MAPPING OF SITTAMPUNDI ANORTHOSITE COMPLEX (SAC) IN SOUTHERN GRANULITE TERRAIN (SGT), INDIA WITH ASTER AND SENTINEL-2A DATA

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Abstract: ***The Sittampundi Anorthosite Complex (SAC) is a well-exposed Archean layered anorthosite-gabbro-ultramafic rock complex in southern India. SAC well preserved** white- and dark-anorthosite,gabbros, and ultramafic rocks. **This study aims to discriminate, characterize, and separate from adjacent and surrounding rocks the anorthosite complex in sitampundi using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Sentinel-2A data. Methods such as band color composites (True color composite, False color composite and Pseudo color composite), Principal Component Analysis (PCA), Minimum Noise Fraction (MNF) and Spectral Angle Mapper (SAM), are applied to discriminate the anorthosite complex in SGT (Southern Granulite Terrain). Band composites enhance the litho units using visible and shortwave infrared bands and thus, assisted in mapping for the anorthosite complex. PCA and MNF have been applied to the ASTER and Sentinel- 2A bands in order to decrease the redundant information in highly correlated bands. PCA and MNF driven band combinations facilitate the validation and help in discriminating the various lithological units exposed in the study area. SAM classifier classification technique was utilized to characterize the selected surface mineral assemblages from Sitampundi Anorthosite Complex using spectral signatures. The above-mentioned digital image processing techniques have been proven resourceful in discrimination of anorthosite complex and associated rocks. The results obtained from ASTER and Sentinel-2A data processing were validated in field, followed by accuracy assessment.***

Keywords: SAC, ASTER, Sentinel-2A, Remote sensing.

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I. INTRODUCTION

Remotely sensed data more convenient and challenging tool to identify the various mineralogical, lithological discrimination and geological structural mapping lithological contact and characterization. The spatial and spectral properties of the (ASTER) Advanced Space born Thermal Emission and Reflection Radiometer data and Sentinel-2A were utilized by digital image processing techniques for lithological mapping in the Sittampundi Anorthosite complex. Image processing techniques in ASTER spectral range of visible and near-infrared (VNIR), and shortwave infrared (SWIR) regions and Sentinel-2A spectral range of visible VNIR, and SWIR regions provide information about the topography and lithology of the area. ASTER data have the combination of good spatial resolution and wide spectral coverage in the visible near-infrared through shortwave infrared to the thermal infrared regions and Sentinel-2A data have good spatial resolution in visible near-infrared regions. Hence, ASTER and Sentinel-2A data are digitally enhanced for lithological discrimination.

The development of advanced remote sensing techniques applications has helped research works due to low cost, high efficiency, quality of results and quick investigations. The growth of remote sensing are mainly gained using distinct earth observation satellites data and informative outputs extracted by digital image processing techniques.

Provide ample opportunities for mineral exploration on tectonic studies and space born geological mapping. Several satellite images are used for various purposes including change detection, land observation, volcano science, petroleum exploration, monitoring water quality, mineral, hydrology, environmental geoscience, mass wasting hazards, earthquakes, mapping of high relief and remote areas and floods etc.,[1]. Remote sensing techniques are broadly used for mapping the geological structure, lithological contact and mineral exploration using ASTER, Landsat and Sentinel-2A optical remote sensing data [2], [3], [4], [5], [6], [7] & [8]. A benefit of ASTER data is the rare combination of good spatial resolution and broad spectral coverage in the visible near-infrared, shortwave infrared and thermal infrared regions. Thus, ASTER data proved the competence for lithological discrimination [9] & [10].

ASTER VNIR region contributes information on the availability of vegetation [11] and mineralogical information on iron oxides and REEs [12], SWIR region appraise OH bearing minerals [13] and TIR region giving information on carbonates and silicates and carbonates [14]. ASTER data has a greater number of bands in the SWIR region than the VNIR and TIR, so the SWIR have high capability to enhance the lithology of the area and mapping. By using TIR bands the emissivity and surface temperature can be calculated. With the help of TIR bands can obtain reflectance, elevation maps, land surface temperature and emissivity [15].

An upgraded geological map using ASTER data generated to find out the ability of ASTER data in discriminating of alteration and regolith in Australia by using the band ratio technique and spectral unmixing techniques used to apply in SWIR, TIR regions in which the Emissivity data have enhanced the mapping of volcanic, sedimentary and meta-sedimentary areas [16] and some minerals in epithermal, porphyry and skarn groups distinguished through band ratio technique by using ASTER bands [17].Ophiolite Complex in Logar and Surrounding Areas (SE Afghanistan) discriminated well by using band ratio (4/8 & 12/4), Relative Absorption Band Depth (RDB) and SAM classification With ASTER Data [18]. The Salem mafic-ultramafic complex discriminated by using PCA, MNF, Relative band depth, SAM and SVM classification using VNIR, SWIR and TIR regions of ASTER data [6].

Lithological discriminated the Shibanjing ophiolite complex of Beishan orogenic in china with the ASTER and Sentinel-2A VNIR and SWIR regions by using PCA, MNF, Band Ratio ((Sentinel-2A band 3+ASTER band 9) /(Sentinel- 2A band 12+ASTER band 8)), SAM and SVM techniques [3]. Assurance of ophiolite complexes is up-and-coming for understanding information on mineralogy, further it leads to zones of mineralization with metallic and nonmetallic ore deposits, petrology and structure of deep-seated oceanic lithosphere [19].

SAC is one of the major geological provinces in India. Anorthosite is a leucocratic mafic igneous rock rich in plagioclase with minor amounts of pyroxenes, olivine and other minerals. SAC is still treated as a lunar highland equivalent rock. The Sittampundi Anorthositic Complex has more value in economic importance by the occurrence of chromite [20] and again the occurrence of Platinum Group Elements (PGE) [21]. The SAC complex have important value due to the relative contents of major oxides in the Sittampundi anorthsoite is showing equivalent of anorthositic rocks in lunar highland because of the associated craters and lunar highland region largely composed of anorthosite and they proved equivalency by a study conducted based on reflectance spectra of terrestrial anorthosites collected from SAC and finally interpreted the diagnostic spectral features of analog anorthosite for remotely exploring lunar highland region. The chemistry and mineralogy of Sittampundi anorthosites are mostly correlated with the lunar highland anorthosite and showing similarity [22], [23].

Various studies have been reported for the identification Sittampundi Anorthosite Complex (SAC) of mafic ultramafic rocks and their associated rocks in Southern Granulite Terrain (SGT) using different remote sensing techniques like color composites (TCC, FCC and PCC), Principal component analysis (PCA) Band Rationing (BR), Spectral Profile and Matching and Spectral Angle Mapper by using ASTER data [24], [25]. Mafic ultramafic rocks and associated rocks types discriminated by using AVIRIS-ng with the help of digital image processing techniques [26] and not much remote sensing study conducted by Sentinel-2A satellite data.

Geochemical study of these anorthosite complexes within this area are expensive and time consuming. So, Digital Image Processing techniques in such cases are selected as sufficient tool. A far-reaching remote sensing study, mapping of Anorthosite complex in sittampundi is important. Therefore, the objectives of this study are to discriminate anorthosite complex and associated rocks within sittampundi using ASTER and Sentinel-2A data.

II. GEOLOGY SETTING OF THE STUDY AREA

SAC is the one of the major Mafic Ultramafic complex in the Southern Granulite Terrain (SGT). Chiefly anorthosites as the first reported granulites in the Sittampundi area [24]. This complex situated in Namakkal District in Tamil Nadu. SAC originated in Neoarchaean age [27] formed metamorphosed anorthositic complex having original igneous stratigraphy. The Neo archaean Sittampundi anorthosite, situated in Namakkal District, in the state of Tamil Nadu, Southern India [28] is a metamorphosed anorthositic complex, preserving an exact igneous stratigraphy overlaid by high-grade metamorphic assemblages [29], [30],[31].The lithology of SAC has been stated the formation of mafic granulites of SAC as the early differentiates of the magma parental to felsic granulites [29],[32],[33]. Another opinion by [28] SAC formed by metamorphosed of layered igneous complex. Another opinion regarding the origin of SAC formed from the pelitic and marly sediments [34] [35]. The other works researchers identified the SAC is an Archean layered anorthositic igneous complex [30] [32]. Sittampundi complex has a length of between 20-25 km exposed over a strike and subjected to deformed structure and multiple folded. SAC bordered by quartzo feldspathic hornblende-biotite gneiss and it's composed of quartzite, marbles, and banded iron formations [32]. The SAC lithological showing the anorthosite, gabbro, pyroxenite mafic-ultramafic rocks majorly which identified by the field investigation and lithology map of the Sittampundi Anorthosite Complex is shown in Figure 1.

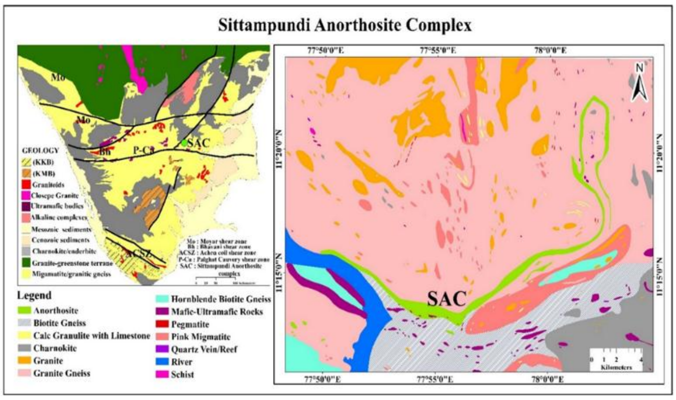

Fig. 1. Geology of the study area (Source GSI)

II. MATERIALS AND METHODS

This study has been carried out by integrating the ASTER and Sentinel-2A data, field investigation and geological map. ASTER data are combined by sufficient spectral and spatial resolution, high spatial resolution in VNIR and SWIR regions and high spectral resolution in SWIR and TIR regions. L1T ASTER cloud free tiles were downloaded from the USGS Earth explorer online site, which were acquired in March 2003. Sentinel-2A satellite mission launched in June 2015 and it is an Earth observation mission from the Copernicus Programme that systematically acquires optical imagery because of its high spatial resolution (10 m to 60 m) coastal waters and land. Cloud free Sentinel-2A (2021 March) freely downloaded from USGS Earth explorer website.

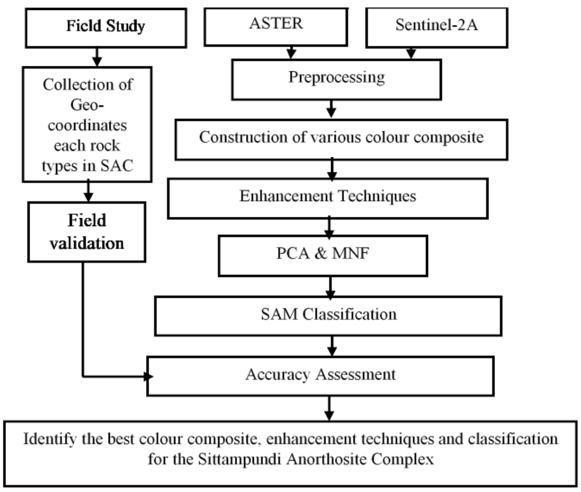

Fig. 2. Methodology applied for this study area

For the digital image processing techniques and the map layout and marking carried out by the use of ENVI 5.2 and ArcGIS 10.5. The methodology adapted for this study area is given in Figure 2, the whole study is done by mainly three steps such as Preprocessing, processing, and post processing. Firstly, all the bands are in the ASTER data atmospherically corrected by FLAASH algorithm and the void filling and orthorectification applied on Sentinel-2A data. The VNIR and SWIR bands of ASTER layer-stacked and resampled in to 15 m resolution and from the Sentinel-2A data the bands which having the 60m resolution (band 1, 9 & 10) was removed and resampled in to 15 m resolution.

All the analyses' part to extract information's done by digital image processing techniques such as color combinations, Principal component analysis (PCA), Minimum Noise Fraction (MNF) and Spectral Angle Mapper (SAM) carried out in Processing section. Then finally, the post processing step represents the comparison, the validation and accuracy assessment with help Geo-coordinates collected from the field study.

IV. RESULTS AND DISCUSSION

Digital Image Processing techniques like the construction of various color composites (Band combinations), enhancement techniques like PCA, MNF, and SAM were used in the present study. Finally, SVM classification was performed to classify the various rock types using ASTER and Sentinel-2A satellite data, and the accuracy was also assessed based on the field verification.

[27] *A. Color Composites*

In color composite images composed of three primary colors of red, green and blue. The federation of all spectral bands with an independed primary color outcome in a color composite image. For this study, applied color composites like color composite images (True color composite (TCC), False color composite (FCC) and Pseudo color composite (PCC) were selected to discriminate the lithology with visible and shortwave infrared raw bands and hence for to discriminate anorthosite complex through the color composite images by using ASTER and Sentinel-2A data.

First band composites images applied on ASTER data (Figure 3), TCC was performed (R: 1, G: 2, B: 3) and it shows anorthosite in off white color, from the FCC (R: 3, G: 2, B: 1) image anorthosite complex visible in cyan color and PCC (R: 6, G: 2, B: 1) image enhanced the anorthosite complex in cyan color very clearly than the TCC and FCC.

Second, the band composites images applied on Sentinel-2A data (Figure 4), TCC was performed (R: 4, G: 3, B: 2) and it shows anorthosite in white color, from the FCC (R: 8, G: 4, B: 3) image anorthosite complex visible in light green color and PCC (R: 12, G: 11, B: 2) image enhanced the anorthosite complex in light violet color very and PCC enhanced anorthosite complex in well than the TCC and FCC.

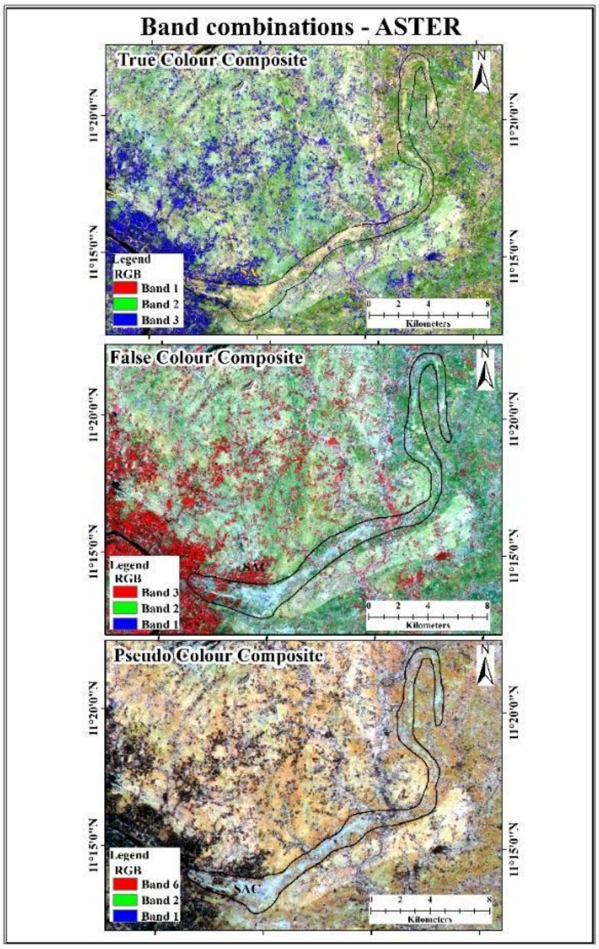

Fig. 3. TCC,FCC &PCC images derived from ASTER data

A. Principal Component Analysis (PCA)

[28] Principal component analysis (PCA) is a method for separating noise components and reducing the dimensionality of data sets by rotating associated components into uncorrelated output bands. First the single band interpretation conducted in ASTER VNIR and SWIR region (Figure 5:a,b,c,d,e,f,g,h &i). From the 9 outputs of PC the better identification of anorthosite complex in PC-6, PC-7 and PC-8 discriminating the anorthosite complex in dark color and the PC-9 showing the anorthosite complex in white color.

Second, the single band interpretation was analyzed using Sentinel-2A data (Figure 6: a,b,c,d,e,f,g,h &i). The single band outputs give better identification of anorthosite complex in PC-2, PC-3, PC-7 and PC-8 discriminating the anorthosite complex in bright color and the PC-4, PC-5 and PC-6 showing the anorthosite complex in white color. Mainly the SWIR region gives more discrimination of anorthosite complex and the Sentinel-2A data well discriminated anorthosite complex than the ASTER data by single band PCA techniques.

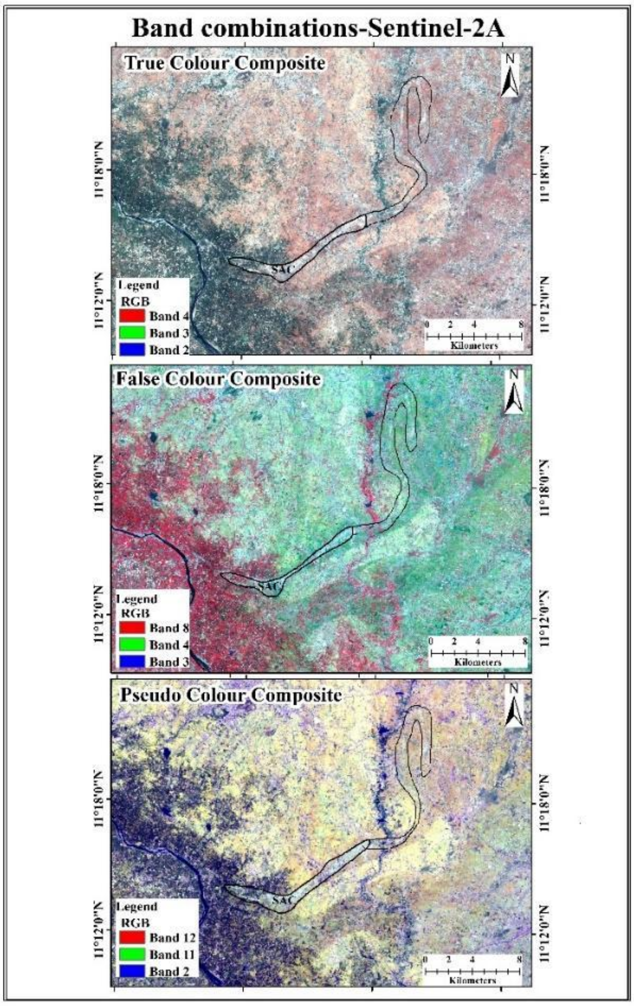

Fig. 4. TCC, FCC & PCC derived from Sentinel-2A data

The band combinations applied on PCA single bands by using ASTER data discriminated the anorthosite complex by using R: 1 G: 9, B: 6 combination shows better discrimination and the anorthosite complex in yellow color shows in Figure 7. The PCA band combination (R: 5, G: 3, B: 8) derived from the Sentinel-2A shows anorthosite complex in orange color and Sentinel-2A gives better identification of anorthosite complex than the ASTER derived PCA band combination.

B. Minimum Noise Fraction (MNF)

The MNF method is a technique for noise reduction [38]. It is based on the linear transform theory, which is extensively used for feature extraction, noise whitening, and spectral data reduction in remote sensing imageries [3], [39].Two separate PCA rotations make up the MNF transform. The data noises are decorrelated in the first rotation, and the noises are rescaled in the second rotation.

The band combinations applied on MNF using ASTER data band combination in R: 7 G: 4, B: 9 combination shows better discrimination of anorthosite complex in pink color shows in Figure 9. The MNF band combination (R: 8, G: 4, B: 3) derived from the Sentinel-2A shows in Figure 10, anorthosite complex in light greencolor and with the help of MNF techniques can discriminate the lithology of the area.

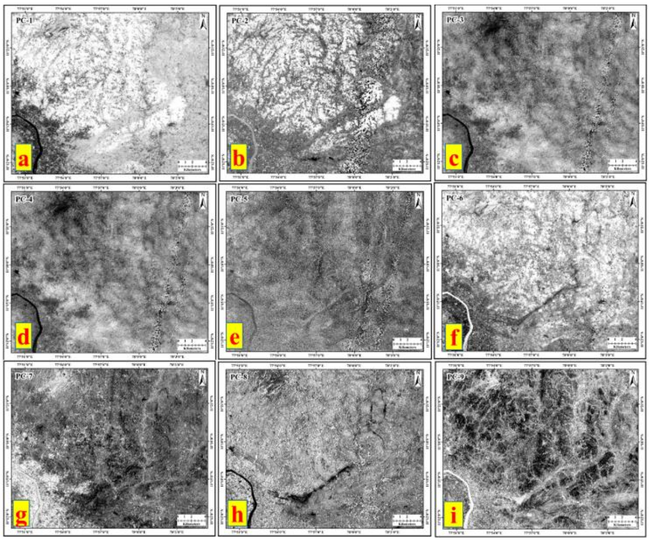

Fig. 5.(a, b, c, d, e, f, g, h & i). Single band PCA analysis- ASTER data.

C. Spectral Angle Mapper (SAM)

Spectral angle mapper (SAM) is a physical-based spectral classification that matches pixels to reference spectra using an n-D angle. The approach calculates the angle between two spectra and treats them as vectors in a space with dimensionality equal to the number of bands to determine spectral similarity.

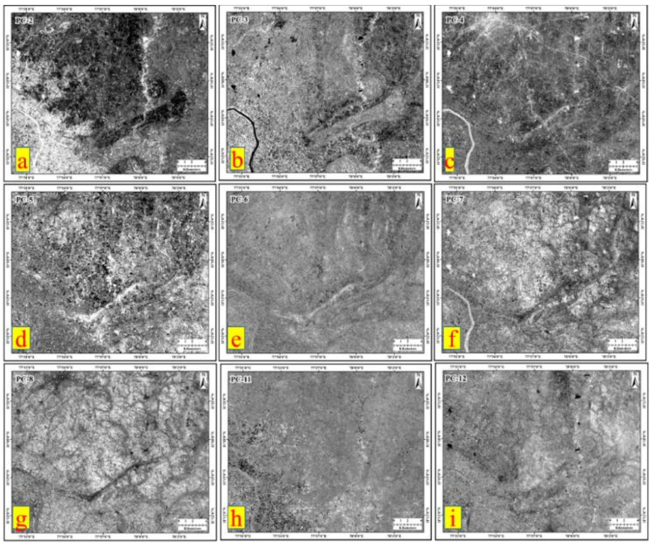

Fig. 6. (a, b, c, d, e, f, g, h & i). Single band PCA analysis- Sentinel-2A data.

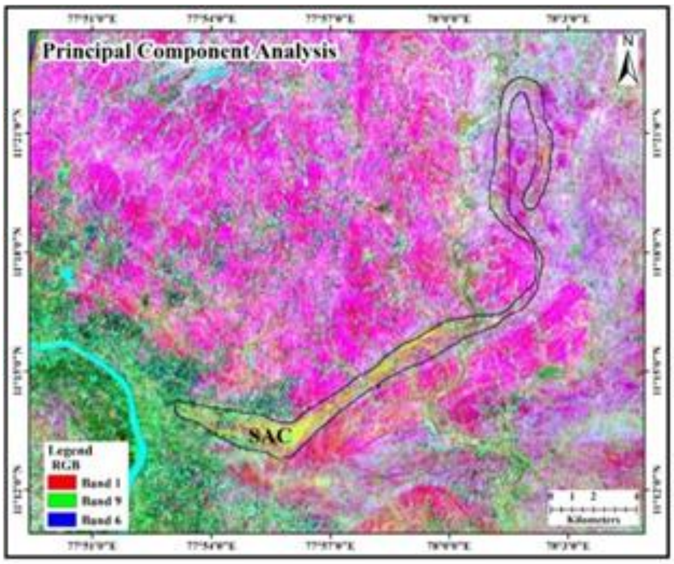

Fig. 7. PCA band combination (R: 1 G: 9, B: 6)- ASTER

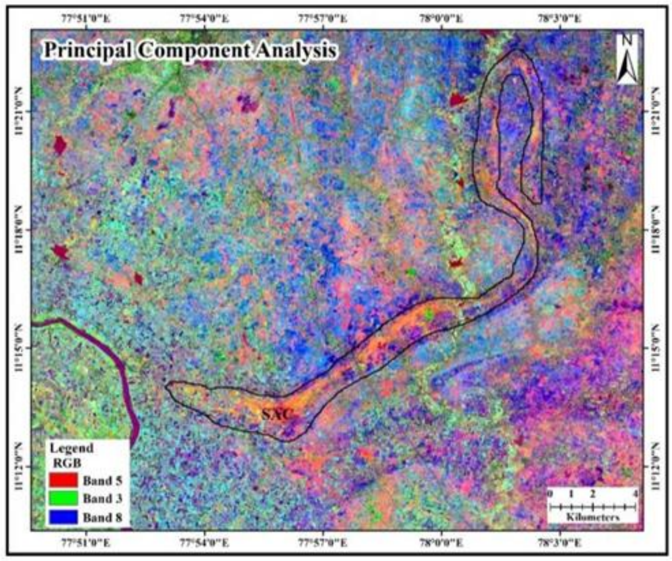

Fig. 8. PCA band combination (R:5, G:3, B:8)- Sentinel-2A

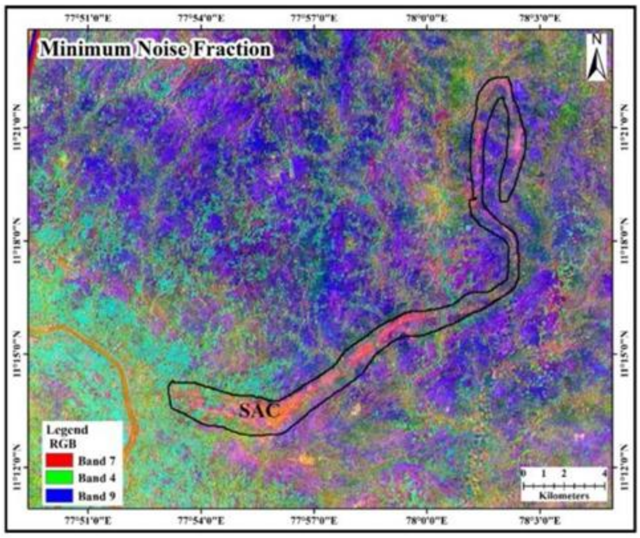

Fig. 9. MNF band combination (R: 7, G: 4, B: 9)- ASTER data

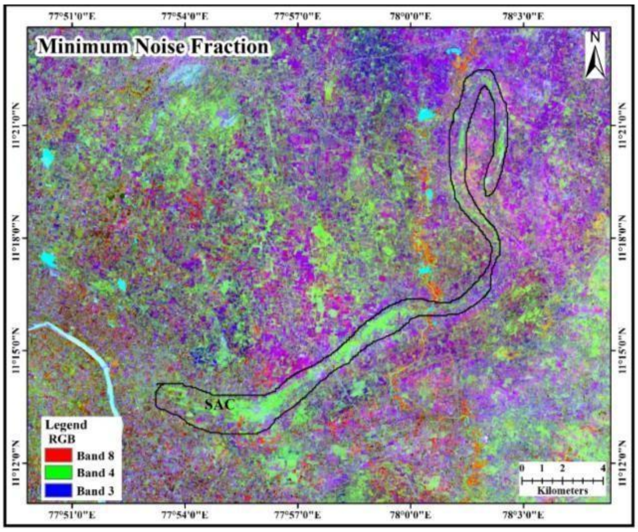

Fig. 10. MNF band combination (R: 8, G: 4, B: 3)- Sentinel-2A data

SAM's endmember spectra can be used by laboratory spectral libraries to extract spectra directly from images (as ROI class pixel).The angle between the endmember spectrum vector and each pixel vector in n-D space is compared by SAM. The smaller the angle, the closer the spectrum is to the reference spectrum [4], [6], [24], [41]. In this study the selection of ROI data training pixels for anorthosite directly extracted from the satellite image based on the Geo-coordinates collected from the field investigation. Finally with help of The SAM classifier classified the lithology of the Sittampundi Anorthosite Complex by using ASTER data shown in Figure 11 and Sentinel-2A data shown in Figure 12.

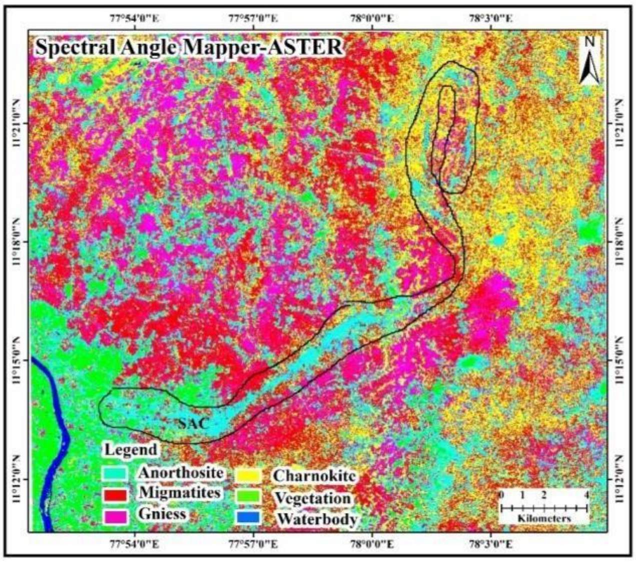

Fig. 11. SAM classification output from ASTER data

IV. FIELD INVESTIGATION AND ACCURACY ASSESSMENT

The accuracy assessment applied on SAM classification output images from ASTER and Sentinel-2A data by calculating the producer Accuracy, user accuracy, overall accuracy and finally the kappa coefficient. The kappa coefficient (K) was discovered to reflect the measurement of agreement between the categorized map and the genuine reference data in SAM classifications. The total user and producer accuracies were also determined. Unlike the overall accuracy, which is determined along the diagonal of the contingency matrix, the kappa coefficient considers the complete contingency matrix. The ratio between the total number of correct pixels and the total number of pixels in the error matrix is the overall accuracy. The producer accuracy includes omission mistakes relating to the specific ROI classes, whereas the user accuracy includes commission errors. The field work carried out and the SAC complex majorly occurred by anorthosite rocks and the gneiss and charnokite are occurred in around SAC complex. The SAC lithology complex rich in anorthosite rock with associated mafic and ultramafic rocks of gabbro and pyroxenite and the chromite deposits are shown in Figures (13 a, b & c).

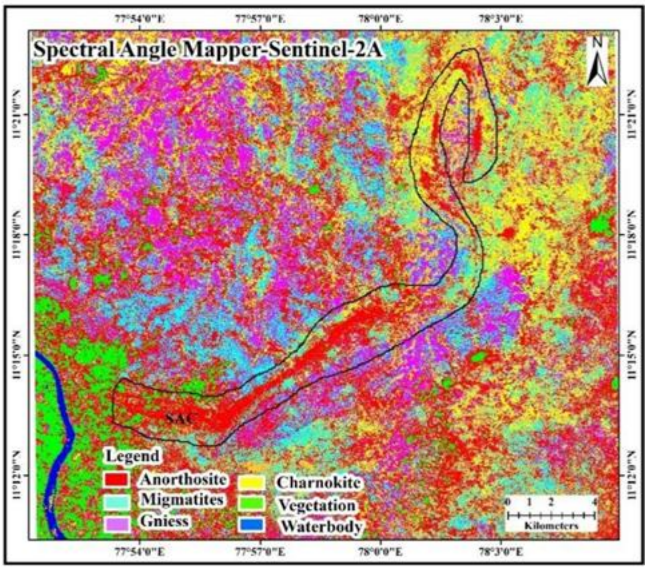

Fig. 12. SAM classification output from Sentinel-2A data

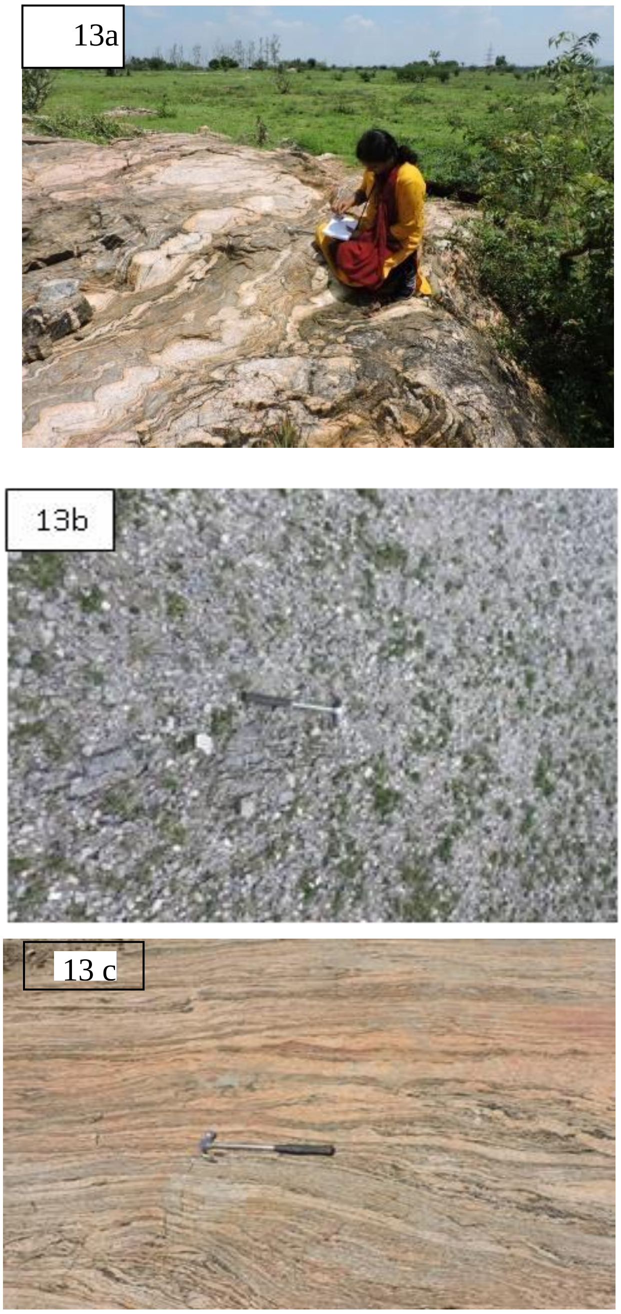

Fig. 13 a & c: outcrops of felsic and mafic magma and 13 b : Anorthosite Outcrop from SAC

Using the Geo-coordinates of anorthosite complex collected from the field, the SAM classification outputs from ASTER and Sentinel- 2A shown substantial agreement to the rock surface. The result shows that high overall accuracy of 84.76 % in Sentinel-2A followed by 79.05 % in ASTER data. The kappa coefficient values from the Sentinel-2A are 0.78 followed by ASTER having 0.72. The SAM derived from the Sentinel-2A data showing the high accuracy than the SAM derived from ASTER data (Table: 1). the result indicates Sentinel-2A is showing better results for discrimination of Anorthosite complex, and it's also inferred that Sentinel-2A playing a vital role in discriminate the rock types. Hence the emerging Sentinel-2A data also can use for lithological identification and mapping.

TABLE I. ACCURACY ASSESSMENT TABLE

Outcrops	**ASTER**		**Sentinel-2A**	
	Producer Accuracy (%)	**User Accuracy (%)**	**Producer Accuracy (%)**	**User Accuracy (%)**
Anorthosite Complex	96.87	88.57	97.05	94.28
Migamatites	82.35	80	85.71	85.71
Gniess	56	70	**75**	**75**
Charnokite	71.42	66.66	68.75	68.75
Overall accuracy (%)	79.05		84.76	
Kappa coefficient	0.72		0.78	

Mapping of rock types in SAC was carried out using ASTER and Sentinel-2A data with the help of various digital image processing techniques like color composites, PCA, MNF and SAM classification. The processing of ASTER and Sentinel-2A data are useful tools for mapping surface lithology. The VNIR and SWIR bands of ASTER and Sentinel-2A are useful to isolate anorthosite deposits. In color composite image analysis, TCC. FCC and PCC, the PCC giving the more discrimination than the TCC and FCC. In PCA resulted outputs, Sentinel-2A derived band combination (R: 5, G: 3, B: 8) gives better discrimination of anorthosite complex than ASTER derived outputs. MNF output also demarcating the boundary of anorthosite complex by ASTER and Sentinel- 2A data, from which the Sentinel-2A derived band combination (R: 8, G: 4, B: 3) giving better identification of anorthosite complex than ASTER data. The spectral angle mapper classifier derived from the Sentinel-2A data showing higher accuracy than the SAM derived from the ASTER data. Finally, the comparison between ASTER and Sentinel-2A data analysis in Color composites (TCC, FCC, and PCC), PCA, MNF, SAM classification, and these enhancement techniques are more useful in the lithological mapping of anorthosite complex and SAM classification of Sentinel-2A data showing more effectiveness in lithological mapping.

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