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Geospatial Analysis and Beneficiation Studies on Iron Ores of Sandur Schist Belt, Dharwar Craton, India

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ABSTRACT: Depletion of iron ore grade makes it predictable to utilize the existing low-grade iron ores with suitable mineral processing techniques to meet the present requirement and demand. Economic beneficiation of these low-grade iron ores remains a challenging task. To find out an effective way of data acquisition, data management, and processing of mineral resources with an in-depth modern and innovative technology like geospatial analysis technique is found essential. A geospatial analysis as a direct adjunct to the field and more recently geo-informatics has played an important role in the study of mineral resource identification and its beneficiation. The present study focused on the diagnostic processing characteristics of iron ores of the Nandihalli area of the Sandur schist belt using geo-informatics. Using Geo-informatics the iron ore samples were drawn from spatial location points. The mineralogical studies reveal that hematite is the major iron-bearing mineral magnetite as minor iron-bearing mineral and silica & alumina as the gangue minerals. Beneficiation studies involving crushing, classification, de-sliming, spiral concentrate, and HGMS (SLon) are tested for the production of quality concentrates. The results indicated that iron ore samples of the Nandihalli area contain 59.78% Fe (T), 4.49% SiO2 and 4.39% Al_2O_3 has obtained different products namely sinter grade concentrate (60.98% Fe, 2.83% SiO_2, and 3.72% Al_2O_3) with 70% weight recovery and pellet grade concentrate (62.39% Fe, 1.93% SiO_2 and 2.02% Al_2O_3) with 15% weight recovery.

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1- Introduction

With the rapid development in the projected iron and steel production capacity in India, the use of lean grade iron ore as a source of iron values is imperative. Technology-driven mechanized mining and utilization of such vast mineral wealth are posing big challenges to mineral engineers throughout the world. Geospatial technology is important for mineral data management activity and usually covers a great part of varied ore beneficiation studies, focused on spatial analysis [1, 2]. Process of characterization data is the ore based on the properties like texture, mineralogy, physical and chemical properties, merits and limitations of beneficiation are less understood, because of lack spatial data management [3]. Utilization of natural resources by Implementation of process characterization and the geotechnical map will increase the sustainability level [4]. The data analysis of iron ore processing and geospatial techniques have attracted the attention of mineral engineers and geoscientists all over the world, not only because they form the backbone of the economic development of the country but also for the interesting ideas on the nature of the source rock, depositional characters, structure, mineralogy, tectonics, geochemistry, digenesis, and history of metamorphism which are inconclusive even to this day. The Sandur schist belt is one of the important greenstone belts in the Dharwar craton of Karnataka [5]. The belt has been a focal point and has drawn the attention of mineral engineers, geologists, and researchers from time to time as the belt consists of rich deposits of iron and manganese ores which are of great economic importance to the country. Scanning through the literature available on the Sandur schist belt, it is clear that most of the research work is concentrated on the southwest and northwest portions of the schist belt [6, 7].

In the current research work, geospatial analysis and beneficiation of iron ores of area 15° 02’ 05.96” N to 76° 34’ 06.27” E were studied which belongs to the southern part of the Sandur schist belt. The literature on geospatial data analysis of this part of the schist belt is scanty. Most of the iron ore beneficiation practices comprise size reduction, classification of fines, gravity concentration, magnetic concentration, pyro-processing followed by agglomeration of concentrates [8]. Process economics involving cost reduction, both capital, and operative, by increasing unit capacities and by reducing energy, development of flexible flow sheet for a concentration of Fe values at coarse sizes has gained much importance in recent times. The use of geospatial technology is suitable for spatial data management related to iron ore deposits at various scales and its beneficiation study in mine development could be expanded further [9]. The present study aims to maintain

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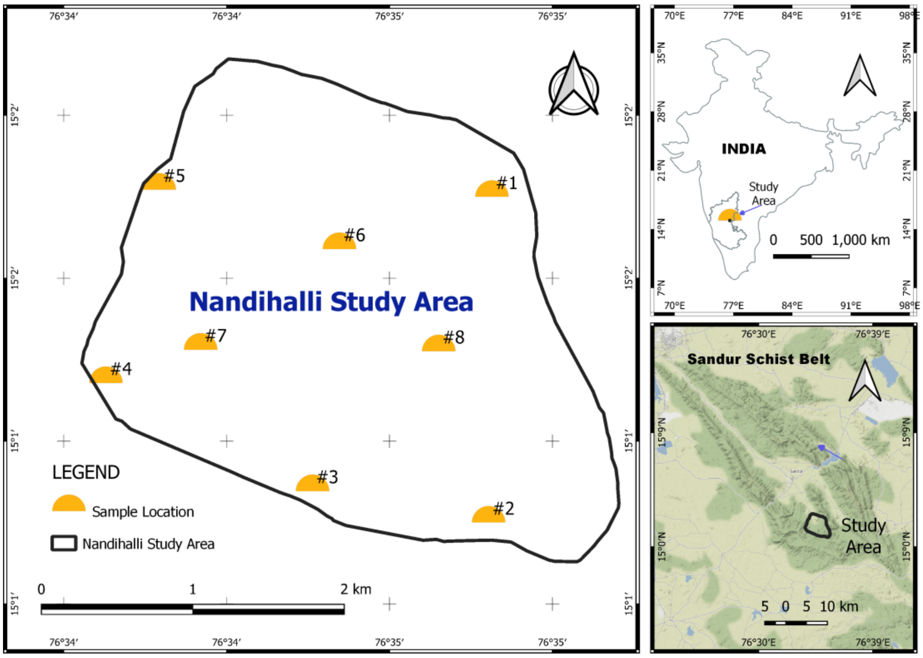


Fig. 1. Location map of the Nandihalli study area.

the spatial data management of iron ores of the Sandur schist belt area with their advanced beneficiation studies and their mineral potentialities in the Dharwar craton. Keeping this in view, an attempt has been made to understand the viability of Iron ores of the study area and their beneficiation for the production of concentrates for metallurgical use through geo-informatics and laboratory beneficiation methods.

2- Material and Methods

The study area under investigation forms the southern part of the Sandur schist belt and lies between longitude 76°45' 00" to 76°52' 40" East and latitude 15°00' 00" to 15°9' 30" North. The area found in the Survey of India topo sheet No. 57A/16 includes part of Ballari district of Karnataka and part of Ananthpur district of Andrapradesh states. The area is accessible from Nandihalli village, which is about 35 km south of Hospet to reach the study area as shown in Fig. 1. There are non-metal roads to reach the interior part where labor quarters of iron ore mines are located.

The current research work of the Nandihalli area forms a part of the Deogiri formations, which is a southern part of the Sandur schist belt. The major rock types of the study area are banded iron formation, chlorite schist, metabasalt, gneisses, granites, laterites, and intrusive dykes shown in Fig. 2. The Nandihalli area in the Deogiri formation is characterized by several hills. Banded iron ore formation is the chief lithological unit of the area [10]. Banded iron ore formation is exposed on the top of the hill ranges, chlorite schist is exposed conformably adjacent to the banded iron ore formation long the slopes and foothill rages [11, 12]. At the foothills of the hill ranges and nalla cuttings, meatballs were observed.

Authors [13-17] are acknowledged that geospatial technology is the most fundamental prerequisite in any geological field and characterization study of minerals. The study area is about 2803 km2. A systematic geological and thematic mapping was carried out using geo-informatics tools such as open-source QGIS, MapInfo Pro version, AutoCAD-MAP, Garmin GPS, and SRTM satellite images. During the preparation of the geological mapping and characterization study, a large number of the fresh outcrop, ores were identified and collected from the in-situ outcrops, the details of the ore sample locations are shown in Fig. 3. In addition to this, the iron ore samples of the Sandur schist belt are subjected to bench scale beneficiation studies to recover the best possible grade of iron values and to prepare the process flow sheet [18-26].

3- Feed Characterization Studies

The sample shows majorly hematitic; dark reddish; the ore specific gravity is 3.62 and the nature of the material is soft to medium-hard ore. The bulk sample chemical analysis is shown in Table 1. Size analysis of the collected sample was carried out using -10+6, -3+1, –1+0.15 mm sieve sizes. The sample indicates that about 80% of the particles were less than 6 mm in size, 50% of the particles were less than -3 mm in size, and nearly 30% of the particles were found to be less than 150 µm in size. Table 2 shows the chemical analysis of the sized sample indicates that the Fe (T) grade of the sample decreased drastically when the size was reduced to 150 µm. The sample confirms that desliming at finer sizes shall improve the grade of the concentrates.

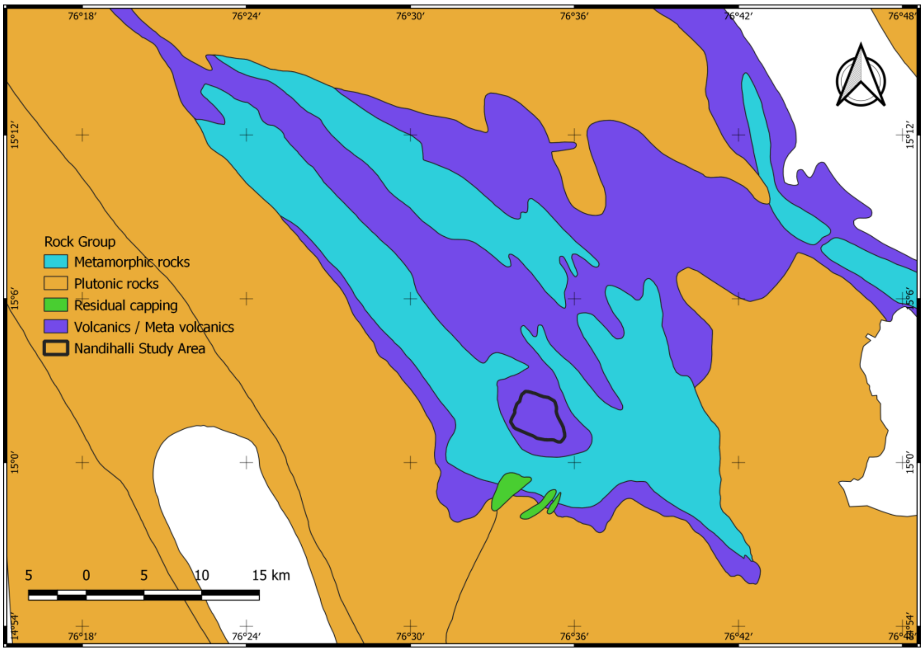
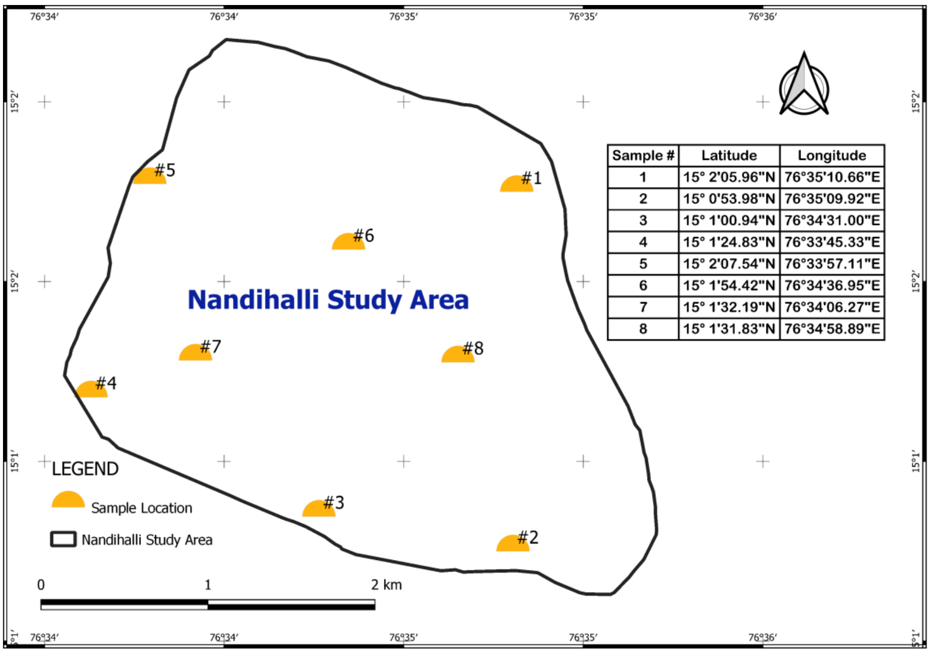


Fig. 2. Geology map of the Sandur Schist Belt.



Sample #	Latitude	Longitude
1	15° 2'05.96"N	76°35'10.66"E
2	15° 0'53.98"N	76°35'09.92"E
3	15° 1'00.94"N	76°34'31.00"E
4	15° 1'24.83"N	76°33'45.33"E
5	15° 2'07.54"N	76°33'57.11"E
6	15° 1'54.42"N	76°34'36.95"E
7	15° 1'32.19"N	76°34'06.27"E
8	15° 1'31.83"N	76°34'58.89"E

Fig. 3. Sample locations map of the Nandihalli study area.

3- 1- Mineralogy

The composite sample is subjected to transmitted and reflected Ore Microscope (ZEISS Axiovert 40 make). Microscopic studies reveal that the samples do contain simple mineralogy with considerable gangue mineral content Fig. 4(b). The sample shows hematite as the major iron-bearing mineral magnetite as a minor mineral and silica, alumina as the gangue minerals. The hematite phase is very loose and is disseminated. The results of mineral phase analysis are shown in Fig. 4(a). The majority of quartzite minerals are free to form. A part of the quartzite is found embedded in hematite. Relative estimation of ore mineral content has been estimated in which the Ore mineral portion acquires approximately 60-75% by the area whereas the gangue mineral constituents contribute in the range of 25-40%.

Table 1. Bulk sample Chemical Analysis.

%Fe (T)	% SiO_2	% Al_2O_3	%LOI
59.7	4.4	4.3	5.1

Table 2. Size-wise chemical analysis.

Size (mm)	Cum passing, wt.%	Fe (T), %	SiO_2, %	Al_2O_3, %	LOI, %
-10+6	89.38	61.19	4.13	4.64	3.39
-3+1	59.64	60.47	5.4	4.64	4.62
-1+0.25	46.7	55.32	6.8	4.71	5.11
-0.15	32.78	50.34	14.3	6.5	6.1

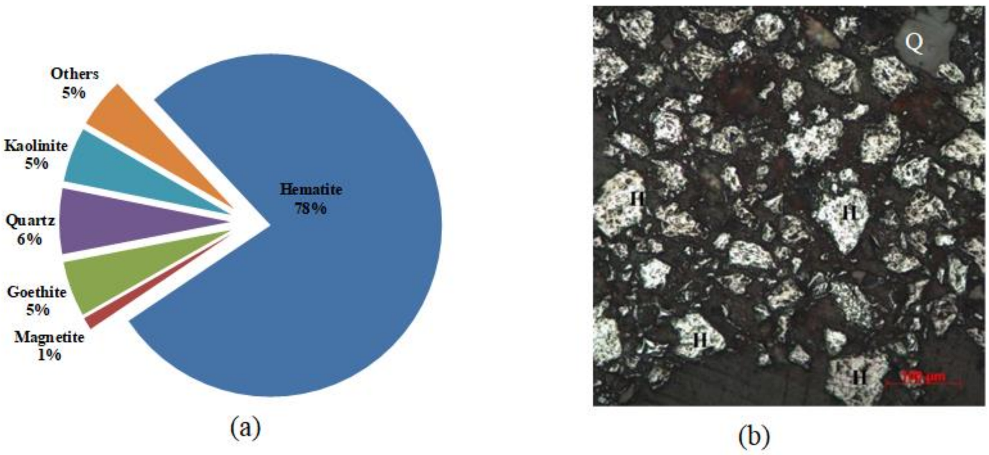


Fig. 4. a) Phase analysis of the sample; b) Optical Micrograph of the sample showing Hematite [H] and Quartz [Q],

3- 2- Beneficiation Studies:

3- 2- 1- Process amenability studies

A representative sample is stage ground in a laboratory ball mill to produce -1, -0.5, and -0.25 mm, and the products were subjected to heavy liquid separation using Bromo from 2.9 SG. The floats and sinks were analyzed for Fe (T). The losses of Fe in float increased with the finesse of size and concentrates meeting pellet grade could not be obtained by heavy liquid separation due to lack of selectivity. The samples are also analyzed for their amenability to magnetic separation by 10,000 gauss bar magnet. The result indicated that the concentre grade increases with an increase in finess of the grind and concentrate assaying >60% Fe was obtained at -120 µm. Further bar magnetic separation yielded better selective results as compared to heavy liquid separation. The amenability tests indicated that the ore sample is more amenable to high-intensity magnetic separation than gravity separation.

3- 2- 2- Bench-scale studies

A detailed bench scale beneficiation study was carried out on the iron ore samples to utilize -3 mm particles by further processing to produce pellet grade concentrate. The beneficiation studies include gravity separation (spirals) of the coarser portion after desliming it and high-intensity magnetic separation of the finer fraction. Fig. 5 depicts the size-wise grade distribution. The drawback in using WHIMS technology is that the grains of quartz may concentrate at high intensities of gauss due to the occlusion effect. Due to this problem separation by gravity using gravity spirals seems a more feasible and better option. Before gravity separation, the sample may have to be subjected to pre-concentration using spirals. Different feed rates, pulp densities, and splitter positions are used for conducting tests. To obtain the final concentrate, desliming by hydro cyclone followed by spiral concentration and magnetic separation using high gradient magnetic separation (HGMS) are chosen as the best route.

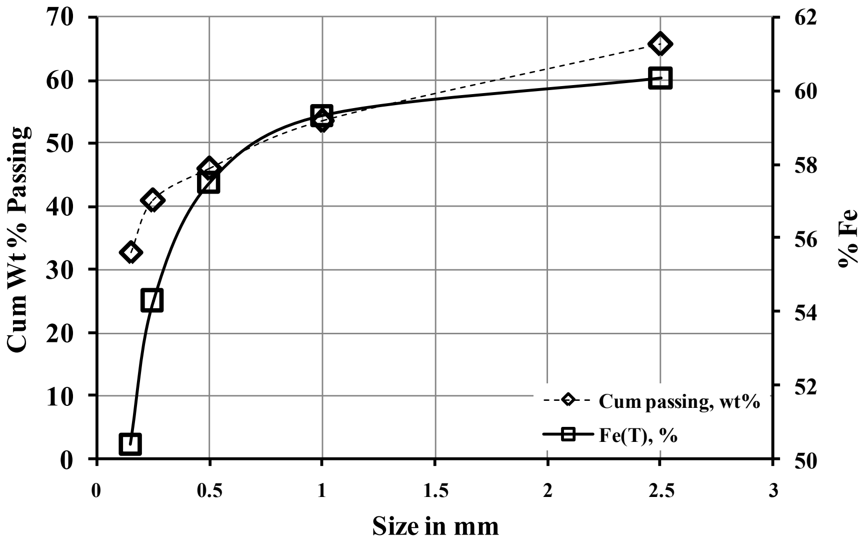


Fig. 5. Size analysis of iron ore sample and %Fe grade.

Table 3. Chemical Analysis of spatial samples of iron ore.

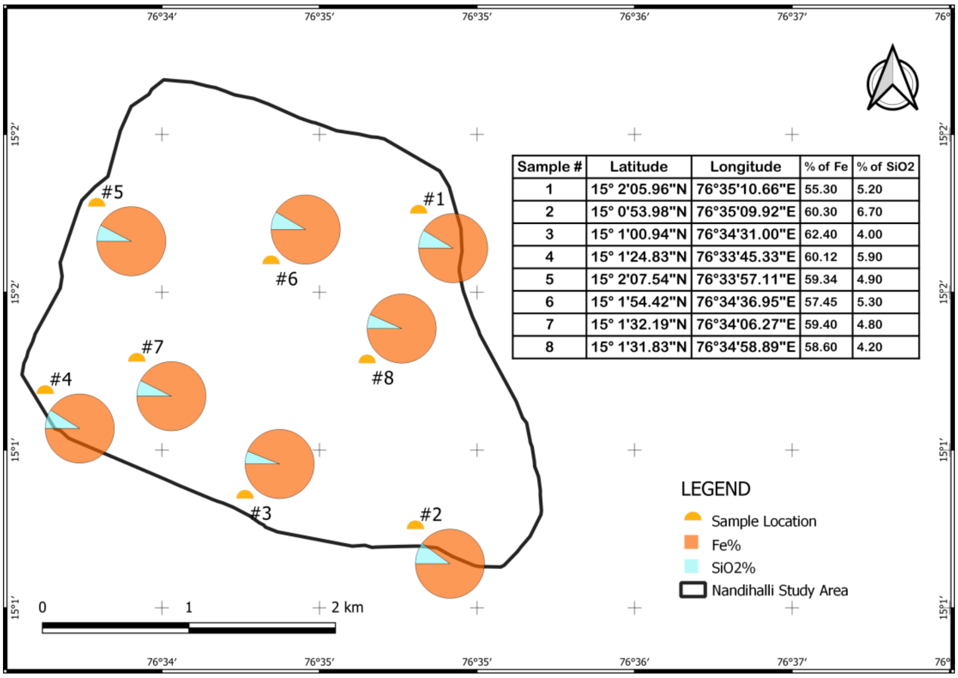
Sample #	Latitude	Longitude	% Fe	%Sio2
1	15° 2'05.96"N	76°35'10.66"E	55.30	5.20
2	15° 0'53.98"N	76°35'09.92"E	59.40	4.80
3	15° 1'00.94"N	76°34'31.00"E	58.60	4.20
4	15° 1'24.83"N	76°33'45.33"E	60.12	5.90
5	15° 2'07.54"N	76°33'57.11"E	59.34	4.90
6	15° 1'54.42"N	76°34'36.95"E	57.45	5.30
7	15° 1'32.19"N	76°34'06.27"E	60.30	6.70
8	15° 1'31.83"N	76°34'58.89"E	62.40	4.00
Composite sample			**59.8**	**4.49**

4- Results and Discussion

Sample collected from the geo-informatics techniques located at various locations of the study is presented in Fig. 3 are analyzed for Fe and SiO_2. Nearly 20 Kg of samples were collected from each location and analyzed for Fe and SiO_2 as shown in Table 3 and spatial chemical analysis is shown in Fig. 6. A composite sample is prepared by mixing samples #1 to #8 for further beneficiation works. The composite sample consisted of brownish-black colored lumps with a considerable amount of brown colored fines. The bulk density of the composite sample was 1.8 t/m^3. The sample assayed 59.7% Fe (T), 4.4% SiO_2, 4.3% Al_2O_3, and 5.1 % LOI. The sample contained mainly hematite with trace amounts of quartz, gibbsite with a subordinate amount of ferruginous clay.

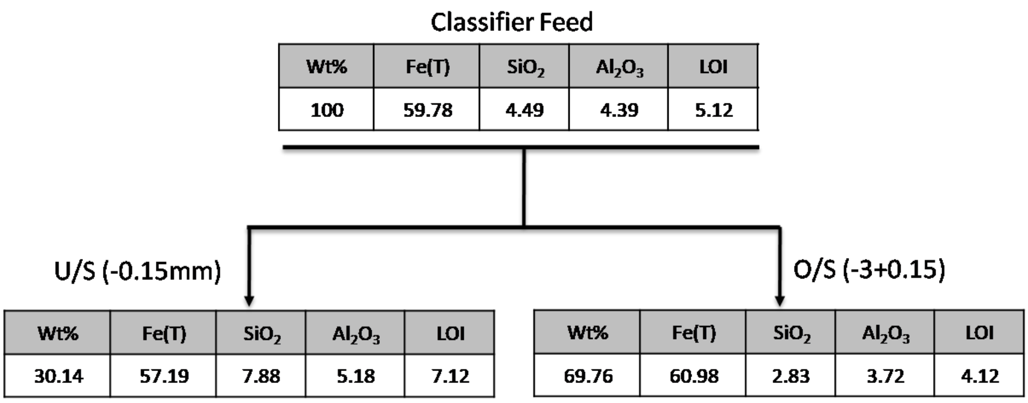
4- 1- Classification studies

Classification of finer range particles is very much essential during beneficiation of soft nature ores. The sample showed the degradation of the Fe (T) grade when reaches -3 mm size. An attempt is made to utilize the fines by using a laboratory model screw classifier (MPE make, Mumbai) with 35% solids with a screw speed of 30rpm to separate the -150 micron size fraction from the feed. The results of the screw classification are as shown in Fig. 7. The oversized fraction, 69%wt recovery with 60.98% Fe can be directly used for sinter grade products. The undersize fraction (-150microns) obtained was 30.14% with 57.19% Fe which can be upgraded further. A detail of the stream analysis of screw classifiers is shown in Fig. 7.



Sample #	Latitude	Longitude	% of Fe	% of SiO2
1	15° 2'05.96"N	76°35'10.66"E	55.30	5.20
2	15° 0'53.98"N	76°35'09.92"E	60.30	6.70
3	15° 1'00.94"N	76°34'31.00"E	62.40	4.00
4	15° 1'24.83"N	76°33'45.33"E	60.12	5.90
5	15° 2'07.54"N	76°33'57.11"E	59.34	4.90
6	15° 1'54.42"N	76°34'36.95"E	57.45	5.30
7	15° 1'32.19"N	76°34'06.27"E	59.40	4.80
8	15° 1'31.83"N	76°34'58.89"E	58.60	4.20

Fig. 6. Spatial chemical analysis of Iron ore samples.



Classifier Feed

Wt%	Fe(T)	SiO_2	Al_2O_3	LOI
100	59.78	4.49	4.39	5.12

U/S (-0.15mm)

Wt%	Fe(T)	SiO_2	Al_2O_3	LOI
30.14	57.19	7.88	5.18	7.12

O/S (-3+0.15)

Wt%	Fe(T)	SiO_2	Al_2O_3	LOI
69.76	60.98	2.83	3.72	4.12

Fig. 7. Chemical analysis of screw classifier products.

4- 2- Desliming studies

The desliming of iron ore slurry desliming studies to remove slimes from the classifier undersize fraction are carried out by using desliming hydro-cyclone [27]. The operating conditions for the hydrocyclone desliming step are vertex finder 40 mm, spigot dia 25 mm with an operating pressure of 1.5 bar. The hydro cyclone was fed with a slurry density of 1150 kg/m^3. This produced an overflow of hydro cyclone containing 51.79% Fe with 25.54% weight and underflow contains 59.10% of Fe with 74.48% of the weight. The size analysis of the product obtained from hydro-cyclone is and the chemical analysis of the products obtained from the hydrocyclone is shown in Fig. 8.

4- 3- Concentration studies

4- 3- 1- . Spiralling

A spiral concentrator is a typical unit operation making use of several separating forces – gravity and centrifugal action, the feed (underflow of the hydro cyclone) is introduced through the feed box, which reduces its velocity and establishes the correct pattern of flow. The feed density-1250 kg/m^3 with a flow rate of 35 Lpm enters the spiral channel as homogeneous slurry, the spiral test set up shown in Fig. 9. Table 4 shows the results of the spiral concentration studies, the concentrate assaying 62.4% Fe with 50.5% recovery (by weight) with an enrichment ratio of 1.05, and the loss of Fe in the tailings is 54.37%.

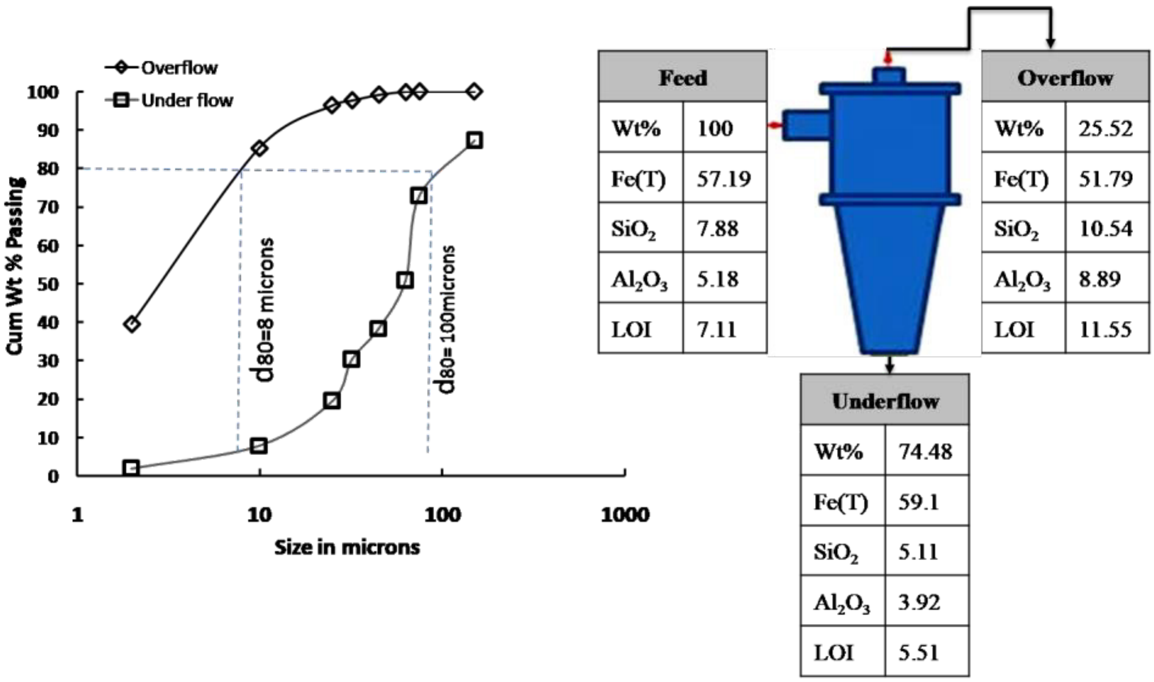


Fig. 8. Results of classifier undersize fractions desliming.

Fig. 9. Spiral Test setup.

Table 4. Spiral concentrates and tails.

Products	wt.%	Fe (T)	SiO_2	Al_2O_3	LOI	Recovery (%Fe)
Concentrate	47.83	62.43	2.13	2.13	3.23	50.5
Tailings	52.17	56.07	7.36	5.71	6.87	49.5
Feed	100	59.10	5.11	3.92	5.51	100

Fig. 10. Laboratory high gradient magnetic separator.

Table 5. HGMS concentrate and tails.

	wt.%	Fe (T)	SiO_2	Al_2O_3	LOI	Recovery (%Fe)
Magnetics	35.49	62.12	1.59	1.86	2.47	40.54
Non-Magnetics	64.51	50.41	10.48	7.64	8.44	59.46
Feed	100	54.37	7.36	5.71	6.87	100

4- 3- 2- Magnetic separation

The laboratory wet high gradient magnetic separator depicted in Fig. 10 is used for separation studies. The tailing sample generated from the spiral concentrator consisted of feed Density-1350 kg/m^3; is introduced to high gradient magnetic separation at the magnetic intensity of 8000 Gauss. The result of magnetic separation is depicted in Table 5 and understood that the spiral tails are amenable for magnetic separation to produce pellet concentrate. The magnetic fractions analyzed 62.12 Fe (T), 1.5%SiO_2 with 40% recovery met the pellet grade concentrate specifications. The overall mass balance of feed and products of magnetic separation is shown in Table 5.

4- 4- Final test

The final test comprises of crushing of composite sample to -3 mm with laboratory jaw crusher, screw classifier to remove -0.15 mm fractions, oversize size fractions assayed 61% Fe with 70% wt % yield produced sinter feed concentrate. The undersize classified products are subjected to a locked cycle test by desliming at -0.15 mm and recycling the cleaner tails back by spiral concentration. The spiral product assayed 62.5 % Fe with 10% yield (by weight) and spiral tails followed by the magnetic product of HGMS meets the specification of pellet grade concentrate assaying 62.5 % Fe with 15% yield (by weight). The above process produced sinter feed with 70% yield (by weight) and pellet feed with 15%

Table 6. Overall Mass Balance.

	wt.%	Fe%	SiO_2	Al_2O_3	Recovery (%Fe)	Product
Spiral classifier O/S	70.01	60.98	2.83	3.72	71.4	Sinter Grade Product
Spiral Concentrate HGMS Mag	15.2	62.5	2.1	2.1	15.9	Pellet grade product
Hydrocyclone O/F	7.8	51.8	10.5	8.9	6.7	Final tails
HGMS Tail	7.7	50.4	10.5	7.6	6.5	
Feed	100.0	59.8	4.5	4.4	100	

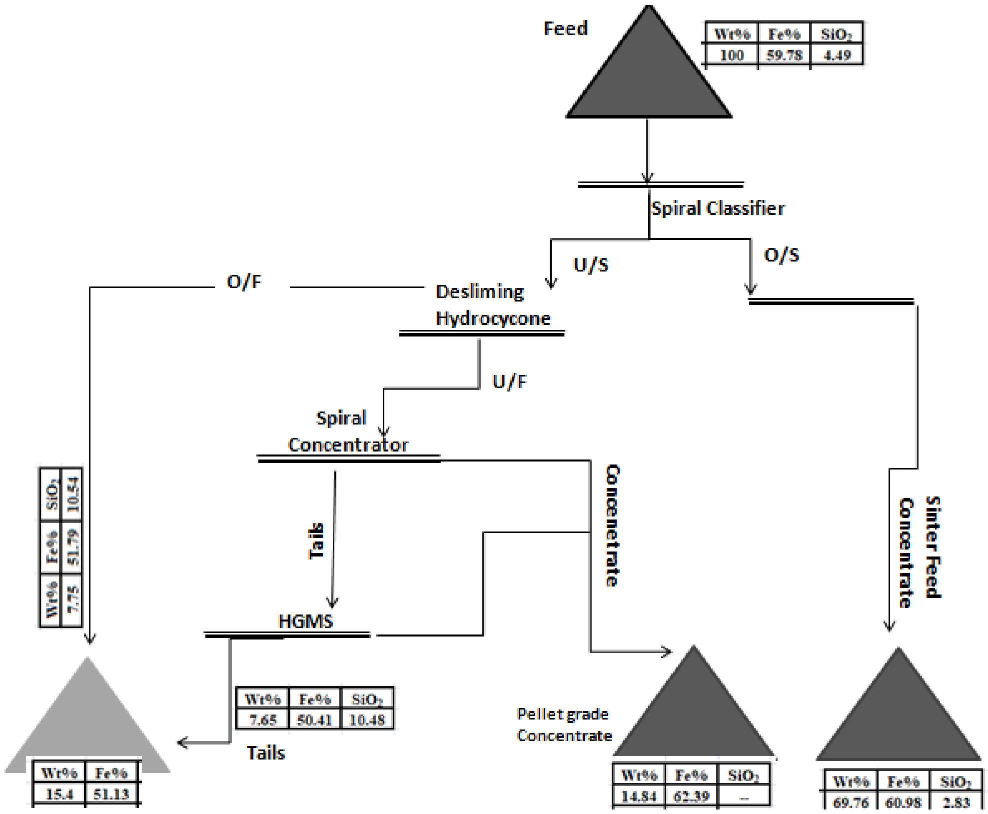


Fig. 11. Laboratory flow sheet to treat the iron ore samples from the study area.

yield as shown in Table 6. The flowsheet is drawn based on the laboratory study is shown in Fig. 11. Detailed pilot plant tests are recommended as the process appears economically and ecologically feasible and can be retrofitted as a tailpiece in the existing mineral processing plants.

5- Conclusion

The greater demand for quality iron ore for iron and steel making has made the mineral processing technology more advanced. The iron ore sample from sandur schist belt lies between longitude 76°45' 00" to 76°52' 40" East and latitude 15°00' 00" to 15°9' 30" North is assessed using geo-informatics with bench-scale beneficiation for its utility in iron and steel making. The area is found in the Survey of India topo sheet No. 57A/16 which includes part of the Ballari district of Karnataka and part of Ananthpur district of Andra Pradesh states is studied for collection of iron ore samples and beneficiation. The iron ore samples of the study area assayed 59.78% Fe (T), 4.49% SiO_2, and 4.39% Al_2O_3. The sample is beneficiated for sinter grade concentrate (60.98% Fe, 2.83% SiO_2, and 3.72% Al_2O_3) with 70% weight recovery and Pellet grade concentrate (62.39% Fe, 1.93% SiO_2, and 2.02% Al_2O_3) with 15% weight recovery. The tailings of the spiral are represented through HGMS to produce pellet grade concentrate assaying 62% Fe, 1.5% SiO2 with 40% recovery.

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