Distribution of nickel in different agro-climatic zones of Jharkhand, India

Kishan Singh Rawat\textsuperscript{a}, Rakesh Kumar\textsuperscript{b} and Sudhir Kumar Singh\textsuperscript{c}

\textsuperscript{a}Centre for Remote Sensing and Geo-Informatics, Sathyabama Institute of Science and Technology, Chennai, India; \textsuperscript{b}Department of Soil Science and Agricultural Chemistry, Bihar Agricultural University, Sabour, India; \textsuperscript{c}K. Banerjee Centre of Atmospheric Ocean Studies, IIDS, Nehru Science Centre, University of Allahabad, Allahabad, India

\textbf{ABSTRACT}

Nickel is a micronutrient and contributes to nitrogen fixation and metabolism of urea and is important for seed germination. For productive soil, the concentration of 1–20 mg kg\textsuperscript{-1} is recommended. The objective of the work was to investigate the distribution of nickel in different agro-climatic zones and identification of different factors that control the distribution. Surface soil samples were collected from different locations and topo-sequences covering three agro-climatic zones of Jharkhand, viz. zone-IV (Baliajur, Jharia, and Dhanbad), zone-V (Bagru, Pakharpat, Kisko, and Lohardaga), and zone-VI (Moshabani, Jadugonda, and Chandil). Total number (n = 225) of soil samples were collected from the surface and examined for nickel. Diethylene triamine penta acetic acid (DTPA) extractable nickel in zones IV, V, and VI were 0.06–2.5, 0.06–2.2, and 0.06–4.46 mg kg\textsuperscript{-1}, respectively, whereas total content of nickel in zones IV, V, and VI were 147–472, 122–486, and 93–630 mg kg\textsuperscript{-1}, respectively. A higher amount of DTPA-extractable and the total content of nickel were observed in lowland against the different topo-sequences. The study of stepwise multiple regression equations showed more impact of soil pH and electrical conductivity on extractable nickel than other soil parameters whereas, in case of total nickel content, organic matter was an important determining factor.

1. Introduction

Soil is a natural resource (Paudel, Thakur, Singh, & Srivastava, 2015) and consists of minerals. Naturally, nickel occurs widely in the environment, being released through both natural and anthropogenic sources, but seldom in its elemental form (Cempel & Nikel, 2006; DEPA, 2005). Nickel’s natural source to the environment include forest fires and vegetation, volcanic emissions, and wind-blow dust, while the anthropogenic activities resulted in atmospheric accumulation of nickel from combustion of coal, diesel oil, and fuel oil, the incineration of waste and sludge as well as from miscellaneous sources (Clayton & Clayton, 1994; McGrath, 1995).

In a natural environment, the distribution of heavy metals has no adverse impact on the plant and human life. But due to pedogenic and biogeochemical process and anthropogenic inputs, the concentration of heavy metals rises to such a level that it becomes phytotoxic (Kirkham, 1983). From a biological point of view, heavy metals can be divided into two categories: essential and non-essential (Reddy & Prasad, 1990). However, essential heavy metals have even been reported to be toxic at high concentrations, e.g., some heavy metals, viz. copper, zinc, nickel, and chromium, are essential for growth at very low concentrations but toxic at slightly elevated levels (Gadd & Griffiths, 1978; Reed & Gadd, 1989).

Same metal concentration in two soils has different availability. Hence, the determinants of metal bioavailability must be understood if one is to predict the effect of a metal. Soil quality criteria must consider the bioavailability of metals (Peijnenburg, Posthuma, Eijsackers, & Allen, 1997). Such criteria can then be used to establish maximum tolerable levels of metals that can be accommodated in soil and as remediation standards. The phytoavailability of nickel has been correlated with free nickel ion activity in soil solution; hence, plant uptake is also dependent on soil pH, organic matter content, and iron-manganese oxide (Ge, Murray, & Hendershot, 2000; Massoura et al., 2006; Rooney, Zhao, & McGrath, 2007).

In 1751, Swedish mineralogist Axel Fredrik Cronstedt was the first person to realize that nickel was a new element. In nature, nickel was found mostly in the form of nickelous (Ni\textsuperscript{2+}), although trivalent Ni had been detected in some enzymes. However, Ni\textsuperscript{2+} had been found to be present abundantly in soils. The hydrated Ni\textsuperscript{2+} ions, Ni(OH\textsubscript{2})\textsuperscript{6+} was the major source of nickel in soil solution which was taken up by plants and microorganisms. Nickel is a micronutrient required at a very low concentration by plants. The critical concentration of nickel in plant ranges from 1.0 to 5.0 mg/kg and nickel in normal soil varied from 0.4 to 1000 mg/kg (Brown, Welch, & Cary, 1987). Nickel toxicity in plants affects various physiological and biochemical processes,
viz. decrease in chlorophyll content, photosynthesis, transpiration activities, impairing membrane permeability and disturbing (Bingham et al., 1980). In human, a high concentration of nickel causes both cancerous (nasal, lungs) and non-cancerous (kidney, lung, asthma, placenta, spermatogenesis) problems.

Normally insoluble nickel compound become soluble in the soil of low pH, which caused nickel to accumulate in plants (Vanselow, 1952), but adding lime to nickel-treated soils counteract the toxic effect on plant growth. Nickel could replace cobalt and other heavy metals located at active sites in metalloenzymes and disrupt their functioning (Chang & Sherman, 1953). The present investigation was carried out on soils of different agro-climatic zones of the state with a view to study the topographical distribution of available and total content of nickel and to identify the influence of important soil characteristics on their availability.

2. Material and methods

2.1. Study area

Soils of Jharkhand, having three agro-climatic zones (Figure 1), viz. Central and north-eastern plateau, Western plateau, and south-eastern plateau, are classified into major soil orders of Entisol, Inceptisol, and Alfisol. The state is popularly known for its coal mines, industries, and metalliferous ores. Out of the several sources, industrial effluents, sewage, and mines are major sources of heavy metals. In the rapid pace of development, we have inflicted serious damage to the natural resources.

2.2. Geology, soils, agriculture, land use, and climate

Dhanbad, Jharia, and Baliaipur (zone-IV, Figure 1) were geologically comprised with Archean granites and gneisses. Three soil orders, namely Entisols, Inceptisols, and Alfisols, were observed in these areas. Important trees were sal, sisam, tendu, mahua, bhelwa, imali, etc. The major cereal crops of the area were paddy, maize, and wheat. Farmers of the area were interested in vegetable and fruit growing and dairy to fulfill the demand of the city areas. The district is in the east of the state and nearer to the Bay of Bengal and also has less elevation. The area provides climatic conditions slightly different from the higher plateau area of the state. During the winter season, temperature ranges from 8.4°C to 34°C and during summer season temperature ranges from 13.3°C to 45.5°C. During the rainy season, the temperature ranges from 15°C to 36°C. The average annual rainfall is 1270 mm.

Bagru, Kisko, Pakharpat, and Lohardaga (zone-V, Figure 1) were geologically comprised with Archean granites and gneisses. In the uplands, considerable thickness of laterite of Pleistocene age was found in the granite and gneisses tracts. Alluvium of the recent to sub-recent age was found in the river valley. Three soil orders, namely Entisols, Inceptisols, and Alfisols, were observed in these areas. The most important mineral was bauxite. Other minerals were feldspar, fire clay, and china clay, and had less economic importance. The main crops were rice followed by millets (mara, gondli, and maize), pulses, wheat, oilseed (sarguja and groundnut), and

![Figure 1. Study area location map.](image-url)
vegetables. Forest areas covered majority of sal, mahua, jamun, and neem vegetation. The district enjoy healthy, pleasant climate throughout the year. The annual average temperature is 23°C, the highest temperature goes to 36°C in summer and lowest of 10°C in winter. The district receives an annual rainfall of 1000 to 1600 mm and it increases from west to east.

Mosabani, Jandugonda, and Chandil (zone-VI) were geologically comprised with granites, gneiss and schist. Formation of igneous, sedimentary, and metamorphic rocks of Dharianian period was found at places. Three soil orders, namely Entisols, Inceptisols, and Alfisols, were observed in these areas. Due to varied landscape, the coverage of forest was found in different proportion in different areas. The sal trees were dominant in this area. Other trees were gamhar, mango, jamun, jack fruit, karanj, palas, etc. Plain areas were quite productive for agriculture and farmers cultivated vegetables and seasonal fruits apart from paddy. The district receives an annual rainfall of 1500 mm and most of it occurs during the rainy season. Mean annual temperature is above 26°C. The temperature ranges from 16°C in winter month to 44°C in summer months.

2.3. Soil analysis
With a view to achieve the objective of the research, a survey was conducted and 225 surface (0–20 cm depth) soil samples were collected from different topo-sequence, i.e., upland, midland, and lowland, from three agro-climatic zones, namely (i) Central and north-eastern plateau, i.e., zone-IV (Baliapur), (ii) Western plateau, i.e., zone-V (Bagru), and (iii) South eastern plateau, i.e., zone-VI (Moshabani) of Jharkhand. The soil samples were analyzed for various physico-chemical properties, viz. organic carbon, pH, EC (1:2.5: soil:water), CEC, CaCO₃, clay, and silt content, by using standard laboratory procedures. The available content of Ni in soil samples was extracted with a solution of 0.005 M DTPA – 0.01 M CaCl₂ – 0.1 M tri-ethanol amine (adjusted to pH 7.3) as outlined by Lindsay and Norvell (1978). The total content was determined after digestion of soil with perchloric-hydrofluoric acids (Hesse, 1994). The concentrations of nickel were measured with the help of atomic absorption spectrophotometer. Regression analysis is a statistical tool of investigation of relationships between variables (Sharma, Kumar, Denis, & Singh, 2018; Patle, Rawat, & Singh, 2019). Multiple linear regression equations were computed between different forms (available and total) of metals and soil properties. Stepwise multiple regression analysis was computed by adopting standard statistical procedures (Panse & Sukhatme, 1961).

2.4. 3D nickel distribution map/contour generation
For generation of 3D nickel distribution map (or special distribution map)/contour, we used trial version of SimplexNumerica software (as Rawat, Kumar, & Singh, 2018; Rawat, Mishra, & Singh, 2017a; Rawat, Tripathi, & Singh, 2017b). Co-ordinates of each sampling point were logged with a hand-held Global Positioning System (GPS) device (Garmin (eTrexH)), with ±15 m horizontal locational accuracy (Rawat, Kumar & Singh, 2018).

3. Results and discussions

3.1. Distribution of nickel in soil
The systematic survey for delineation of Ni from soil was conducted and analyzed in 225 surface soil samples collected from different topo-sequence, i.e., upland, midland, and lowland from Central and north-eastern plateau, western plateau, and South eastern plateau of Jharkhand. These soil samples belong to soil order Entisols, Inceptisols, and Alfisols.

DTPA-extractable nickel in upland soils of areas under zones IV, V, and VI ranged 0.06–2.08 mg kg⁻¹, 0.06–0.68 mg kg⁻¹, and 0.76–3.1 mg kg⁻¹ with a mean value of 0.83 mg kg⁻¹, 0.2 mg kg⁻¹, and 1.58 mg kg⁻¹, respectively (Table 1). In midland soils, it ranged 0.06–2.5 mg kg⁻¹, 0.06–1.48 mg kg⁻¹, and 0.06–3.42 mg kg⁻¹ with a mean value of 1.08 mg kg⁻¹, 0.64 mg kg⁻¹, and 1.52 mg kg⁻¹, respectively, whereas in lowland soils, extractable nickel varied 0.38–1.54 mg kg⁻¹, 0.52–2.2 mg kg⁻¹, and 0.84–4.46 mg kg⁻¹ with a mean value of 0.59 mg kg⁻¹, 0.87 mg kg⁻¹, and 1.35 mg kg⁻¹, respectively. Overall, DTPA-extractable nickel in areas of zones IV, V, and VI ranged 0.06–2.5, 0.06–2.2, and 0.06–4.46 mg kg⁻¹, respectively. The magnitude of DTPA-extractable nickel in lowland soils was higher than midland followed by upland due to soil drainage and clay content which affect their status (Anderson & Christensen, 1988).

Barman et al. (2015) suggested that the low proportion of residual Ni fraction may be related to the unusually high organic carbon content in soil, where Ni might have been associated with recalcitrant fraction of organic matter. They explained that lower SOC and clay contents might be responsible for lower CEC in these soils, which might have been responsible for poor retention of Ni as cation. In upland soils of zones IV, V, and VI, the total content of nickel varied 147–297, 122–156, and

| Agro-climatic zone | Topography | Range | Mean | S.D |
|--------------------|------------|-------|------|-----|
| IV Zone, i.e., Central and north-eastern plateau | Upland | 147–297 | 200.84 | 43.88 |
| Medium | 291–371 | 307.16 | 36.16 |
| Lowland | 351–472 | 419.12 | 38.35 |
| V Zone, i.e., Western plateau | Upland | 122–156 | 141.32 | 9.95 |
| Medium | 167–347 | 263.56 | 60.50 |
| Lowland | 253–486 | 348.88 | 62.93 |
| VI Zone, i.e., South eastern plateau | Upland | 93–297 | 173.12 | 56.21 |
| Medium | 219–367 | 275.2 | 41.26 |
| Lowland | 421–630 | 528.92 | 66.89 |
93–297 mg kg\(^{-1}\) with a mean value of 200.84, 141.32, and 173.12 mg kg\(^{-1}\), respectively (Table 2). Soil samples of zones IV, V, and VI under midland condition ranged 291–371, 167–347, and 219–367 mg kg\(^{-1}\) with a mean value of 307.16, 263.56, and 275.2 mg kg\(^{-1}\), respectively, whereas in lowland soils, they ranged 351–472, 253–486, and 421–630 mg kg\(^{-1}\) with a mean value of 419.12, 348.88, and 528.92 mg kg\(^{-1}\), respectively. The mean values of total nickel in lowland soils were higher than in midland followed by upland because of clay percentage and organic matter content that influenced their status. The observation was inconformity with the finding of Mitsimbonas, Karyotis, Haroulis, and Argyropoulos (1998).

In upland soils, according to Ewetola, Oyediran, Owoade, and Ojo (2010) and Rawat et al. (2018), a relationship between slope position and soil properties where middle slope showed the highest clay content and the major pedogenic processes influenced the relationship between slope position and mineral weathering, erosion and eluviation-illuviation processes. The parent rocks as a lithogenic control (higher correlation with soil properties), chemical industries, mineral fertilizers, untreated industrial effluents, sewage, and mine wastewater are the major sources of cobalt and other minerals in soil and water (Gautam et al., 2015).

The 3D representation and contour plots (Figure 2) of available Ni and total Ni in IV evidently identify, categorize, and quantify the specific areas where the enrichment of Ni is higher. The available Ni was observed low in the center as 30 mg kg\(^{-1}\) (Figure 2(a)). Similarly, the total Ni concentration was observed very low in those regions. Similarly, in zone-V, it was observed that soils have low availability of Ni in the majority of area whereas the total Ni has slightly fewer values as compared to zone IV (Figure 2(b)). In the agro-climatic zone VI, the total and available Ni content is illustrated in Figure 2(c), which shows similar patterns as zone V.

### 3.2. Multiple linear regression models

Multiple regression equations were estimated through stepwise method to analyze the relative impacts of different factors responsible for determining the content of nickel in the soils. In the process of regression analysis, the dependent variables were categorized as available Ni and total Ni. The independent variables or the explanatory variables were recognized as \(X_1\) (pH), \(X_2\) (EC), \(X_3\) (Organic carbon), \(X_4\) (CaCO\(_3\)), \(X_5\) (Silt), \(X_6\) (Clay), and \(X_7\) (CEC).

The results presented in Table 3 using stepwise method had enabled us to choose the statistically most relevant equation stating the relationship between the nickel (extractable and total) and the factors determining their concentration. Stepwise method had yielded a number of alternative equations for each form of nickel in the different soil profile analyzed here. However, the equations which had statistically significant coefficients in them at least at the 5% levels of significance were finally selected for the discussion. Using this statistically supported process of selection of predicting equations, the following regression equations were selected at 5% level of significance for different soil profiles for heavy metal in the soils analyzed (Table 3).

Size of the coefficient of the multiple determinations \(R^2\) indicated that 45.09% of the available nickel was determined by pH and EC. In case of the total content of nickel, they were determined by organic carbon up to 20.6%. In a quantitative way, it could be said that one unit increase in EC increased available nickel by 0.003 unit whereas one unit increase in pH reduced the available nickel by 0.255 units. The prediction equation for the total content of Ni had indicated that they were determined by organic carbon which has a positive impact on the total content of Ni. Again in a quantitative way, it could be inferred that one unit increase in organic carbon increased the total Ni by a greater proportion of 31.78 units.

The metal concentration and soil properties are known to influence metal bioavailability (pH, organic carbon, clay content, and effective CEC) in agricultural and grazing land soil in Europe (Reimann et al., 2009, Rawat et al., 2018; Reimann, Demetriades, Eggen, & Filzmoser, 2011). In urban areas, the soil is polluted by direct disposal of untreated waste on soil. The crops and vegetables are grown on these soils and irrigated by untreated sewage wastewater having elevated concentration of heavy metals (Bharose, Singh, & Srivastava, 2013; Gautam, Sharma, Tripathi, Ahirwar, & Singh, 2013).

### 3.3. Multiple linear regression models

Multiple regression equations were estimated through stepwise method to analyze the relative impacts of different factors responsible for determining the

| Table 2. Total Ni contents (mg kg\(^{-1}\)) in soils of different topo-sequences (agro-climatic zones) of Jharkhand. |
|---------------------|-------------|------|------|
| **Agro-climatic zone** | **Topography** | **Range** | **Mean** | **S.D** |
| IV Zone, i.e., Central and north-eastern plateau | Upland | 0.06–2.08 | 0.83 | 0.58 |
| | Medium | 0.06–2.50 | 1.08 | 0.53 |
| | Lowland | 0.38–1.54 | 1.10 | 0.29 |
| V Zone, i.e., Western plateau | Upland | 0.06–0.68 | 0.20 | 0.18 |
| | Medium | 0.06–1.48 | 0.64 | 0.32 |
| | Lowland | 0.52–2.20 | 1.58 | 0.42 |
| VI Zone, i.e., South eastern plateau | Upland | 0.76–3.10 | 1.58 | 0.70 |
| | Medium | 0.063–3.42 | 1.52 | 0.78 |
| | Lowland | 0.84–4.46 | 2.38 | 1.13 |

### 4. Conclusion

DTPA-extractable nickel was 0.06–2.5 mg kg\(^{-1}\) in zone-IV; 0.06–2.2 mg kg\(^{-1}\) in zone-V whereas 0.06–4.46 mg kg\(^{-1}\) in zone-VI, respectively. The magnitude of DTPA-extractable nickel in lowland soils was higher than in midland followed by upland due to soil
drainage and clay content which affects its status. Total content of Ni were 147–472 mg kg\(^{-1}\) in zone-IV; 122–486 mg kg\(^{-1}\) in zone-V whereas 93–630 mg kg\(^{-1}\) in zone-VI, respectively. However, a higher amount of the total content of Ni was noted in lowland topo-sequence with a mean value of 419.12 in zone-IV; 348.88 mg kg\(^{-1}\) in zone-V, and 528.92 mg kg\(^{-1}\) in zone-VI, respectively. The study of stepwise multiple regression equations showed more impact of soil pH and EC on the available content of nickel than

Table 3. Predictability of available and total content of Ni with relation to soil characteristics Figure in parenthesis indicates S.E. of coefficient.

|                     | Stepwise multiple regression equation | \(R^2 \times 100\) |
|---------------------|---------------------------------------|---------------------|
| Available Ni        | \(Y = 1.6916 - 0.255 X_1^* + 0.00375X_2^{**}\) | 45.09               |
|                     | \((0.0487)\) \((0.0008)\)             |                     |
| Available Ni        | \(Y = 1.828 - 0.2322X_1^{**}\)       | 25.25               |
|                     | \((0.0559)\)                           |                     |
| Total Ni            | \(Y = 241.06 + 31.78X_3^{**}\)       | 20.63               |
|                     | \((8.7294)\)                           |                     |

* level of significance at \(p = 0.05\%), ** level of significance at \(p = 0.01\%) and \(X_1, X_2, X_3, X_4, X_5, X_6\) and \(X_7\) indicate pH, EC, Organic Carbon, CaCO\(_3\), silt, clay and CEC, respectively.

Figure 2. (a) 3D representation of available and total Ni content in agro-climatic zone IV. (b) 3D representation of available and total Ni content in agro-climatic zone V. (c) 3D representation of available and total Ni content in agro-climatic zone VI.
other soil parameters whereas, in case of total content, organic matter was the important determining factor.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**ORCID**

Sudhir Kumar Singh http://orcid.org/0000-0001-8465-0649

**References**

Anderson, P. R., & Christensen, T. H. (1988). Distribution coefficients of Cd, Co, Ni, and Zn in soils. *Journal of Soil Science, 39*, 15–22.

Barman, M., Datta, S. P., Rattan, R. K., & Meena, M. C. (2015). Chemical fractions and bioavailability of nickel in alluvial soils. *Plant Soil Environment, 61*(1), 17–22. doi:10.17221/613/2014-PSE.61.017

Bharose, R., Singh, S. K., & Srivastava, P. K. (2013). Heavy metals pollution in soil-water-vegetation continuum irrigated with ground water and untreated sewage. *Bulletin Environment Sciences Researcher, 2*, 1–8.

Bingham, F. T., Page, A. L., & Strong, J. E. (1980). Yield and cadmium content of rice grain in relation to addition rates of cadmium, copper, nickel and zinc with sewage sludge and liming. *Soil Science, 130*, 32–8. doi:10.1097/00010694-198007000-00006

Brown, P. H., Welch, R. M., & Cary, E. E. (1987). Nickel: A micronutrient essential for higher plants. *Plant PhysiologyPlant, 85*, 801–803.

Cempel, M., & Nikel, G. (2006). Nickel: A review of its sources and environmental toxicology. *Polish Journal of Environmental Studies, 15*(3), 375–382.

Chang, A. T., & Sherman, G. D. (1953). The nickel content of some Hawaiian soil and plants and the relation of nickel to plant growth. *Hawaii Agricultural Experiment Station, Bulletin, 19*, 3.

Clayton, G. D., & Clayton, F. E. (1994). *Pattys industrial hygiene toxicology* (4th ed). New York: A Wiley-Interscience Publication.

DEPA. (2005). *Draft risk assessment. Nickel* (CAS No: 7440-02-0), EINECS No: 231-111-4. Copenhagen: Danish Environmental Protection Agency.

Ewertola, E. A., Oyediran, G. O., Owoade, F. M., & Ojo, O. I. (2010). Variations in soil physical properties along toposequence of an alfisol in Southern Guinea Savanna of Nigeria. *International Journal of Agricultural Engineering and Biotechnology*, 3(3), 303–305.

Gadd, G. M., & Griffiths, A. J. (1978). Microorganisms and heavy metal toxicity. *Microbial Ecology, 4*, 303–317.

Gautam, S. K., Maharana, C., Sharma, D., Singh, A. K., Tripathi, J. K., & Singh, S. K. (2015). Evaluation of groundwater quality in the Chotanagpur plateau region of the Subarnareka river basin, Jharkhand state, India. *Sustainability of Water Quality and Ecology, 6*, 57–74.

Gautam, S. K., Sharma, D., Tripathi, J. K., Ahirwar, S. K., & Singh, S. (2013). A study of the effectiveness of sewage treatment plants in Delhi region. *Applications Water Sciences, 3*, 57–65.

Ge, Y., Murray, P., & Hendershot, W. H. (2000). Trace metal speciation and bioavailability in urban soils. *Environmental Pollution, 107*, 137–144.

Hesse, P. R. (1994). *A text book of soil chemical analysis*. New Delhi: CBS Publishers and Distributors.

Kirkham, M. B. (1983). Study on accumulation of heavy metals in soils receiving sewage water. *Agriculture, Ecosystems and Environment, 9*, 251–255.

Lindsay, W. L., & Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal, 42*, 421–428.

Massoura, S. T., Echevarria, G., Becquer, T., Ghanabaja, J., Leclerc- Cessac, E., & Morel, J.-L. (2006). Control of nickel availability by nickel bearing minerals in natural and anthropogenic soils. *Geoderma, 136*, 28–37.

McGrath, S. P. (1995). Nickel. In B. J. Alloway (Ed.), *Heavy metals in soils* (Vol. XIV, pp. 368). London: Blackie Academic & Professional.

Mitsimbonas, T., Karyotis, T., Haroulis, A., & Argyropoulos, G. (1998). Distribution of nutrients and heavy metals in agricultural soils of Larissa region. *Georgiak-Ereuna-Nea-Seira, 20*, 48–54.

Panse, V. G., & Sukhatme, P. V. (1961). *Statistical methods for agricultural workers*. New Delhi: ICAR.

Patle, G. T., Rawat, K. S., & Singh, S. K. (2019). Estimation of infiltration rate from soil properties using regression model for fallow cultivated land. *Geology, Ecology, and Landscapes, 3*(1). doi:10.1080/24749508.2018.1481633

Paudel, D., Thakur, J. K., Singh, S. K., & Srivastava, P. K. (2015). Soil characterization based on land cover heterogeneity over a tropical landscape: An integrated approach using earth observation data-sets. *Geocarto International*, 30(2), 218–241.

Peijnenburg, W. J. G. M., Posthumus, L., Eijssackers, H. J. P., & Allen, H. E. (1997). A conceptual framework for implementation of bioavailability of metals for environmental management purposes. *Ecotoxicology and Environmental Safety, 37*, 163–172.

Rawat, K. S., Kumar, R., & Singh, S. K. (2018). Topographical distribution of cobalt in different agro-climatic zones of Jharkhand state, India. *Geology, Ecology, and Landscapes*. doi:10.1080/24749508.2018.1481654

Rawat, K. S., Mishra, A. K., & Singh, A. K. (2017a). Mapping of groundwater quality using normalized difference dispersal index of Dwarka sub-city at Delhi national capital of India. *ISH Journal of Hydraulic Engineering, 23*(3), 229–240.

Rawat, K. S., Tripathi, V. K., & Singh, S. K. (2017b). Groundwater quality evaluation using numerical indices: A case study (Delhi, India). *Sustainable Water Resources Management*. doi:10.1007/s40899-017-0181-9

Reddy, G. N., & Prasad, M. N. V. (1990). Heavy metal binding proteins peptides, occurrence, structure, synthesis and function review. *Environmental and Experimental Botany, 30*, 252–264.

Reed, R. H., & Gadd, G. M. (1989). Metal tolerance in euakaryotic and prokaryotic algae. In A. J. Shaw (Ed.), *Heavy metal tolerance in plants: Evolutionary aspects* (pp. 105–118). Boca Raton, Florida: CRC Press.

Reimann, C., Demetriades, A., Eggen, O. A., & Filzmoser, P. and The EuroGeoSurveys Geochemistry expert group (2009). *The EuroGeoSurveys geochemical mapping of agricultural and grazing land soils project (GEMAS)—Evaluation of quality control results of aqua*
regia extraction analysis (NGU Report 2009. 49). 94. 
Trondheim, Norway: Geological Survey of Norway.
Reimann, C., Demetriades, A., Eggen, O. A., &
Filzmoser, P. and The EuroGeoSurveys Geochemistry 
expert group (2011). The EuroGeoSurveys geochemical 
mapping of agricultural and grazing land soils 
project (GEMAS) – Evaluation of quality control results 
of total C and S, total organic carbon (TOC), cation 
exchange capacity (CEC), XRF, pH, and particle 
size distribution (PSD) analysis (NGU Report 11.043). 
90. Trondheim, Norway: Geological Survey of Norway.

Rooney, C. P., Zhao, F. -J., & McGrath, S. P. (2007). 
Phytotoxicity of nickel in a range of European soils: 
Influence of soil properties, Ni solubility and 
speciation. *Environmental Pollution*, 145, 596–605.

Sharma, B., Kumar, M., Denis, D. M., & Singh, S. K. (2018). 
Appraisal of river water quality using open-access earth 
observation data set: A study of River Ganga at 
Allahabad (India). *Sustainable Water Resources 
Management*, 1-11. doi:10.1007/s40899-018-0251-7

Vanselow, A. P. (1952). Microelements in citrus. *California 
Agriculture*, 6, 5.