https://doi.org/10.31705/ISERME.2024.21

Exploration and Characterization of Potential Iron Ore Occurrence in Pelpitigoda, Sri Lanka

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Abstract

Iron is widely used across industries in worldwide, with an annual usage of over 1.8 billion tonnes, steadily increasing over decades. Due to this high consumption of iron, it is crucial to find new sources of iron. Therefore, this research project was designed with the objectives of exploring the potential iron occurrence and characterize the mineralogy and geochemistry of the Pelpitigoda area. The methodology comprises two phases. In the initial phase, geological settings were studied to understand the rock formations and structures surrounding the area. It was followed by a magnetic susceptibility survey to identify variations and anomalies, along with systematic sample collection across the deposit. The phase two was completed with laboratory analysis, including sample preparation, colorimetry, X-ray Diffraction (XRD), X-ray Fluorescence (XRF), and Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Notably, colorimetry results from phase two indicated iron content ranging between 40-60 wt% in the samples, with XRD analysis identifying goethite as the predominant mineral, alongside magnetite, hematite, and gibbsite. XRF results revealed an average iron content of 38.47 wt%. Furthermore, ICP-MS analysis showed lower potential for valuable metals like V, Cr, Co, Ni, and Zn in the area. The significance of this research lies in its potential to identify a new iron ore occurrence in the Pelpitigoda area. The comprehensive characterization of the mineralogy and geochemistry provides valuable insights into the composition and distribution of iron-bearing minerals in the area. Future work entails completing the last phase of roasting the samples to extract iron oxide, followed by comprehensive laboratory testing of the prepared samples.

Keywords: Goethite, Iron ore exploration, magnetic survey, XRF analysis.

1 Introduction

Iron contains approximately 32% of the mass of Earth, with its elemental presence ranging from around 5% in the Earth's crust to a significant 80% in the Earth's core [1]. Hence, it is unsurprising that various commonly found iron minerals exist, along with numerous surface iron ore deposits on Earth [2]. Iron is a fundamental metal extensively utilized across various industries globally and the annual global consumption of iron stands at approximately 1885 million tonnes, a figure that has been consistently rising over the past few decades [3]. The majority of this iron is produced from low-grade iron ores found in regions such as China, Japan, Western Europe, Australia, South America, India, and North America, and is primarily used for steel production. However, the exploration of new iron ore deposits is critical to meet the growing demand and ensure sustainable resource availability [3].

Sri Lanka is home to several magnetite-rich, high-grade iron ore deposits located in regions such as Panirendawa near Bingiriya, Chilaw in the Puttlam district, and Wilagedara near Tambakanda in the Kurunegala district. Additionally, the southwestern part of the island features significant mineral deposits like Ambalangoda near Godakele and Mount Lavinia along the coastline [4] [5]. The Rathnapura District, particularly in areas, such as Rakwana, Balangoda, and Kalawana in the Sabaragamuwa Province, also hosts notable deposits, alongside other areas in the Galle and Matara districts of the southern province and Kalutara in the western province [6] [7].

A recent discovery in the Pelpitigoda area of Ingiriya, Kalutara District, indicated the presence of magnetic rocks and unusually colored laterites resembling slag. To clarify that information, we conducted a preliminary survey on this area. This preliminary observation suggested a potential iron ore occurrence, prompting the initiation of this research project to evaluate the mineralogical and geochemical characteristics of the Pelpitigoda iron ore deposit, to explore a new iron resource in Sri Lanka.

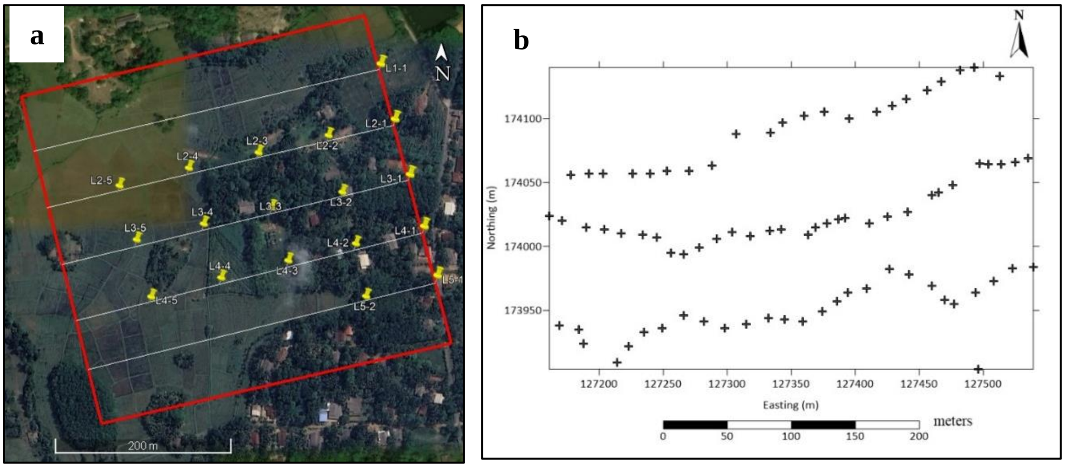

Figure 22 (a) Survey map for sampling and magnetic susceptibility survey; (b) Post map of the magnetic susceptibility survey.

2 Methodology

2.1 Study area

The Pelpitigoda area is characterized by its unique geological and physical features. The soil predominantly consists of lateritic formations, indicative of intense weathering processes typical in tropical regions [10]. These lateritic soils are often dispersed with outcrops of laterite, a highly weathered material rich in iron and aluminum oxides. Additionally, the area features slag-type rock formations that are distinguished by their black coloration and significant magnetism (Figure 4). The magnetic properties of these formations are recognizable and suggest the presence of iron-bearing minerals.

The geological context of Sri Lanka's iron ore deposits provides a foundation for understanding the potential of the Pelpitigoda area. These hydrated iron ore deposits are prevalent in the southwest zone of Sri Lanka, with significant deposits forming in the Sabaragamuwa Province's Rathnapura District and additional occurrences in the Galle and Matara districts of the southern province [3] [4]. The area consists with charnockitic gneiss, quartzite, predominantly basic rocks like pyriclasites, and undifferentiated Highland series; garnet sillimanite schist and gneiss, quartz-feldspar granulite, charnockitic gneiss, pyriclasite, pyroxene, and amphibolite, according to the geological map (Figure 2) by the Geological Survey and Mines Bureau of Sri Lanka.

2.2 Sample Collection

Twenty-one samples were collected from the Pelpitigoda area using the systematic-judgmental sampling method to ensure a representative sample collection. These samples were specifically collected from the B horizon (20-35 cm) along a pre-defined survey path to maintain consistency and accuracy in the sampling process. The area is characterized by laterite outcrops, which were prevalent at most of the sampling locations. Notably, some of these samples exhibited slag-type formations. Of the twenty-one samples collected, eighteen were rock samples, and the remaining three were soil samples.

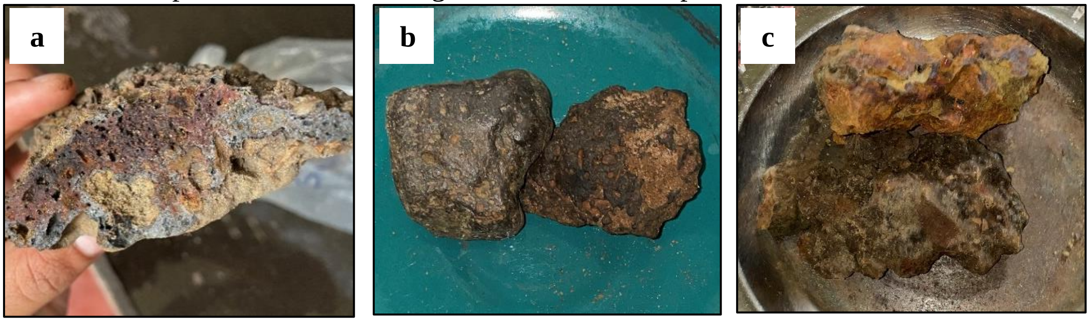

Figure 4 (a), (b) Slag-type rock formations exhibiting black color with metallic or sub-metallic luster (a-sample: PPG-1, b-sample: PPG-4); (c) Reddish colored laterite sample (c-sample: PPG-2).

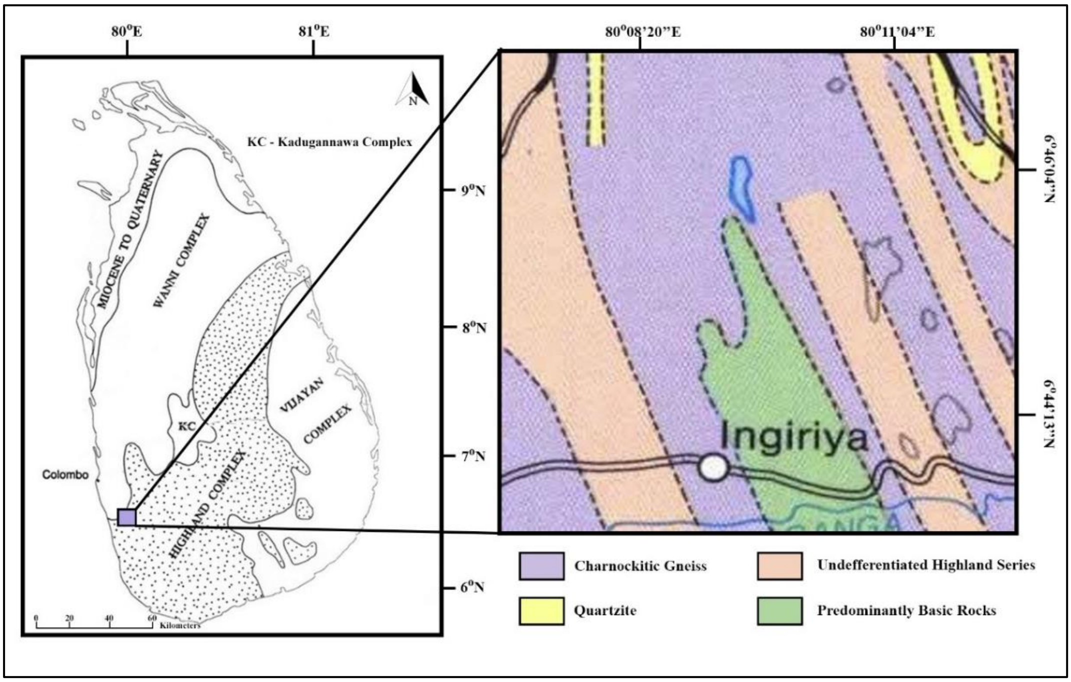

Figure 23 Geology and Location of Sampling Site

2.3 Magnetic Survey

The magnetometer survey is a passive geophysical method that detects variations in magnetic properties between the target feature and its surrounding environment [8]. AMC-6 fluxgate Magnetometer was used for data acquisition. As per the pre-defined survey path, field data acquisition was continued with a hand-held GPS instrument with the magnetometer. Raw data files were obtained from the mobile acquisition system.

2.4 Sample Analysis

All samples were initially oven-dried at 105°C for 24 hours to ensure the complete removal of moisture. Then, the rock samples underwent an initial crushing phase using a laboratory jaw crusher, followed by the Tema mill to achieve a fine powdered form. In contrast, the soil samples were directly processed using the Tema mill to produce the necessary powdered samples. Each powdered sample was then sieved through a 63 µm sieve to prepare for the digestion process [9] [10].

A precisely measured 0.500 g portion of each fine powder sample was subjected to digestion with aqua regia. This reagent was prepared mixture of 3 ml of hydrochloric acid (HCl), 1 ml of hydrogen peroxide (H_2O_2), and 1 ml of nitric acid (HNO_3). The digestion process involved heating each sample uniformly at 120°C for 3 hours. The digested samples were filtered through a 0.45 µm filter paper [9].

Twelve digested and filtered samples were selected and diluted to analyze the critical metal concentration using inductively coupled plasma mass spectrometry (ICP-MS). The iron concentration of each sample was analysed using colorimetric method by spectrophotometer. Therefore, 1 ml of the digested and filtered samples was diluted to 1000 times for the analysis. In each analytical experiments, analytical grade chemicals were used for the solution preparation and standard series. The samples were replicated three times to maintain the precision and accuracy of the analysis.

Fine powder samples of less than 63 µm from 4 selected samples were prepared for X-ray Diffraction (XRD) analysis. The XRD analysis was conducted with 2 theta values ranging from 5 to 80 degrees. Furthermore, fine powder samples less than 500 µm from 5 selected samples were used for X-ray Fluorescence (XRF) analysis. This device is applicable for conducting geochemical analyses of earth materials both in the field and in the laboratory [11] [12] [13].

3 Results and Discussion

3.1 Mineralogical analysis of the samples

The XRD analyses carried out for 4 powdered iron ore samples revealed that goethite [FeO(OH)] is the main mineral constituent of this area (Figure 3). In addition to goethite, hematite (Fe_2O_3) and magnetite (Fe_3O_4) were identified as the primary iron-bearing minerals. The samples also contained gypsum ($CaSO_4.2H_2O$), gibbsite [$Al(OH)_3$], kaolinite [$Al_2Si_2O_5(OH)_4$], and quartz (SiO_2) as subordinate minerals. All the samples (PPG-1, PPG-2, PPG-3, PPG-4) show clear peaks corresponding to the standard XRD pattern for Goethite.

These results indicate a significant presence of iron-rich minerals, which are characteristic of lateritic soils. The predominance of goethite, a hydrated iron oxide, suggests extensive weathering and leaching processes. In addition to iron minerals, the presence of quartz, kaolinite, gypsum, and gibbsite suggests a complex mineralogical composition influenced by secondary weathering processes [14]. Quartz is a common constituent in many geological formations, while kaolinite and gibbsite are secondary minerals that typically form through the weathering of alumino-silicate minerals [7].

The slag-type rock formations exhibit a black color with a metallic or sub-metallic luster (Figure 4). According to James (1966) [15], these features indicate the magnetically positivity of the rocks and clarify the presence of iron-bearing minerals. These formations also display iridescent coating, possibly due to the thin film interference phenomenon, which can produce a color similar to an oil slick (Figure 4-b). Such iridescent coatings are sometimes referred to as turgite, a compound likely comprising a mixture of hematite and goethite with absorbed water [15].

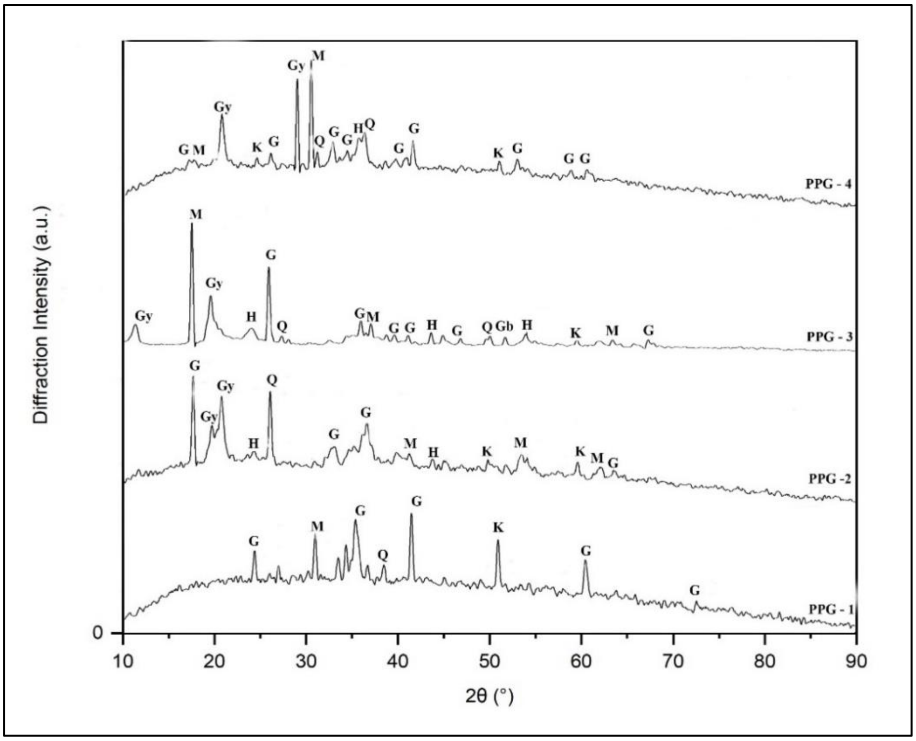

Figure 3 The XRD pattern yielded for four iron ore samples (G-goethite, M-magnetite, H-hematite, K-kaolinite, Gb-gibbsite, Q-quartz, Gy-gypsum (samples: PPG-1, PPG-2, PPG-3, PPG-4)).

3.2 Geochemical analysis of the samples

The geochemical analysis of the Pelpitigoda samples involved a series of tests including colorimetry, XRF, and ICP-MS. The colorimetry test was performed on all samples to estimate the iron content by the spectrophotometer. A calibration series was carried out to determine the values at R = 0.995 (Figure 5). Subsequently, XRF analysis was carried out on four selected samples to validate colorimetric results. Fe (wt%) analyzed by XRF for the selected samples shows a strong positive correlation with Fe (wt%) analyzed by the colorimetric method (R = 0.93) (Figure 6). The above correlations were calculated and plotted using Minitab® 21.2 software. Additionally, ICP-MS was conducted on eight samples to identify trace elements other than iron.

Table 10 Geochemistry of Pelpitigoda samples obtained by XRF analysis (2023)

ID	XRF (wt%)								Colorimetry (wt%)
	SiO_2	Al_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Fe	Fe
L4-R	0.30	2.44	ND	ND	0.11	ND	0.01	45.96	45.45
L2-2L	6.92	6.16	ND	ND	0.09	0.01	ND	41.13	44.37
L4-2	14.41	25.59	ND	ND	0.07	ND	ND	26.38	30.07
PPG-1	13.12	2.57	ND	ND	0.11	0.61	0.04	40.43	45.33
Dela-2	0.00	1.16	ND	ND	0.08	ND	0.18	42.20	45.57
Ave	8.69	9.19	NA	NA	0.10	0.16	0.01	38.48	41.31
Min	0.30	2.44	NA	NA	0.07	0.00	0.00	26.38	30.07
Max	14.41	25.59	NA	NA	0.11	0.61	0.04	45.96	45.45
SD	6.48	11.07	NA	NA	0.02	0.30	0.02	8.43	7.51

NA-Not available; ND-Not detected

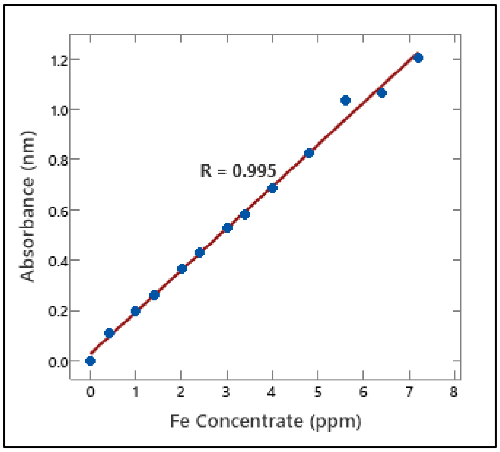

Figure 5 Correlations of Fe (ppm) by Colorimetric method with Absorbance (nm) by spectrophotometer.

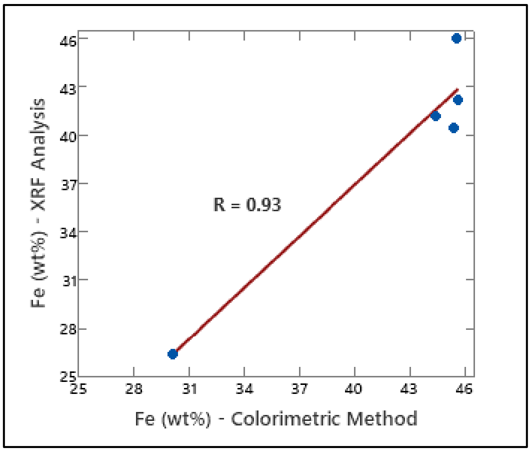

Figure 6 Correlations of Fe (wt%) by XRF analysis with Fe (wt%) by Colorimetric method.

The geochemical data, summarized in Table 2, shows that the average iron concentration in the samples is 42.64 wt%, highlighting the area's richness in iron. The concentrations of other major oxides such as SiO2 and Al2O3 are significantly lower, ranging from 0.30-14.41 wt% and 2.44-25.59 wt%, respectively. The variability in alumina content can be linked to the occurrence of kaolinite and gibbsite, the principal alumina-bearing secondary minerals in the samples. Compared to the UCC values, trace elements, such as As, V, Co, Zn, Rb, Pb, and U were lower in the soil whereas Ni and Cr were enriched. These low levels may be attributed to the limited presence of such metal bearing minerals in the area. Therefore, the economic potential of these metals are low in this area.

Table 11 Geochemistry of Pelpitigoda samples obtained by ICP-MS and Colorimetric analysis.

ID	ICP-MS (ppm)									Colorimetry (wt%)
	As	V	Cr	Ni	Co	Zn	Rb	Pb	U	Fe
UCC	5.7	106	73	34	15	75	94	20	2.6	-
L2-2L	12.29	423.76	448.05	1754.34	3.29	562.73	2.11	7.95	2.58	44.37
L2-3	8.35	90.29	93.08	2907.84	6.36	1413.75	1.03	27.54	1.88	51.16
L3-3S	2.33	61.31	88.52	471.06	1.80	ND	2.84	28.22	1.12	31.45
PPG-1	7.11	28.01	78.99	2041.18	9.83	194.05	11.7	1.20	1.19	45.33
L2-2S	2.39	ND	86.16	840.93	1.88	37.82	0.71	1.90	0.47	30.07
L3-2S	2.04	68.74	192.78	468.62	0.84	220.92	0.96	3.30	2.35	32.05
L4-R	6.72	77.16	101.04	2470.56	7.11	642.29	0.47	3.94	3.58	45.45
L4-3	8.11	225.64	232.52	1280.12	2.11	149.42	5.59	9.57	1.95	43.05
L2-1L	NA	NA	NA	NA	NA	NA	NA	NA	NA	44.85
L4-2L	NA	NA	NA	NA	NA	NA	NA	NA	NA	43.83
L2-4L	NA	NA	NA	NA	NA	NA	NA	NA	NA	48.28
L3-1L	NA	NA	NA	NA	NA	NA	NA	NA	NA	41.30
L3-2	NA	NA	NA	NA	NA	NA	NA	NA	NA	37.46
L3-4	NA	NA	NA	NA	NA	NA	NA	NA	NA	42.57

L3-4L	NA	NA	NA	NA	NA	NA	NA	NA	NA	45.27
L4-1	NA	NA	NA	NA	NA	NA	NA	NA	NA	44.67
L4-1L	NA	NA	NA	NA	NA	NA	NA	NA	NA	42.75
L4-3L	NA	NA	NA	NA	NA	NA	NA	NA	NA	43.71
PPG-3	NA	NA	NA	NA	NA	NA	NA	NA	NA	42.45
PPG-4	NA	NA	NA	NA	NA	NA	NA	NA	NA	52.72
Ave	6.17	139.27	165.14	1529.33	4.15	460.14	3.18	10.45	1.89	42.64
Min	2.04	28.01	78.99	468.62	0.84	37.82	0.47	1.20	0.47	30.07
Max	12.29	423.76	448.05	2907.84	9.83	1413.75	11.7	28.22	3.58	52.72
SD	3.65	140.29	127.71	916.50	3.22	475.40	3.84	11.13	0.97	5.92

NA-Not available; ND-Not detected
UCC- Upper Continental Crust values (Source: [16])

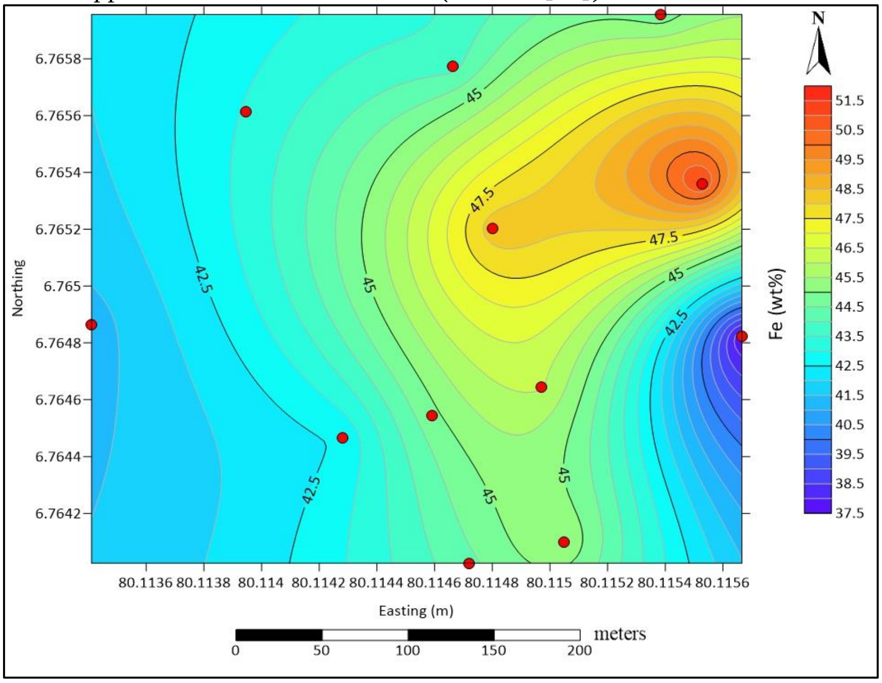

Figure 24 Iron Concentration (Fe wt%) distribution of the sampled area

3.3 Magnetic Survey

The magnetic survey aimed to identify magnetic signatures of iron-bearing minerals in the area. The predominant presence of goethite, hematite an iron-bearing mineral with relatively low magnetic susceptibility compared to magnetite [17] [18]. The absolute magnetic readings ranged between 250 nT and -1043 nT, indicating no significant anomalies attributable to the goethite concentration in this area.

4 Conclusion

The comprehensive exploration and characterization of the Pelpitigoda area have the presence of significant iron ore occurrence, predominantly composed of goethite, hematite, and magnetite. Systematic sampling indicates substantial iron content ranging from 40-60%, averaging 42.64%. The mineralogical analysis through XRD has identified goethite as the primary iron-bearing mineral, alongside notable amounts of magnetite, hematite, gibbsite, and gypsum. The geochemical data, including ICP-MS results, revealed the lower potential for economically valuable metals like Ni, Co, Cr, V, and Zn. These findings suggest that the Pelpitigoda area holds considerable potential for iron extraction, providing valuable insights into its mineralogical and geochemical characteristics. By extracting the iron oxides from this iron ore, it can be effectively utilized for small-scale industrial applications in Sri Lanka, such as the clay roofing tile industry and the production of iron catalysts. This study significantly contributes to the understanding of Sri Lanka's iron ore potential and opens new paths for resource development in the region.

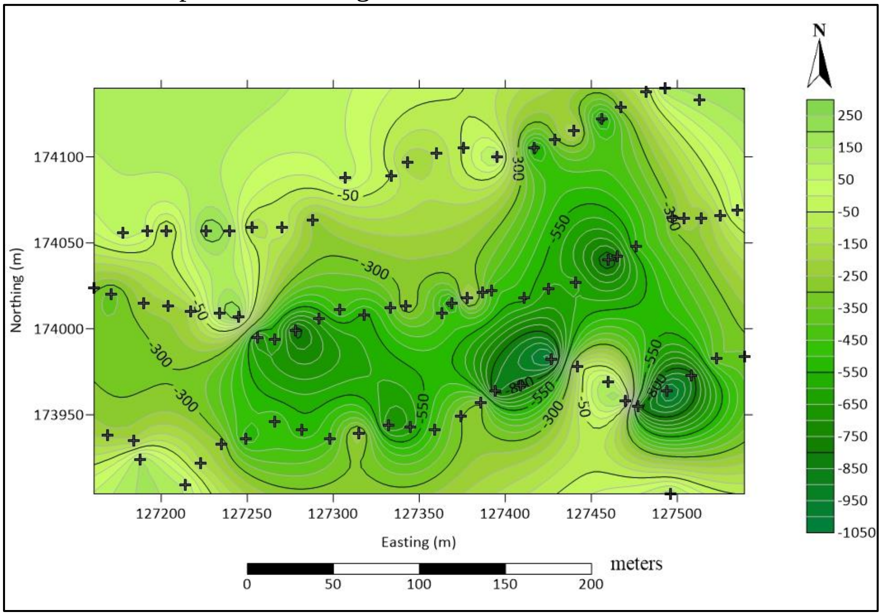

Figure 25 Magnetic Susceptibility variation in sampled area

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