocks and alkaline igneous rocks (Barałkiewicz & Siepak, 1999). Xia et al. (2015) and Sardans et al. (2008) stated in their studies that drought factor increases trace elements such as Cu, Cr, Zn, Al, Ni, Co, Pb, and As at a certain toxic level in plant organs and soil. Concentrations such as Al, Ni, Cu, Zn, Cd, and Pb are toxic in the soil during drought (Tipping et al., 2003). However, sampling sites were nonsignificant for most heavy metals (Cu, Pb, and Zn concentrations) (Figs. 4 f, g, h and Table 4). Kozlov et al. (2000) argued that the high pH value in the soil will increase the Ni concentration in the plant. Also, Yang et al. (2021) argued that the movement of Pb and Zn was significantly negatively correlated with soil pH. Heavy metal toxicity is more significant for plants during dry seasons and is effective because heavy metal in soil increases due to the evaporation of water in dry seasons (Punia, 2021).

The concentrations of Mg, Ca, K, Cu, Zn, Pb, and P in the soil were nonsignificantly, but Cr and Ni concentrations were significantly lower in *A. negunda*, *A. pseudoplatanus*, and *A. platanoides* trees in Kastamonu University Campus forests ($p < 0.05$; Table 4). In general, the highest Cr concentration was observed in little-drying and very-drying *A. platanoides* trees (152 ± 6.6 mg kg^{-1} and 146.5 ± 9.2 mg kg^{-1}), and significantly lower values were observed in healthy *A. platanoides* and little-drying *A. pseudoplatanus* trees (123.8 ± 94.1 mg kg^{-1} and 124.4 ± 4.9 mg kg^{-1} (Table 4). Similarly, Khan et al. (2018) found that Cr concentration at high concentrations in all samples also seems to have anthropogenic sources, but not the same ones as other contaminants in Dhaka City, Bangladesh. The highest Ni concentrations were also significantly lower, with little and very-drying *A. platanoides* trees (106.9 ± 3.1 mg kg^{-1} and 102 ± 3.5 mg kg^{-1}) compared to *A. pseudoplatanus* trees ($p < 0.05$; Table 4). In our study, heavy metal accumulation in soils was higher compared to maple leaves (Table 4). Similarly, Kosiorek et al. (2016) stated that heavy metal accumulation in soil was higher than in the leaves and needles of trees.

The Pearson correlation coefficients of metals in the Kastamonu University Campus are shown in Table 5. A significantly positive correlation was found between soil elemental pairs Mg-Cr (0.547), Ni–Cr (0.870), K-Mg (0.955), Cu-P (0.738), P-Pb (0.774), Pb-Cu (0.993), Zn-P (0.863), Cu–Zn (0.409), Pb–Zn (0.481), Cu-Mg (0.371), K-Cu (0.355), Pb-Mg (0.392), and K-Pb (0.366) at $p < 0.001$. Zn was significantly positively correlated ($p < 0.01$) with Ca and Mg, different from maple soils (Table 5). Significant negative correlations in soils were found for some elemental pairs at $p < 0.001$; Mg-Ca (-0.597), K-Ca (-0.678), Cu-Ca (-0.545), Ca-Pb (-0.502), Ni-Cu (-0.480), and Pb-Ni (-0.430). According to these results, the increase in Pb, Cu, and Ni concentrations is considered anthropogenic origin. Savacı & Öksüz (2020) found that a significant positive correlation was found between Cr-Ni (0.993), Pb-Ni (0.777), Cu-Ni (0.947), Mo-Ni (0.991), Pb-Cr (0.764), Cu-Cr (0.934), Mo-Cr (0.985), Cu-Pb (0.859), Zn-Pb (0.851), Mo-Pb (0.715), Zn-Cu (0.647) and Mo-Cu (0.934) at $p < 0.01$. Kosiorek et al. (2016) found that significant correlations were between soil Pb concentrations vs. Zn (0.869, $p < 0.05$), Cu (0.899, $p < 0.05$), as well as Zn vs. Cu (0.772, $p < 0.05$). Similarly, Baltas et al. (2020) found a significant relationship between Cr and Ni (0.824) in soils. Alsabhan et al. (2022) stated that there was a strongly relationship between soil Cr and Ni (0.994) concentrations. Yalçın & Çimrin (2019) found a significant relationship between Ni-Pb (0.31) and Pb-Cu (0.61) at $p < 0.001$, while Liu et al. (2013) found a significant relationship between Cu and Zn (0.878) at $p < 0.01$. Dartan et al. (2015) stated that there was a high correlation between Cr-Mg (0.543) and K-Zn (0.702). Thus, a high and positive relationship between metals indicates that metals increase or decrease by the same amount in soils. As a result, the medium and high correlation between these metals has shown that pollutants probably shared the same source, and others may have emerged from separate sources in these areas. The high correlations between these metals are thought to be a possible effect of the excessive accumulation of metals in bedrock, which decomposes due to drought factors.

Severe drought events can cause the sudden death of many trees (Camarero, 2021). In other cases, increased mortality of trees is observed over the next few years, often through interaction with other biotic


a)
Ca Conc. (mg/kg)
91.061 - 104.468
104.469 - 117.875
117.876 - 131.282
131.283 - 144.689
144.690 - 158.096
Sampling Location
b)
Mg Conc. (mg/kg)
556 - 615
616 - 674
675 - 734
735 - 793
794 - 852
Sampling Location
c)
Cr Conc. (mg/kg)
108 - 120
121 - 132
133 - 144
145 - 156
157 - 168
Sampling Location
d)
Ni Conc. (mg/kg)
93 - 95
96 - 97
98 - 100
101 - 102
103 - 104
Sampling Location
e)
K Conc. (mg/kg)
6.108 - 6.760
6.761 - 7.412
7.413 - 8.063
8.064 - 8.715
8.716 - 9.367
Sampling Location
f)
Cu Conc. (mg/kg)
15 - 18
19 - 21
22 - 25
26 - 28
29 - 31
Sampling Location
g)
Pb Conc. (mg/kg)
12 - 17
18 - 22
23 - 27
28 - 32
33 - 37
Sampling Location
h)
Zn Conc. (mg/kg)
66 - 69
70 - 72
73 - 75
76 - 78
79 - 82
Sampling Location
1:280
Meters

◀**Fig. 4** Spatial distribution for soil nutrients under maple trees for **a**) Ca, **b**) Mg, **c**) Cr, **d**) Ni, **e**) K, **f**) Cu, **g**) Pb, and **h**) Zn in Kastamonu University Campus, Türkiye

or abiotic stressors (Schuldt et al., 2020; Teshome et al., 2020). This study revealed that the severe droughts observed between 2018 and 2022 (Fig. 3) caused maple species to dry out and thus contaminated the soil with Cr and Ni concentrations (Fig. 4). We can see that the extraordinary drought experienced in 2020 seriously affected the three most vulnerable maple species (Table 1 and Fig. 3). Within the context of climate change drought indices, SPEI shows a severe decrease in the distribution and importance of *Acer* subsp (Fig. 3). We did not detect any consistent pattern of climate sensitivity in *Acer* subsp., indicating that recent warming was associated with a current downward trend in its growth. The consequences of such interactions between different stressors are difficult to predict (Anzano et al., 2021). Trees are often susceptible to drought following cavitation caused by thawing-freezing events and are more vulnerable to insect attacks (Lombardero et al., 2021).Similarly, it has been observed that *Acer* subsp. are infested with *Corythucha arcuata, Phyllactinia marissalli,* and *Phyllosticta minima* (Fig. 2).

Conclusions

This study examined the effects of abiotic stresses (heavy metal accumulation and drought) on the leaves and soil of three maple species (i.e., *A. negunda, A. pseudoplatanus*, and *A. platanoides*). Drought and heavy metals both had a negative impact on the growth of maple species when evaluated separately. The effects of two stresses appeared to contribute to the drying out of maple species. However, no synergistic effect was found between drought and heavy metal stress. This study revealed that drought stress affects maple species, which are more affected by drought stress and when soils are under metal stress. According to SPEI climate values, it was observed that the severe drought observed between August 2020 and August 2021 caused an increase in metal accumulation in the soil (Ca, Mg, Cr, and Ni concentrations) and leaves (Cu, Zn) of maple species. These nutritional disorders appear to reduce the productivity of maple species, their resistance to fungal diseases such as *Phyllosticta minima* and *Phyllactinia marissallii*, insect attacks such as *Corythucha arcuata*, extreme temperatures, and drought. Therefore, it is understood that metal pollution causes water stress in plants under extreme drought.

As a result, the negative effects of these ongoing climate changes will require continued vigilance in the field and data analysis to detect these changes, as we expect forest ecosystem dynamics to be negatively affected. Resistance and durability to climatic stressors should also be compared between hardwood species of different ages, diameters, and canopies. Further studies are needed to facilitate the identification of healthy tree species despite rapid changes in climatic conditions.

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Authors' contributions All authors contributed to the study's conception and design. Material preparation, data collection, and analysis were performed by Gamze SAVACI, Sabri ÜNAL, Esra Nurten YER ÇELİK, and Mertcan KARADENİZ. The first manuscript draft was written by Gamze SAVACI, and all authors commented on previous versions. All authors read and approved the final manuscript.

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Data availability The data sets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Competing interests The authors declare no competing interests.

Ethics approval This research did not involve human participants or animals.

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