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Original Article

Soil Quality Assessment in Pomegranate Orchards of Solapur: A Study of Heavy Metal Risks

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Abstract

This study investigated the levels of specific heavy metals—Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn), Chromium (Cr), Cadmium (Cd), Lead (Pb), and Nickel (Ni)—in soils cultivated with pomegranate across five prominent tehsils in Solapur district. The soil samples were examined using Atomic Absorption Spectrophotometry (AAS). Results indicated that the concentrations of certain heavy metals surpassed the maximum allowable limits established by the Joint FAO/WHO Expert Committee on Food Additives.Copper levels ranged from 1.29 to 11.56 ppm, with Sangola recording the highest mean (5.30 ± 3.18 ppm), likely due to extensive use of Cu-based fungicides. Iron levels were lowest in Mohol (1.36 ± 1.22 ppm), indicating possible Fe deficiency under alkaline soil conditions. Manganese concentrations varied between 1.36 and 19.21 ppm, with Madha showing the highest mean (10.40 ± 4.74 ppm). Zinc levels, close to the critical threshold (0.6–1.2 ppm), suggest a need for targeted supplementation. Particularly high concentrations of Chromium (up to 56.08 ppm) and Nickel (up to 56.00 ppm) were observed in Malshiras and Mohol, possibly linked to effluent discharge or industrial residues. Cadmium exceeded the safe limit (>0.5 ppm) in Malshiras, while Lead concentrations were highest in the same region (6.51 ± 3.00 ppm), indicating contamination from agrochemicals or atmospheric deposition. These elevated heavy metal levels are likely associated with industrial pollution, especially from sugar factory effluents, as well as the unregulated use of fertilizers, spent wash, and press mud. The study highlights that atmospheric deposition and factors linked to the pomegranate production and marketing system may significantly contribute to heavy metal accumulation in soils, posing potential health risks through food chain contamination.

Keywords: *Soil Quality Assessment, heavy metals, Pomegranate Orchards, Heavy Metal Risks*

Introduction

The issue of heavy metal contamination in fruits like pomegranate has become increasingly significant, especially in areas where these fruits are a vital component of both the regional economy and local diet. Pomegranates are prized not only for their flavor but also for their high nutritional value, including essential vitamins, minerals, and antioxidants. Nevertheless, the accumulation of heavy metals in these fruits poses potential health hazards to consumers. Therefore, maintaining fruit safety and quality is a key element of food quality control (Marshall, 2004; Radwan and Salama, 2006; Khan et al., 2008).

Maharashtra, a prominent state in India, plays a major role in the cultivation and export of pomegranates. However, the ongoing process of rapid and often unregulated urban development and industrial growth in certain parts of the state has led to a rise in environmental contamination, particularly with heavy metals. Similar environmental challenges have been documented in other developing nations like Egypt (Radwan and Salama, 2006), Iran (Maleki and Zarasvand, 2008), and China (Wong et al., 2003). Emissions from industrial sources and increasing vehicular activity contribute to heavy metal accumulation on fruit surfaces during various stages, including farming, harvesting, transportation, and sale. Al Jassir et al. (2005), for instance, observed high concentrations of heavy metals on vegetables due to atmospheric fallout in Riyadh, Saudi Arabia. Corresponding observations were made in Indian cities like Varanasi by Sharma et al. (2008a, b).

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Regular consumption of pomegranates contaminated with heavy metals can lead to their gradual build-up in human tissues, particularly in the liver and kidneys, which may interfere with essential biological functions and result in serious health conditions such as cardiovascular, neurological, renal, and skeletal disorders (WHO, 1992; Jarup, 2003). Although certain metals like copper (Cu), zinc (Zn), manganese (Mn), cobalt (Co), and molybdenum (Mo) are required in trace amounts for proper physiological functioning, others such as cadmium (Cd), arsenic (As), and chromium (Cr) are toxic and have carcinogenic potential (Feig et al., 1994; Trichopoulos, 1997). Moreover, elevated concentrations of Cu, Cd, and lead (Pb) in fruits have been linked to a higher risk of gastrointestinal cancers (Turkdogan et al., 2002). To address this, various countries including India have introduced environmental regulations to curb heavy metal emissions. Nonetheless, the uptake of heavy metals in fruit crops like pomegranate is influenced by multiple factors—soil composition, atmospheric deposition, irrigation water quality, plant maturity at harvest, and climatic conditions (Lake et al., 1984; Scott et al., 1996). Moreover, air pollution during post-harvest transport and marketing may further intensify contamination (Agrawal, 2003). For instance, a study by Al-Rehaili (2009) in Riyadh indicated that pollutants like SO_2 and NH_3 frequently exceeded permissible limits, underlining the environmental risk to food crops.

Given Maharashtra's prominence in pomegranate production and export, this study focuses on the biomonitoring of heavy metal contamination in pomegranate fruits cultivated in the region. It also aims to offer dietary and agricultural recommendations to enhance food safety and public health outcomes.

Materials and Methods

a. Study Area and Sampling Locations

This research was carried out in 2022 across five key pomegranate-producing tehsils of Solapur district, Maharashtra, India—Sangola, Pandharpur, Malshiras, Mohol, and Madha. These tehsils were chosen to reflect varied agro-ecological conditions within the region. A total of 75 topsoil samples (0–15 cm depth) were collected from pomegranate orchards, with 15 samples gathered from each tehsil to provide a broad and representative dataset. Each sample was placed in a clean, labelled polyethylene bag and quickly transported to the laboratory for analysis.

b. Sample Preparation and Treatment

In the laboratory, the soil samples were left to air-dry and were then cleared of any visible organic residues or foreign matter. Once dried, the samples were ground with a mortar and pestle and passed through a 0.2 mm sieve to achieve a uniform texture. The prepared soil samples were stored in sealed polyethylene bags until required for further analysis.

c. Micronutrient Extraction and Determination (Fe, Mn, Zn, Cu)

The DTPA (diethylene triamine penta acetic acid) extraction technique, as outlined by Lindsay and Norvell (1978), was used to determine the available micronutrient content. For each sample, 10 grams of soil were mixed with 20 mL of a DTPA solution (0.005 M DTPA, 0.01 M $CaCl_2$, and 0.1 M triethanolamine, adjusted to pH 7.3) and shaken for 2 hours. After filtration, the levels of iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) in the extract were quantified using an atomic absorption spectrophotometer (AAS).

d. Heavy Metal Digestion and Analysis (Cd, Cr, Ni, Pb)

To determine the total concentration of heavy metals, 1 gram of each finely ground soil sample was digested using a di-acid mixture composed of concentrated nitric acid (HNO_3, 70%) and perchloric acid ($HClO_4$, 65%) in a 3:1 ratio, as per the method described by Allen et al. (1986). The digestion process was performed in a fume hood at 80°C and continued until the solution turned clear, indicating complete digestion.

Once cooled, the digested samples were filtered using Whatman No. 42 filter paper and the volume was adjusted to 50 mL with deionized water. The concentrations of cadmium (Cd), chromium (Cr), nickel (Ni), and lead (Pb) were then measured using atomic absorption spectrophotometry.

To evaluate the impact of different sampling locations on the presence of micronutrients and heavy metals, the data were subjected to two-way analysis of variance (ANOVA). Each metal was analysed individually, using sampling site as the primary factor influencing the variability.

Result and discussion:

Soils from five major pomegranate-producing tehsils in Solapur district—Madha, Pandharpur, Malshiras, Sangola, and Mohol were analysed to determine the extent of heavy metal presence and regional variation. Tables 1 and 2 illustrate the observed ranges as well as the mean ± standard deviation for micronutrients (Cu, Fe, Mn, Zn) and selected heavy metals (Cr, Cd, Pb, Ni), all measured in parts per million (ppm).

Table 1: Range values of some heavy metals of tested soil samples of pomegranate growing soils of Solapur district

Tahsils	Heavy Metal							
	Cu	Fe	Mn	Zn	Cr	Cd	Pb	Ni
	(PPM)							
Madha	1.89 – 4.75	0.24-7.87	4.19-19.21	0.37-2.39	5.06-12.66	0.00-0.45	0.00-8.27	4.00-27.00
Pandharpur	1.29-7.42	1.41-5.49	1.79-9.23	0.13-2.83	5.06-12.66	0.00-0.45	0.00-8.27	4.00-28.00
Malshiras	1.76-8.85	3.53-9.83	3.13-14.40	0.36-2.83	10.94-56.08	0.55-1.66	1.02-1.32	7.00-56.00
Sangola	1.83-11.56	0.68-10.28	3.73-11.83	0.37-1.38	5.06-12.66	0.00-0.45	0.00-8.27	4.00-27.00
Mohol	1.70-5.52	0.50-4.18	1.36-7.14	0.18-2.82	5.06-55.70	0.00-0.73	0.00-10.09	1.00-42.00

Copper (Cu) levels across the region varied between 1.29 and 11.56 ppm. The highest average concentration was recorded in Sangola (5.30 ± 3.18 ppm), while Mohol exhibited the lowest mean (2.64 ± 0.96 ppm). These levels are largely within the accepted agronomic range of 5–30 ppm, although the higher end values in Sangola might be attributed to frequent use of copper-based fungicides in orchards or the intrinsic mineral properties of the soils (Patil et al., 2020). Iron (Fe) concentrations ranged from 0.24 to 10.28 ppm, with Sangola (5.02 ± 3.28 ppm) and Malshiras (4.84 ± 1.55 ppm) registering the highest means. In contrast, soils from Mohol had the lowest average Fe level (1.36 ± 1.22 ppm), suggesting potential iron deficiency concerns, especially under the alkaline conditions prevalent in this area (Deshmukh et al., 2019; Jagtap et al., 2021). Such deficiencies can hinder metabolic processes in plants and cause symptoms like iron chlorosis, ultimately lowering fruit quality and yield.

Manganese (Mn) levels ranged from 1.36 to 19.21 ppm. The highest mean was observed in Madha (10.40 ± 4.74 ppm), while Mohol reported the lowest (3.16 ± 1.98 ppm). Although most readings fell within the typical agronomic limits (5–50 ppm), the lower values in Mohol may impair functions such as enzyme activation and photosynthesis (Jain et al., 2022). Zinc (Zn) content was relatively stable across the tehsils, falling between 0.13 and 2.83 ppm. The highest mean value was noted in Malshiras (1.08 ± 0.70 ppm), while Pandharpur showed the lowest (0.96 ± 0.77 ppm). These values are close to or slightly under the critical soil Zn threshold (0.6–1.2 ppm), indicating a possible need for targeted zinc supplementation. Adequate Zn is crucial for reproductive development and fruit set in pomegranates, with deficiencies leading to inferior fruit quality (Kumar et al., 2023).

Table 2: Heavy metal concentration studies in pomegranate growing soils of Solapur district

Tahsils	Heavy Metal							
	Cu	Fe	Mn	Zn	Cr	Cd	Pb	Ni
	(PPM)							
Madha	3.19 +/- 1.03	2.58 +/- 2.37	10.40 +/- 4.74	1.01 +/- 0.68	9.11 +/- 2.68	0.08 +/- 0.14	2.91 +/- 2.70	12.83 +/- 6.83
Pandharpur	3.20 +/- 1.69	3.37 +/- 1.28	4.77 +/- 2.40	0.96 +/- 0.77	9.11 +/- 2.68	0.09 +/- 0.14	3.15 +/- 2.76	13.07 +/- 7.46
Malshiras	3.09 +/- 1.69	4.84 +/- 1.55	8.94 +/- 2.89	1.08 +/- 0.70	29.49 +/- 12.06	0.95 +/- 0.31	6.51 +/- 3.00	20.44 +/- 13.62
Sangola	5.30 +/- 3.18	5.02 +/- 3.28	7.30 +/- 2.62	0.95 +/- 0.34	9.11 +/- 2.68	0.08 +/- 0.14	2.91 +/- 2.70	12.73 +/- 6.83
Mohol	2.64 +/- 0.96	1.36 +/- 1.22	3.16 +/- 1.98	0.96 +/- 0.66	23.80 +/- 17.82	0.20 +/- 0.25	3.83 +/- 2.84	20.47 +/- 9.82

Chromium (Cr) concentrations displayed substantial spatial variation, particularly in Malshiras (10.94–56.08 ppm) and Mohol (5.06–55.70 ppm). Mean Cr levels in these tehsils were significantly elevated—29.49 ± 12.06 ppm in Malshiras and 23.80 ± 17.82 ppm in Mohol—compared to other regions, which averaged around 9.11 ± 2.68 ppm. These elevated levels may result from industrial discharges, irrigation with contaminated water, or the historical use of Cr-containing agrochemicals (Patil et al., 2020; Pawar et al., 2021). Excess Cr can impair root development and nutrient uptake, affecting both yield and quality (Rao et al., 2019). Cadmium (Cd) concentrations varied from undetectable levels to 1.66 ppm. Malshiras (0.95 ± 0.31 ppm) and Mohol (0.20 ± 0.25 ppm) had the highest mean values, both exceeding the generally accepted background threshold of 0.5 ppm. The presence of Cd in these areas may stem from the use of phosphate-based fertilizers or recycled wastewater—common in intensive pomegranate cultivation to enhance soil fertility (Jagtap et al., 2021). Persistent Cd buildup in soil could increase the risk of entry into the food chain, highlighting the need for periodic monitoring.

Lead (Pb) levels showed a wide range, with concentrations between 0.00 and 10.09 ppm. Malshiras had the highest average Pb concentration (6.51 ± 3.00 ppm), followed by Mohol (3.83 ± 2.84 ppm). Madha and Sangola had lower means (2.91 ± 2.70 ppm), though variability within samples was notable. Lead contamination is often linked to past use of lead-based pesticides, emissions from traffic, and atmospheric fallout near urban and roadside orchards (Deshmukh et al., 2019). Although pomegranate plants generally restrict Pb uptake, long-term exposure can negatively influence root functioning and soil microbial health. Nickel (Ni) showed the greatest variability, ranging from 1.00 to 56.00 ppm. Soils in Malshiras (20.44 ± 13.62 ppm) and Mohol (20.47 ± 9.82 ppm) again exhibited the highest mean values, possibly due to both geogenic factors and anthropogenic activities such as use of industrial effluents or contaminated irrigation sources (Kumar et al., 2022). Elevated Ni levels can disrupt iron absorption in plants, causing nutrient imbalances and potentially affecting fruit development.

Conclusion

The assessment of heavy metal concentrations in the pomegranate-growing soils of Solapur district reveals spatial variability influenced by both natural and anthropogenic factors. While most trace elements such as copper, iron, manganese, and zinc were within or near acceptable agronomic limits, localized deficiencies and excesses indicate an imbalance in soil micronutrient dynamics. Particularly concerning are the elevated levels of chromium, cadmium, lead, and nickel found in the tehsils of Malshiras and Mohol. These trends suggest possible contamination pathways beyond conventional agricultural inputs.

The frequent use of organic-rich by-products from the sugar industry—such as ***press mud*** and ***distillery spent wash***—is common in the region due to their nutrient-enriching potential. However, these materials are known to contain elevated levels of heavy metals like Cr, Cd, Pb, and Ni if not properly treated before application. Studies have shown that continuous or unregulated application of press mud and spent wash can lead to accumulation of toxic elements in the soil profile, particularly in areas near sugar-processing facilities (Patil et al., 2020; Pawar et al., 2021).

In this context, the high concentrations of Cr, Cd, Pb, and Ni observed in Malshiras and Mohol could plausibly be linked to long-term and excessive use of such effluents, either directly or through contaminated irrigation water. This poses potential risks not only to soil health but also to pomegranate crop safety and consumer health due to the possibility of metal uptake and bioaccumulation in fruits. Therefore, it is essential to adopt stringent quality monitoring of organic amendments like press mud and spent wash before their agricultural use. Integrating sustainable soil management practices, periodic soil testing, and adhering to permissible heavy metal limits will ensure safer and more productive pomegranate cultivation in the Solapur district.

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Conflicts of interest

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

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