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Original Article

Soil Elemental Profiling and its Influence on the Mineral Potential of *Andrographis paniculata (Burm. F.) Nees* across Six Districts in Odisha, India

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Abstract

Introduction: Soil composition plays an important role in determining the phytochemical constituents there by the therapeutic efficiency of medicinal plants. In this work a comparative analysis of soil elemental profiles collected from six villages of six districts of Odisha like Balangir, Dhenkanal, Khordha, Malkangiri, Nabarangpur and Puri districts were carried out to estimate their influence on the elemental contents of a widely used medicinal plant Andrographis paniculata, which serves a significant position in Ayurveda as a traditional medicine. This plant is known for its anti-inflammatory, hepato-protective and source of anti-cancerous properties because of presence of the compound andrographolide. **Methods:** Soil samples and *A. paniculata* leaves were collected and analysed to evaluate the elemental composition, specifically the micro elements, trace elements and heavy metal contaminants X-ray florescence (XRF) spectroscopic analysis. **Results**: This study reveals no statistically significant overall correlation between the elemental contents of soil and leaves of *A. paniculata* collected from the area. **Conclusion**: This comparative soil mineral profiling and mineral content in *A. paniculata* leaf across six districts highlights distinct variations in nutrient availability, nutrient accumulation and heavy metal contamination. There is no significant influence on the mineral content of *A. paniculata* in relation with soil mineral content, but still this study will serve as a useful foundation for future research and sustainable cultivation.

Keywords: *Andrographis Paniculata, Leaf Elemental Content, Soil Elemental Analysis, XRF Spectroscopy*

Introduction

Andrographis paniculata (Burm. f.) Nees, is known as 'Kalmegh' or the "king of bitters," belonging to family *Acanthaceae*. This plant is commonly found in tropical and subtropical regions of Asia and is native to India and Sri Lanka. This plant possesses significant pharmacological potentiality because of the presence of diterpenoids like andrographolide, including phenolics, flavonoids, and other bioactive compounds (Mehta *et al*., 2021; Raman *et al*., 2022). This plant is recognized for it's as anti-inflammatory, antioxidant, antiviral, immunomodulatory and hepatoprotective properties (Okhuarobo *et al*., 2014; Fatima *et al*., 2026 a). The accumulation of these secondary metabolites in the plants not only depend on genetic factors, variability of the species, agricultural methods and geographical locations but also depend on the soil properties, including its elemental composition (Ozyigit *et al* 2023). Odisha has varied agro-climatic zones ranging from forested highlands of Koraput to mining affected land of Dhenkanal. Nutrients play a vital role in regulating plant metabolism, and production of secondary metabolites. It is reported that the increased levels of micronutrients like zinc and copper are linked to

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higher diterpenoid production in some medicinal plants (Verma *et al*., 2019; Tripathi *et al*., 2022; Assunção *et al*., 2022).

Heavy metals like cadmium, lead, mercury, and arsenic show significant risks. Their presence in soil can reduce the metabolic pathways, result oxidative stress and alter secondary metabolite contents, challenging the phytochemical efficacy (Asiminicesei *et al*., 2024). But in some cases, moderate heavy metal stress is shown to stimulate the bioactive compounds accumulation. It is reported that andrographolide content is increased in *A. paniculata* saplings when exposed to low concentrations of mercury, lead, and silver. Phenolic and flavonoid contents also enhanced in as compared to unstressed controls (Antony & Nagella, 2020). Sometimes stress-induced situation might seem beneficial, or high concentrations of toxins can suppress the synthesis of majority of metabolites and degrade the entire plant health (Miransari *et al*., 2025). The current study is carried out to address this critical gap by comparing the soil elemental and heavy metal contents from six villages of six districts of Odisha such as Balangir, Dhenkanal, Khordha, Puri, Malkangiri and Nabarangpur and their impact on the elemental composition of *A. paniculata*.

Materials and Methods

Collection of Samples

Soil and *A. paniculata* plant samples were collected from six villages belonging to six districts of Odisha, which represent distinct geographical regions with different agro-climatic conditions (Table 1). Difference in climate, rainfall, soil type, topography, and vegetation in these districts compel to carry out the comparative studies. These regions were selected based on the agricultural activity, and variations in the levels of industrial and anthropogenic impact, which play the vital role in influencing the soil quality. Six soil samples were collected from each selected site from a depth of 0 to 20 cm using a sterile auger. These samples were mixed thoroughly for each district and were allowed to air dry in the laboratory at 25–28 °C temperature, sieved to discard the waste and bricks. Then subjected to grind using a grinder, and sieved using a 2 mm sieve to analyze.

Table 1: *Soil and Plant Sample of A. paniculata Collected Areas*

Sl. No.	Village/Township	Block/Area	Districts	Geographical Region
1	Titilagarh	Titilagarh	Balangir	Western Plateau
2	Birasal	Kankadahada	Dhenkanal	Central Table Land
3	IMMT campus	Bhubaneswar	Khordha	Coastal Plain
4	Talasuan-Junei	Kakatpur (Konark)	Puri	Coastal Plain
5	Balimela	Korukonda	Malkangiri	Eastern Ghats Southern Odisha
6	Khatiguda	Umarkote	Nabarangpur	South-Western Plateau

Plant samples of *A. paniculata* were collected from the naturally grown land. The plant samples were identified by Dr. Nabin Kumar Dhal, Chief Scientist, CSIR-IMMT, Bhubaneswar, and also cross verified with ‘Flora of Orissa’. The collected plant species was stored in the Herbarium Unit, Department of Botany, Centurion University of Technology and Management, Bhubaneswar, India.

Elemental Content Analysis by X-ray Florescence (XRF)

X-ray florescence analysis is carried out to analyse the mineral composition of different plant samples. The testing was carried out at the Advanced Testing and Calibration Laboratory (ATCL), Centurion University of Technology and Management, Bhubaneswar, Odisha. Epsilon 1 was the model of the XRF spectroscopy used for this particular test, manufactured by PANalytical B.V., Netherlands. Two grams of six soil and shade dried leaf powder samples of *A. paniculata* were taken separately for XRF spectroscopic analysis to evaluate the mineral composition. Each sample was placed in separate sample cups and loaded into the machine for primary filtration procedure, where the X-ray fluorescence spectra were allowed to run 30 seconds using the primary filter. The XRF spectroscopy quantification software estimated the name and quantity of minerals present in the supplied sample in the unit of percentage (%). In an interval of every 2000-second measurement, the source, sample, and detector were positioned in a non-coaxial geometrical configuration to ensure accuracy. Total 12 samples were

named in abbreviations such as Birasal-Kankadahada-Dhenkanal soil (BKS), Birasal-Kankadahada-Dhenkanal leaf (BKL), Balimela Malkangiri soil (BMS), Balimela-Malkanagiri leaf (BML), Titilagarh-Balangir Soil (TBS), Titilagarh-Balangir leaf (TBL), IMMT campus-Khordha soil (IKS), IMMT campus-Khordha leaf (IKL), Khatiguda-Nabarangpur Soil (KNS), Khatiguda-Nabarangpur Leaf (KNL), Talasuan-Junei Konark Soil (TJS), and Talasuan-Junei Konark Leaf(TJL).

Results

Mineral Content Analysis by XRF Spectroscopy Analysis

Table 2 revealed the presence of 37 different mineral compounds from the six soil samples and six *A. paniculata* leaf samples collected from different locations. Out of 37 minerals 11 minerals such as Ca, K, Cl, S, P, Fe, Si, Mn, Ti, Zn, Sr, and Cu were detected from the all the soil (Fig. 1) and leaf samples collected from these six locations (Fig. 1 a-f), whereas a number of trace and few rare earth elements such as Samarium (Sm), Europium (Eu) and Ytterbium (Yb) are detected in leaf samples of few specific locations such as KB, TN and TJ in very negligible amount as revealed by XRF spectroscopy graphs (Fig. 2 a-f), revealing distinct geochemical characteristics of sampling locations. Maximum amount of Calcium (Ca) and potassium (K) were detected in all samples, although their concentrations varied substantially among different areas.

The highest calcium concentration was recorded in leaf samples of *A. paniculata* (58.669%), whereas the soil of same locality contained 5.808%, indicating that the soil content alone is not responsible for the Ca content of the leaf samples. Iridium (Ir) was detected from the soil sample collected from IMMT-Khordha with 0.004% and from the *A. paniculata* collected from Balimela-Malkangiri leaf (BML) with 0.001% while Samarium (Sm) was detected from Balimela-Malkangiri leaf (BML) with 0.010% and Tin (Sn) with 0.039% from IMMT-Khordha-soil samples (Fig. 3). p-values remain ≥ 0.05 revealing that there is no co-relation between the soil mineral contents and leaf mineral contents. The maximum amount of calcium was recorded in the IK soil sample (8.613 %), followed by IK with 7.771%, whereas minimum concentration of calcium was reported in TB soil. Si was detected with its maximum concentration of 53.517 % in IK soil sample followed by TJ sample with 51.233% and minimum percentage of 32.301 was detected in BK soil sample (Table 2). Potassium was detected maximum of 10.200% in TJ soil sample followed by TB (8.466%) and least concentrations of 3.522% in KN soil sample indicating significant heterogeneity in calcium, silicon and potassium availability. Potassium was detected maximum of 10.200% in TJ soil sample followed by TB (8.466%) and least concentrations of 3.522% in KN soil sample indicating significant heterogeneity in calcium, silicon and potassium availability.

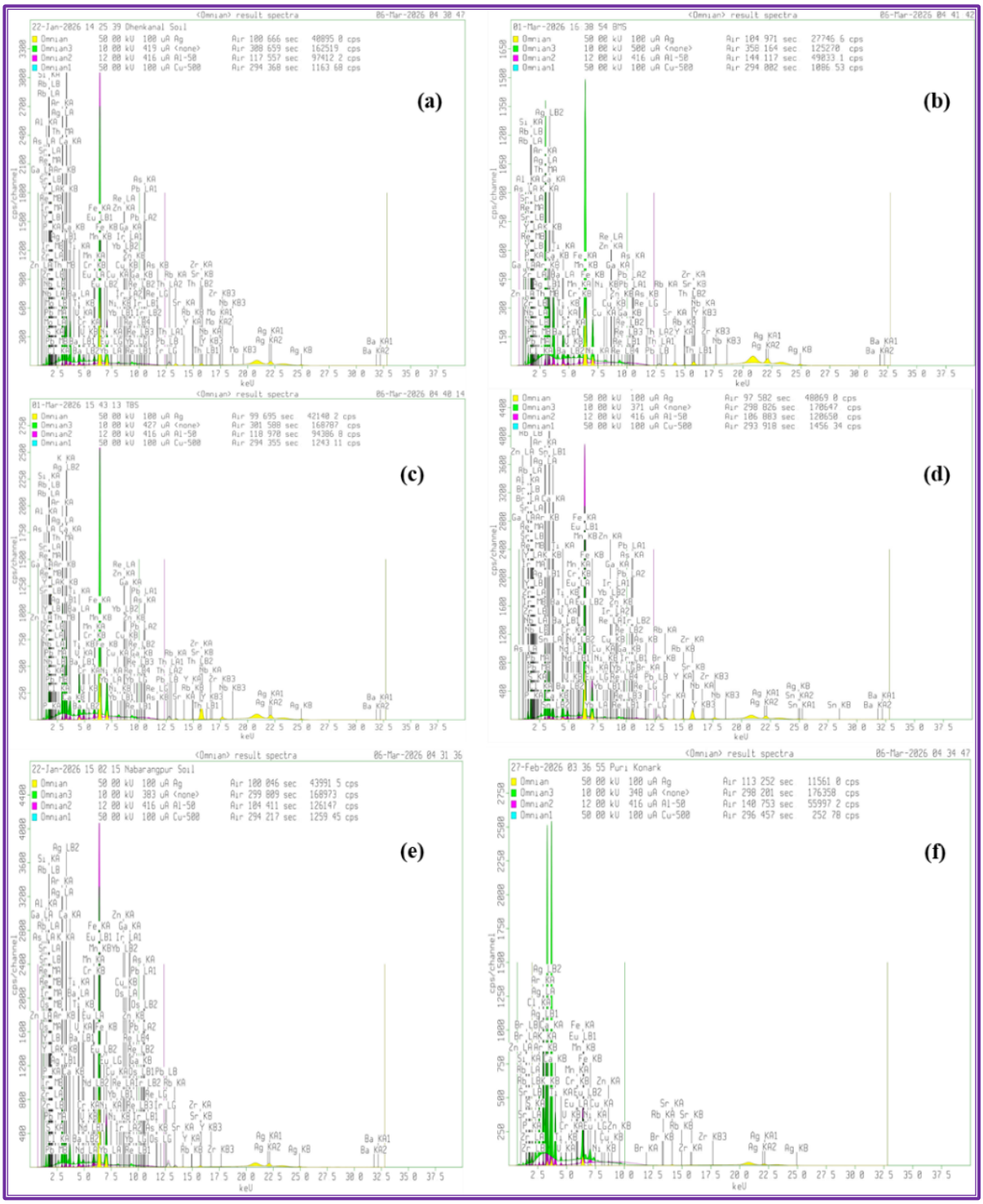


Figure 1: *XRF Spectroscopy Graph Showing Mineral Composition of Soil Samples from Different Locations (A) BKS, (B) BMS, (C) TBS, (D) IKS, (E) KNS, (F) TJS*

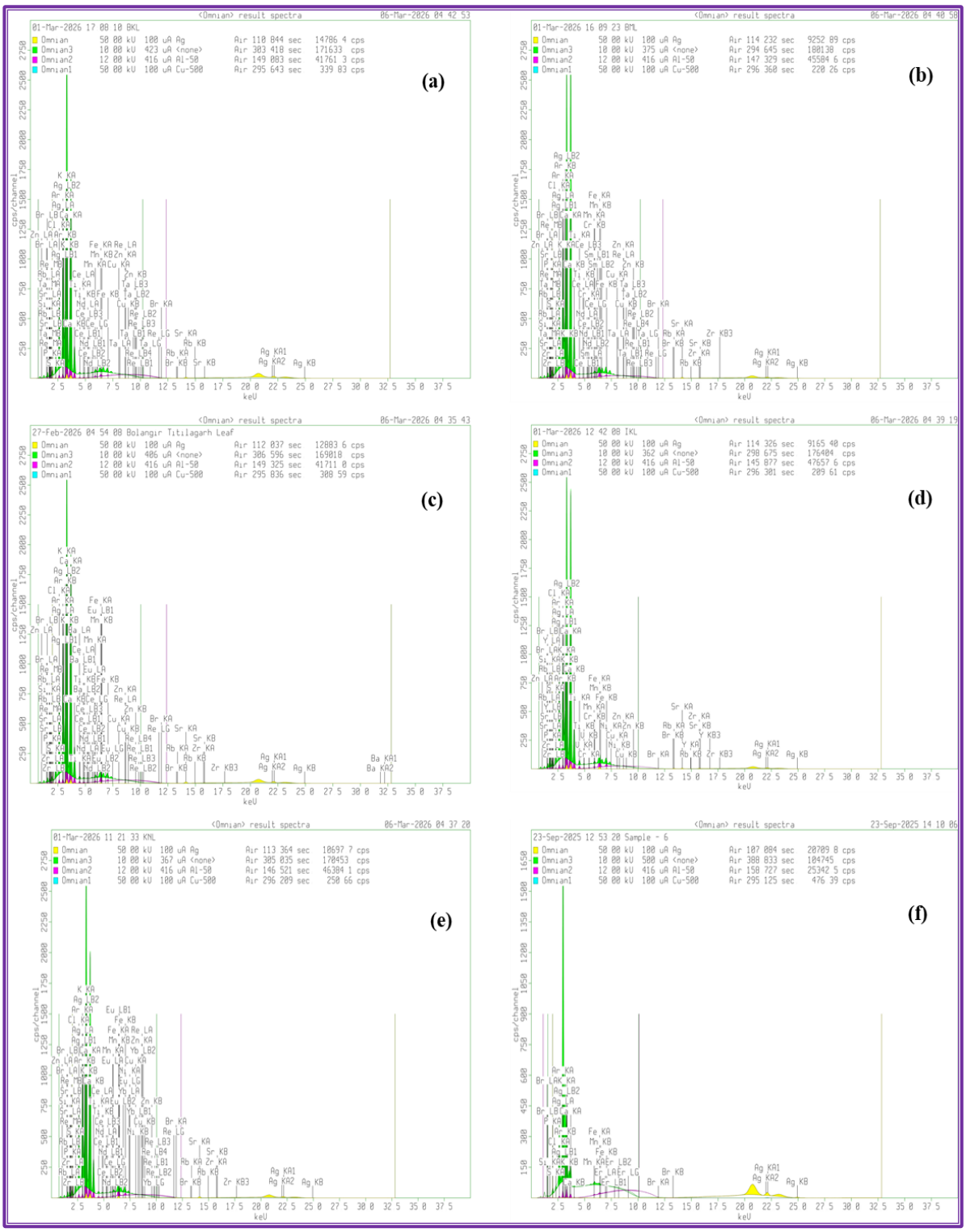


Figure 2: *XRF Spectroscopy Graph Showing Mineral Contents of Leaf of A. paniculata (A) BKL,* (b) BML, (c) TBL, (d) IKL, (e) KNL, (f) TJL

Variations in mineral contents suggested the differences in soil fertility across locations. Chlorine (Cl) content ranged from 0.462 % in BM soil to 0.187 % in KN soil sample. Sulphur (S) content ranged from 0.963 % in BM soil to 0.022 % in BK soil sample. Phosphorus (P) content remained below 1% in all soil samples which ranged from 0.884 % in TJ soil to 0.389% in KN soil sample. Chlorine (Cl), sulphur (S), and phosphorus (P) were detected across six locations with relatively low variation in comparison to Ca and K. Low phosphorus content in all locations reflects stable phosphorus availability among sampling

sites. Similarly, micronutrients distribution showed greater variability than that of the macronutrients. Manganese (Mn), titanium (Ti), zinc (Zn), copper (Cu), and strontium (Sr) were detected in most samples, although their concentrations remained comparatively low. Several trace elements were detected only in selected locations suggesting an irregular distribution. Rare-earth elements such as cerium (Ce), europium (Eu), and samarium (Sm) were detected in few soil samples, which reflects localized geochemical enrichment (Fig. 3).The mineral composition of the soil samples as well as the leaf samples of *A. paniculata* collected from different locations revealed noticeable variation in both macro and micronutrient composition, indicating that the soil composition is influenced by local geological formations, practices involved in land use, and availability of nutrients.

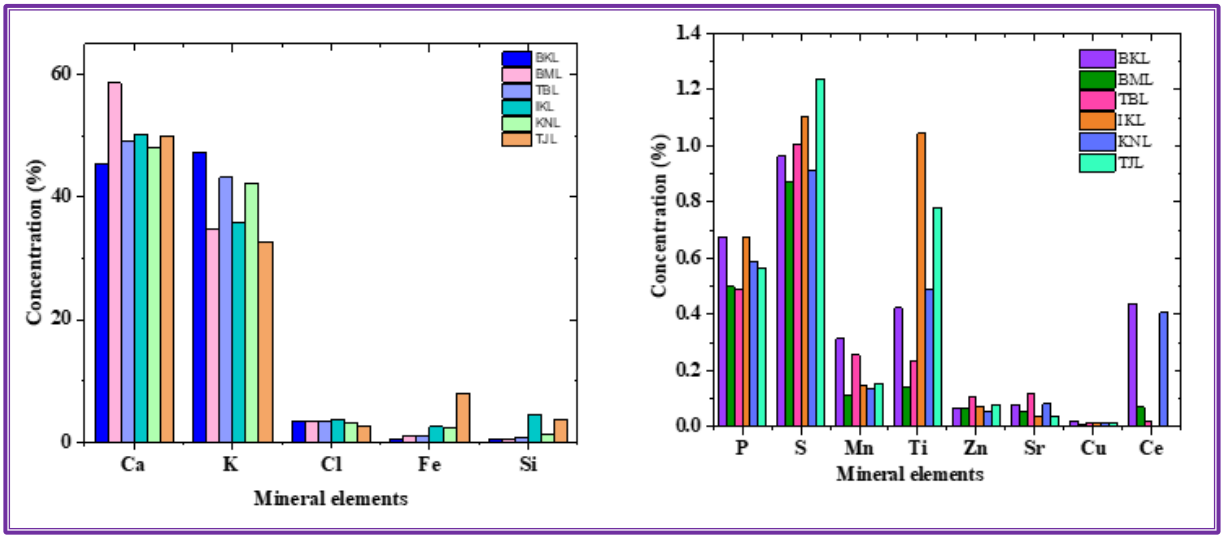


Figure 3: *Mineral Contents of Leaf of A. paniculata (a) BKL, (b) BML, (c) TBL, (d) IKL, (e) KNL, (f) TJL*

Pearson Correlation Analysis: Soil (X) vs Leaf (Y)

No, statistically significant correlation is observed between the soil and leaf elemental concentrations of the samples collected from the location Birasal-Kankadahada-Dhenkanal (BK), because the value of p = 0.5381 which is greater than 0.05. Similar results were also revealed for other five locations such as Balimela-Malkangiri (BM), Titilagarh-Balangir (TB), IMMT campus-Khordha (IK), Khatiguda-Nabarangpur (KN), and Talasuan-Junei (TJ) (Table 2, Table 3). The Pearson correlation analysis between soil and leaf collected from the specific locations are positive with very low value where r-value ranges from 0.036 to 0.264, which indicates very little linear relationship between various elemental concentrations. All the p-values are not statistically significant as with >0.05. Therefore, there is nocorrelations between the mineral content of the soil and the leaf samples of *A. paniculata*, which suggests that mineral content in soil do not predict the mineral composition in leaves collected from these six locations suggesting that other factors such as mineral uptake selectivity, rhizospheric bacteria, mineral solubilisation, transport and accumulation plays an important. Highest r-value (0.264) and lowest r-value (0.036) were determined from TJ and KN respectively. The correlation between the elemental concentrations' values of leaf samples of *A. paniculata* collected from 6 locations was depicted in Table 4.

***Table 2**: Soil and Leaf Mineral Content Values (%) using XRF Spectroscopy Across 6 Locations*

Sl. No.	Minerals	BK		BM		TB		IK		KN		TJ	
		Soil	Leaf	Soil	Leaf	Soil	Leaf	Soil	Leaf	Soil	Leaf	Soil	Leaf
1	Ca	4.488	45.378	5.808	58.669	1.186	49.246	7.771	50.216	2.158	48.219	8.613	50.024
2	K	7.879	47.383	6.345	34.691	8.466	43.199	6.006	35.920	3.522	42.259	10.200	32.735
3	Cl	0.257	3.353	0.462	3.284	0.211	3.300	0.287	3.678	0.187	3.189	0.371	2.558
4	S	0.022	0.963	0.963	0.875	0.040	1.003	0.167	1.105	0.003	0.913	0.122	1.238
5	P	0.487	0.674	0.812	0.499	0.484	0.487	0.818	0.675	0.389	0.586	0.884	0.566
6	Fe	40.948	0.467	32.050	1.000	31.399	0.986	17.273	2.442	45.854	2.306	17.468	7.952
7	Si	32.301	0.411	40.255	0.490	39.192	0.842	53.517	4.479	25.529	1.203	51.233	3.720
8	Mn	0.388	0.313	0.479	0.111	0.707	0.255	0.441	0.148	1.007	0.138	0.505	0.152
9	Ti	1.867	0.423	2.549	0.143	3.490	0.234	3.582	1.045	1.307	0.488	3.040	0.780
10	Zn	0.080	0.064	0.049	0.066	0.077	0.104	0.062	0.071	0.060	0.054	0.077	0.078
11	Sr	0.079	0.077	0.222	0.056	0.037	0.120	0.052	0.037	0.032	0.082	0.037	0.036
12	Cu	0.088	0.019	0.063	0.009	0.051	0.013	0.023	0.011	0.129	0.016	0.028	0.014
13	Ce	--	0.439	0.439	0.069	--	0.018	--	--	--	0.406	--	--
14	Rb	0.194	0.019	0.072	0.016	0.049	0.017	--	--	--	--	0.049	0.015
15	Br	--	0.014	0.014	0.008	--	0.030	--	0.030	--	0.036	0.004	0.005
16	Re	--	0.002	0.002	0.001	0.001	0.001	0.003	--	--	--	--	--
17	Ta	0.071	0.002	0.002	--	--	--	--	--	--	--	--	--
18	Ni	--	--	0.116	--	0.051	--	0.083	0.025	0.186	0.009	0.020	0.007
19	Ba	0.309	--	0.704	--	0.161	0.088	0.158	--	0.408	--	0.185	--
20	Pb	0.048	--	0.024	--	0.024	--	0.022	--	0.019	--	0.022	--
21	Ga	--	--	0.02	--	0.037	--	0.007	--	0.025	--	--	--
22	Y	0.030	--	0.018	--	0.025	--	0.012	--	0.013	--	0.025	--
23	Zr	0.161	--	0.251	0.001	1.053	0.002	0.488	0.020	0.122	0.001	1.053	--
24	Nb	0.014	--	0.012	--	0.028	--	0.008	--	--	--	0.028	--
25	Th	0.031	--	0.010	--	0.025	--	0.013	--	--	--	0.01	--
26	Al	9.848	--	9.522	--	13.005	--	8.435	--	18.464	--	6.490	--
27	Cr	0.066	--	0.089	--	0.074	--	0.416	0.074	0.063	--	0.037	0.037
28	As	0.022	--	0.002	--	--	--	0.004	--	--	--	--	--
29	V	0.065	--	0.064	--	0.109	--	0.049	0.011	0.084	--	0.03	0.016
30	Sm	--	--	--	0.010	--	--	--	--	--	--	--	--
31	Sn	--	--	--	--	--	--	0.039	--		--	--	--
32	Eu	0.228	--	--	--	--	0.056	0.183	--	0.376	0.082	0.166	0.057
33	Rb	--	--	--	--	--	0.017	0.065	0.034	0.043	0.011	--	--
34	Ga	0.023	--	--	--	--	--	--	--	--	--	0.037	--
35	Mo	0.005	--	--	--	--	--	--	--	--	--	--	--
36	Yb	0.025	--	--	--	0.018	--	0.010	--	0.018	0.002	0.009	--
37	Ir	--	--	--	--	--	--	0.004	--	--	--	0.001	--
p-value		0.53812		0.54686		0.68452		0.26580		0.83049		0.11432	

p-value significance: p < 0.001: Very highly significant, p < 0.01: Highly significant, p < 0.05: Significant, p ≥ 0.05: Not significant

(BK: Birasal-Kankadahada-Dhenkanal, BM: Balimela-Malkangir, TB: Titilagarh-Balangir, IK: IMMT campus-Khordha, KN: Khatigud-Nabarangpur, TJ: Talasuan-Junei Konark)

Table 3: *Pearson Correlation Results Soil and Leaf Samples Collected From 6 Locations*

Location	Soil Col (X)	Leaf Col (Y)	Pearson r	r^2	p-value	Significance	Strength
BK	BKS (Col C)	BKL (Col D)	0.104521	0.010925	0.538129	ns	Very Weak
BM	BMS (Col E)	BML (Col F)	0.102295	0.010464	0.546867	ns	Very Weak
TB	TBS (Col G)	TBL (Col H)	0.069085	0.004773	0.684529	ns	Very Weak
IK	IKS (Col I)	IKL (Col J)	0.187750	0.035250	0.265807	ns	Very Weak
KN	KNS (Col K)	KNL (Col L)	0.036432	0.001327	0.830493	ns	Very Weak
TJ	TJS (Col M)	TJL (Col N)	0.264029	0.069711	0.114321	ns	Very Weak

X = Soil, Y = Leaf, n = 37 elements each
*Significance: *** p<0.001, **p<0.01, *p<0.05, ns = not significant*

Table 4: *Mineral Content Values of Leaf of A. paniculata Collected from 6 Locations*

Sl No.	Minerals	BKL	BML	TBL	. IKL	KNL	TJL	Pearson r	*p*-value
1	Ca	45.378	58.669	49.246	50.216	48.219	50.024	-0.0855	0.872
2	K	47.383	34.691	43.199	35.920	42.259	32.735	-0.5379	0.271
3	Cl	3.353	3.284	3.300	3.678	3.189	2.558	-0.564	0.2437
4	S	0.963	0.875	1.003	1.105	0.913	1.238	0.6315	0.1787
5	P	0.674	0.499	0.487	0.675	0.586	0.566	-0.0596	0.9107
6	Fe	0.467	1.000	0.986	2.442	2.306	7.952	0.8251*	0.0432*
7	Si	0.411	0.490	0.842	4.479	1.203	3.720	0.672	0.1438
8	Mn	0.313	0.111	0.255	0.148	0.138	0.152	-0.5603	0.2475
9	Ti	0.423	0.143	0.234	1.045	0.488	0.780	0.571	0.2365
10	Ce	0.439	0.069	0.018	--	0.406	--	0.0031	0.9953
11	Zn	0.064	0.066	0.104	0.071	0.054	0.078	-0.3511	0.495
12	Sr	0.077	0.056	0.120	0.037	0.082	0.036	-0.0901	0.8652
13	Rb	0.019	0.016	0.017	--	--	0.015	-0.3078	0.5529
14	Cu	0.019	0.009	0.013	0.011	0.016	0.014	-0.5192	0.2911
15	Br	0.014	0.008	0.030	0.030	0.036	0.005	0.159	0.7635
16	Re	0.002	0.001	0.001	--	--	--	-0.9165*	0.0102*
17	Ta	0.002	--	--	--	--	--	-0.6547	0.1583
18	Ni	--	--	--	0.025	0.009	0.007	0.4772	0.3385
19	Ba	--	--	0.088	--	--	--	-0.1309	0.8047
20	Zr	--	0.001	0.002	0.020	0.001	--	0.1222	0.8176
21	Cr	--	--	--	0.074	--	0.037	0.4472	0.3739
22	V	--	--	--	0.011	--	0.016	0.6805	0.1369
23	Rb	--	--	0.017	0.034	0.011	--	0.1965	0.7091
24	Eu	--	--	0.056	--	0.082	0.057	0.6899	0.129
25	Sm	--	0.010	--	--	--	--	-0.3928	0.441
26	Yb	--	--	--	--	0.002	--	0.3928	0.441

**** p<0.001 ** p<0.01 * p<0.05= significant, ns = not significant, r = ≥ 0.7 (strong), r = ≥0.4 (moderate)*

Differences in the mineral contents of the soil may or may not impact in the mineral accumulation in *A. paniculata.*

Discussion

Soil collected from Dhenkanal, in contrast, reveals elevated heavy metal contents because of anthropogenic activities and other geographical factors, while the soil samples collected from Malkangiri represented an intermediate condition, with balanced nutrients and moderate contamination, which is also reported earlier (Verma *et al*., 2019; Asiminicesei *et al*., 2024). Despite the recognized relevance of interactions of soil and plant metabolite, linking of the soil mineral profiles and mineral composition of *A. paniculata* have not been reported. Most literature documents have been based on the chemical composition, therapeutic efficacy and the abiotic stress responses like drought or fertilizers of *A. paniculata* but seldom correlates soil geochemistry to macro and micro elemental contents (Okhuarobo *et al*., 2014; Gowda *et al*., 2023, Intharuksa *et al*., 2022). The impact of three plant growth promoting bacteria (PGPB), Bacillus subtilis (MTCC 736), *Azospirillum brasilense* (MTCC 4037) and Pseudomonas fluorescens (MTCC 666) on soil parameters (micro and macro nutrients) and their ability

to promote the growth and elemental contents of *A. paniculata*, grown in that soil was evaluated (Fatima *et al*., 2026 b). Inoculations of B. subtilis with P. fluorescens increased growth and dry yield in a pot experiment including the N, P and K uptake in the leaf in comparison with the control (Fatima *et al*., 2026b).

Literature stated that the micro and macro plant nutrient content in the fruits and leaves of *Rosa spinosissima* L. and *Plantago atrata* Hoppe. grown in their natural habitats showed highest macro (Ca, Mg) and micro (Fe, Cu, Mn, Zn) nutrient content in the leaves than the fruits (Kadıoğlu, 2025). Another Atomic Absorption Spectroscopy (AAS) study revealed that the leaves of the plant samples collected from CSIR-IMMT, Bhubaneswar, are richer in Fe, Mn, Ni, Pd metals and stems are rich in Fe metal. This suggested that *A. paniculata* plants grown in urban area are rich in trace metals like Fe, Cu, along with few other toxic metals (Parida *et al*., 2022). The weak correlations exist for most mineral elements suggest that elemental uptake by the plant is not only governed by soil elemental composition but by other factors like bioavailability of nutrient, physicochemical properties of the soil, absorption efficiency by the roots, element mobility, nutrient accumulation mechanisms and physiological regulation within the plant.

Limitations

The present study reveals the information on soil mineral composition and its influence on the mineral accumulation potential of *A. paniculata* across six districts of Odisha. The study was focused on the relationship between mineral content and accumulation in *A. paniculata* which is limited to six districts of Odisha. Other districts of Odisha and other states of India may be carried out to find out the relationship between soil mineral composition and mineral accumulation in *A. paniculata.*

Future Scope

Elemental content of *A. paniculata* should be considered before making the formulations for the required therapeutic potential as a number of factors such as microbial activity of the soil, genetic variability among plant populations, methods of cultivation, and impact of environmental stress can influence the elemental uptake.

Conclusion

Despite the recognized relevance of interactions of soil and plant metabolite, linking of the soil mineral profiles and mineral composition of *A. paniculata* have not been reported. Most literature documents have been based on the chemical composition, therapeutic efficacy and the abiotic stress responses like drought or fertilizers of *A. paniculata*, but seldom correlate soil geochemistry to macro and micro elemental contents. This comparative soil mineral profiling and mineral content in *A. paniculata* leaf across six districts highlights distinct variations in nutrient availability, nutrient accumulation and heavy metal contamination. There is no significant influence on the mineral content of *A. paniculata* in relation with soil mineral content, but still this study will serve as a useful foundation for future research and sustainable cultivation.

Conflict of Interest

The authors declare that no conflict of interest

Availability of Data and Materials

All data generated or analyzed during this research are available in this article.

Authors' Contributions

KM surveyed, collected the samples, carried out the experimental work, and prepared the draft manuscript, AKM supervised the work, and SP conceived, supervised and edited the manuscript. All authors read and approved the final manuscript.

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References

Antony, A., & Nagella, P. (2020). Effect of heavy metals on the andrographolide content, phytochemicals and antioxidant activity of Andrographis paniculata. *Asian Journal of Chemistry*, *32*, 2748-2752. https://doi.org/10.14233/ajchem.2020.22831

Antony, A., & Nagella, P. (2021). Heavy metal stress influences the andrographolide content, phytochemicals and antioxidant activity of Andrographis paniculata. *Plant Science Today*, *8*(2), 324-330. https://doi.org/10.14719/pst.2021.8.2.1034

Asiminicesei, D. M., Fertu, D. I., & Gavrilescu, M. (2024). Impact of heavy metal pollution in the environment on the metabolic profile of medicinal plants and their therapeutic potential. *Plants*, *13*(6), 913. https://doi.org/10.3390/plants13060913

Assunção, A. G., Cakmak, I., Clemens, S., González-Guerrero, M., Nawrocki, A., & Thomine, S. (2022). Micronutrient homeostasis in plants for more sustainable agriculture and healthier human nutrition. *Journal of Experimental Botany*, *73*(6), 1789-1799. https://doi.org/10.1093/jxb/erac014

De Groote, H., Tessema, M., Gameda, S., & Gunaratna, N. S. (2021). Soil zinc, serum zinc, and the potential for agronomic biofortification to reduce human zinc deficiency in Ethiopia. *Scientific Reports*, *11*(1), 8770. https://doi.org/10.1038/s41598-021-88304-6

Fatima, B., Mishra, U., & Singh, A. (2026). Medicinal and Nutritional Importance of Andrographis paniculata in Human Health. In *Medicinal Plants and their Bioactive Compounds in Human Health: Volume 2* (pp. 531-547). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-95-3620-7_24

Fatima, B., Mishra, U., & Singh, A. (2026). Novel insights of bioinoculants on augmented productivity of *Andrographis paniculata* Wall. ex Nees. *Vegetos*, 1-15. https://doi.org/10.1007/s42535-025-01598-z

Gowda M, P., Sharangi, A. B., Upadhyay, T. K., Alotaibi, N. M., Alotaibi, M. O., Alshammari, N., & Saeed, M. (2023). Elicitor-Mediated Response of Growth, Yield, and Quality of Kalmegh (*Andrographis paniculata* Wall. ex-Nees, Family Acanthaceae). *Agronomy*, *13*(9), 2313. https://doi.org/10.3390/agronomy13092313

Intharuksa, A., Arunotayanun, W., Yooin, W., & Sirisa-Ard, P. (2022). A comprehensive review of Andrographis paniculata (Burm. f.) Nees and its constituents as potential lead compounds for COVID-19 drug discovery. *Molecules*, *27*(14), 4479. https://doi.org/10.3390/molecules27144479

Kadıoğlu, B. (2025). Macro and Micro Nutritional Content and Physiochemical Soil Properties of Some Naturel Medicinal and Aromatic Plants. *Turkish Journal of Nature and Science*, *14*(2), 82-91. https://doi.org/10.46810/tdfd.1481031

Mehta, S., Sharma, A. K., & Singh, R. K. (2021). Therapeutic journey of Andrographis paniculata (Burm. f.) nees from natural to synthetic and nanoformulations. *Mini Reviews in Medicinal Chemistry*, *21*(12), 1556-1577. https://doi.org/10.2174/1389557521666210315162354

Miransari, M., Adham, S., Miransari, M., & Miransari, A. A. (2025). The effects of nutrients on the growth and quality of medicinal and aromatic plants, affecting athletic abilities. *Journal of Trace Elements and Minerals*, *11*, 100205. https://doi.org/10.1016/j.jtemin.2024.100205

Okhuarobo, A., Falodun, J. E., Erharuyi, O., Imieje, V., Falodun, A., & Langer, P. (2014). Harnessing the medicinal properties of Andrographis paniculata for diseases and beyond: A review of its phytochemistry and pharmacology. *Asian Pacific Journal of Tropical Disease*, *4*(3), 213-222. https://doi.org/10.1016/S2222-1808(14)60509-0

Ozyigit, I. I., Dogan, I., Hocaoglu-Ozyigit, A., Yalcin, B., Erdogan, A., Yalcin, I. E., ... & Kaya, Y. (2023). Production of secondary metabolites using tissue culture-based biotechnological applications. *Frontiers in Plant Science*, *14*, 1132555. https://doi.org/10.3389/fpls.2023.1132555

Parida, S., Sahoo, D., & Mishra, P. K. (2022). Study of Metals and Element characterization of Andrographis paniculata plant of Khordha region, Odisha. *Research Journal of Pharmacognosy and Phytochemistry*, *14*(4), 257-264. http://dx.doi.org/10.52711/0975-4385.2022.00045

Raman, S., Murugaiyah, V., & Parumasivam, T. (2022). Andrographis paniculata dosage forms and advances in nanoparticulate delivery systems: An overview. *Molecules*, *27*(19), 6164. https://doi.org/10.3390/molecules27196164

Sethi, G., Behera, K. K., Sayyed, R., Adarsh, V., Sipra, B. S., Singh, L., ... & Behera, M. (2025). Enhancing soil health and crop productivity: the role of zinc-solubilizing bacteria in sustainable agriculture. *Plant Growth Regulation*, *105*(3), 601-617. https://doi.org/10.1007/s10725-025-01294-7

Son, Y. J., Park, J. E., Lee, N., Ju, Y. W., Pyo, S. H., Oh, C., ... & Nho, C. W. (2024). Copper-or Zinc-Fortified Nutrient Solution in Vertical Farming System Enriches Copper or Zinc and Elevates Phenolic Acid and Flavonoid Contents in *Artemisia annua* L. *Agronomy*, *14*(1), 135. https://doi.org/10.3390/agronomy14010135

Tripathi, R., Tewari, R., Singh, K. P., Keswani, C., Minkina, T., Srivastava, A. K., ... & Sansinenea, E. (2022). Plant mineral nutrition and disease resistance: A significant linkage for sustainable crop protection. *Frontiers in Plant Science*, *13*, 883970. https://doi.org/10.3389/fpls.2022.883970

Verma, H., Negi, M. S., Mahapatra, B. S., Shukla, A., & Paul, J. (2019). Evaluation of an emerging medicinal crop Kalmegh [*Andrographis paniculata* (Burm. F.) Wall. Ex. Nees] for commercial cultivation and pharmaceutical & industrial uses: A review. *Journal of Pharmacognosy and Phytochemistry*, *8*(4), 835-848. https://www.phytojournal.com/archives/view-pdf/9042/8-3-617