Iraqi Geological Journal (Scopus indexed)
igj-iraq.org

Article Review Form

Please fill in English language

I. About Journal:

The ***Iraqi Geological Journal (IGJ)*** is a peer-reviewed and Scopus indexed journal, issued twice a year in English by the Union of Iraqi Geologists (UIG). The IGJ brings together multidisciplinary interests in one journal and is to disseminate information on all aspects of research and development Earth Sciences. Contributions in the form of original research articles, scientific comments, and reviews in all fields of the Earth Sciences, and their related are considered for publication. Researchers and graduate students are cordially invited to submit their papers to *IGJ*. The IGJ has a particular interest in publishing which have conclusions international and local studies of general interest. Editors welcome original contributions that have not been published elsewhere.

II. The Information of Article Review

Article No.	2733
Journal Title	Iraqi Geological Journal (IGJ)
Article Title	**Characteristics of Limestone Outcrops Based on Landsat 8 Image and Geochemical Analysis in South Buton Regency, Southeast Sulawesi Province, Indonesia**
Reviewer's Name	
Qualification	
E-mail	
Mobile	
Affiliation	
General comments:	
The idea of using remote sensing for geological mapping of limestone in Buton is good, but the scope of work is too simple. Using band ratio, color compositing, and NDVI is a very common case in prospecting of mineral deposit. But limestone is visible in normal photos and the area is not so large, so it is better to use drone to get aerial photograph. The definition of limestone outcrops is not clear.	
Do introduction include the importance of research, the previous studies, the research objectives. The objective must place at the latest paragraph of research.	
Yes, the introduction include the importance of research, the previous studies, the research objectives. The objective is placed at the latest paragraph of research.	
Do the research contain materials and methods	
Yes, the research contain materials and methods.	
Suggestions for improvement:	
In the method, the authors always mention that remote sensing method is useful to identify mineralization, but the term of mineralization is not relevant with the presence of limestone because limestone is a rock type and does not have mineralization. The objective of using remote sensing for mapping limestone outcrop is not clear. The number of samples is limited for this study, and the justification for selecting the sampling location is not clear.	

Tables and Figures are they Ok; give useful comments:
Fig. 1: It does not indicate the specific study site and also did not involve location of sampling. Figs. 2, 3, 5: What is the lithology in the area covered by vegetation? If it is limestone, it is not correct to observe it as non-limestone. Table 1: It needs references. Fig. 04: It is better to unite three spectral curves into one graph. Table 2: What is the difference for the geochemical composition between unmined limestone and mined limestone? May be using XRD we can compare the composition of clay mineral for both locations. I suggest adding more samples and measuring the spectral of samples using spectrometer then comparing them to the spectral in satellite images.
What do you think about the English language:
The English is quite good. The authors must be consistent to use term of “study” or “research”, not mixing it, i.e. study site or research area?
What do you think about the reference:
The references are all right, but some reference formats are not consistent.

Article score:

Ten-point System	**Relevance**	**Originality**	**Significance**	**Technical soundness**	**Clarity of presentation/ language**
Enter a score between 0 to 10					

Enter final score of the research between 0 to 10	

Final Evaluation		
☐ **Accept Submission**	☐ **Revisions Required**	☐ **Resubmit for Review**
☐ **Resubmit Elsewhere**	☐ **Decline Submission**	☐ **See Comments**

In case of rejection, please give the reasons why you reject publication.

The objective of this study is not clear, and what were discussed is different from the objective. What authors did was just simple study, there is no new idea of using Landsat image. I think using drone for aerial mapping is more effective in case just want to map the spread of limestone. Moreover, the result of geochemical tests with limited number of samples is not discussed in detail in relation to the spectral analysis and so on. The originality of this study is low because it is similar to the following article: Heriyansyah, A.F., Chalik, C.A., Wakila, M.H., Harwan, H., and F, F., 2022. Identifikasi Sebaran Batugamping Menggunakan Data Citra Landsat 8 Di Pulau Buton Bagian Selatan. Jurnal Geomine, 10(1), 59–74, https://doi.org/10.33536/JG.V10I4.985

Date of receipt: / /
Date of achievement: / /
Any additional comments I do not recommend this manuscript to be followed up for publication, because of its low quality and originality.

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Finally, I would like to reject this manuscript for publication. Please improve it and submit again next time.

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Reviewer's Name	
Qualification	
E-mail	
Mobile	
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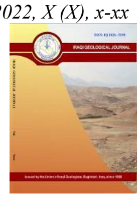
General comments:	
Most of the notes are fixed on the research paper.	
Do introduction include the importance of research, the previous studies, the research objectives. The objective must place at the latest paragraph of research.	
Yes	
Do the research contain materials and methods	
It is not clear enough.	
Suggestions for improvement:	
The research needs some linguistic and scientific corrections.	

Tables and Figures are they Ok; give useful comments:
Yes, to some extent.
What do you think about the English language:
good
What do you think about the reference:
It is important to add some references that are installed within the research upload.

Iraqi Geological Journal

Journal homepage: https://www.igj-iraq.org



Characteristics of Limestone Outcrops Based on Landsat 8 Image and Geochemical Analysis in South Buton Regency, Southeast Sulawesi Province, Indonesia

Received: 18 August 2022

Accepted:

Published:

Abstract

Identification of limestone outcrops aims to determine the potential location, distribution, and quality of limestone. With advances in remote sensing technology, limestone identification can be carried out using Landsat 8 OLI satellite imagery data. This study aims to identify the characteristics of the limestone potential area with the Landsat 8 image processing method used is band ratio, color composite and NDVI. Each result of the Landsat 8 image processing method can show the characteristics and distribution of limestone outcrops based on color and spectral differences from Landsat 8 image data. Spectral analysis of Landsat 8 image data was carried out to see the reflectance level of each band which can show differences in unexposed limestone outcrops. or unmined and exposed or mined limestone. The NDVI method can show potential locations of limestone whose vegetation has been disturbed by mining activities. The chemical characteristics of limestone can be determined by geochemical testing of X-Ray Fluorescence (XRF) limestone samples. for geochemical analysis XRF is carried out in the laboratory to determine the main chemical elements and trace elements of a rock. This research will help industrial engineers explore the potential of limestone in south Buton.

Keywords: ~~l~~Limestone; Landsat~~-~~8; ~~b~~Band ~~r~~Ratios; ~~colour~~ Colour C~~c~~omposite; NDVI

1. Introduction

Limestone in the southern Buton area is widespread and clearly exposed. One of the exposed limestone~~ hills~~ ~~in the South Buton~~ is the Rongi Hill, which is included in the reef limestone Wapulaka Formation. ~~In South Buton,~~ Southeast Sulawesi Province is one of the prospective areas for limestone exploration and mining. The area is marked by the existence of two mining business permit areas located in South Buton. As infrastructure, population, and regional development increase, the exploitation of limestone is increasingly supporting the government and society to meet infrastructure needs. Limestone is the primary raw material required for drainage and infrastructure (Soni and Nema, 2021).

~~Geological mapping is important, especially for geologists~~ Geological mapping is important for any geological work and provides vital information about the geology of the area, such information can be used for several proposes (Bety, 2022).. Remote sensing is the initial method used for geological mapping that covers a large area. This method is inexpensive and time consuming for obtaining surface rock information (Abdelmalik, 2020). The rapid advancement of remote sensing techniques and technologies is increasingly beneficial to

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Discrimination different lithological units using a remote sensing application: A case study in the Dokan Area, Kurdistan Region – Iraq

JOURNAL OF WATER AND LAND DEVELOPMENT

DOI: 10.24425/jwld.2022.142312

2022, No. 55 (X–XII): 109–114

researchers across various disciplines. A significant use case can be found in geological studies, where these techniques are employed for mapping structural features and rock types, as well as identifying and locating economically significant mineral deposits (Amer et al, 2010); (Gad, S., and Kusky, T., 2006). The processing of remote sensing data requires many algorithms and mathematics/statistics that have been developed and used to improve the interpretation of geological features/targets. In the fields of lithology mapping and mineral exploration, two techniques stand out as the most effective and widely used: band ratio and principal component analysis (PCA) (Abdelmalik, 2020). Spectral integration of remote sensing data from each studied target stands as the most crucial remote sensing method. The spectral curve of remote-sensing data contains information that reveals the physical and chemical properties of each object, target, or rock under examination. Studies have demonstrated that the distinctive spectral patterns of rocks and minerals are produced by mechanisms linked to electron movement and transition (Hunt, 1977). The spectral signature of remote sensing data is influenced not only by the rock's chemical makeup but also by its physical characteristics, such as porosity and grain size (Hunt, 1977). The distribution of rocks and minerals on the surface was determined and interpreted using these characteristic spectral patterns.

The Landsat 8 OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor) were introduced in 2013, marking the ~~most~~ recent enhancements to the Landsat satellite program. This iteration of Landsat features decreased bandwidth and incorporates two new spectral bands. Multiple studies have shown Landsat 8's capability in delineating geological structures and detecting zones of hydrothermal alteration (Benaissi et al., 2022; Lu and He, 2022; Osinowo et al., 2021;Salih, 2023), which shows that the spectral data from the Landsat 8 band are very helpful in lithology mapping. Regional geological mapping was performed by Pour and Hashim (2011) utilizing Landsat 8 and ASTER satellite imagery, employing the band-ratio index technique. In lithology mapping, the textural characteristics of Landsat 8 images prove beneficial.(Wei et al., 2016). In addition to the band ratio method, the color combination method can be used for geological mapping, as was done by Pour et al. for hydrothermal alteration mapping using Landsat 8 (Beiranvand & Hashim, 2023).

Limestone mining locations usually experience land cover changes that impact long-term land and environmental conditions. The normalized differential vegetation index (NDVI) method can be used to assess changes in vegetation cover due to changes in land cover caused by active limestone mines. Venkata et al. used Landsat 8 to calculate the NDVI value to detect limestone mining locations and their impact on environmental changes (Venkata et al., 2022).

The research sought to evaluate limestone potential in South Buton, Southeast Sulawesi Province, utilizing Landsat 8 imagery through the application of band ratio, color combination, and NDVI techniques. This research was also carried out by field studies to obtain several limestone samples from locations that were not limestone mining locations and limestone samples from active or former limestone mining sites. Spectral analysis was performed to determine the reflection level of each band indicated by the limestone at the study site. The anticipated outcomes of this research are expected to benefit scientists, industry stakeholders, and the ecosystem in the realm of limestone exploration and environmental stewardship. By contributing to the development of eco-conscious mining sites, this study aims to promote long-term sustainability in the sector..

2. Materials and Methods

2.1. Study Area

The research area was the South Buton Regency, Southeast Sulawesi Province. The ~~research~~ selected area is the Wapulaka Formation, which is a limestone formation of algae and coral reefs. The

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The Application of Remote Sensing Techniques for Identification the Gypsum Rocks in the Qara Darbandi Anticline, Kurdistan Region of Iraq
Iraqi Geological Journal
2024, 57 (1E), 308-322

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Recently, digital image processing has opened new opportunities and facilitates the ways for companies and industries
to investigate the natural resources, i.e., petroleum, mineral, uranium…, remotely.
Arabian Journal of Geosciences (2023) 16:153
https://doi.org/10.1007/s12517-023-11209-3
Hydrocarbon seepage detection by integrating remotely sensed and geochemical data: scanning the lithological alteration

age of ~~This~~ formation is late Pliocene to Pleistocene and consists of bioclastic limestone (Sikumbang, 1995). The limestone in the study area is characterized by coastal steps that rise to the surface because the geology of the southern island of Buton is bordered by the Flores Sea (Figure 1). Based on ESDM (Energy and Mineral Resources) data at https://geoportal.esdm.go.id/minerba/ there are two limestone IUPs (Mining Business Permits) for industries located in South Buton Regency. The IUP remained in the exploratory stage. The research area was located at geographical coordinates 122°40' – 122°55' East Longitude and 5°45'-5°25' South Latitude.

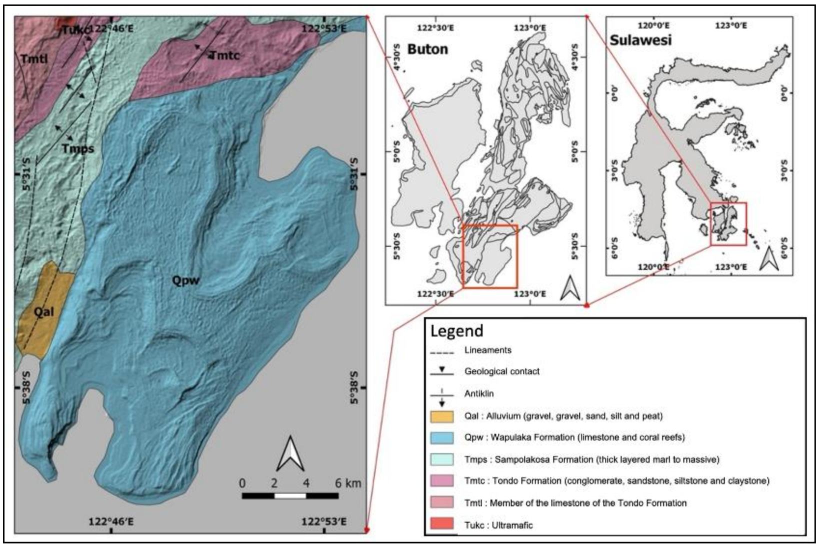

Fig. 1. Geological map of the research area in South Buton, Southeast Sulawesi Province

2.2. Data

For this study, the geospatial information was acquired from the United States Geological Survey (USGS) Earth Explorer platform, accessible at https://earthexplorer.usgs.gov/. ~~Table 1 shows the spectral specifications and spatial resolution of the Landsat 8 OLI (Operational Land Imager). The American Earth Observation Satellite (USGS and NASA) launched Landsat 8 OLI, the latest Landsat mission, in February 2013.~~ This satellite features 11 bands, encompassing visible, infrared, and thermal ranges. Table 1 shows the spectral specifications and spatial resolution of the Landsat 8 OLI (Operational Land Imager). ~~The spectral coverage includes VNIR (0.435-0.673 m), SWIR (1.56-2.29 m), and TIR (10.6-12.5 m).~~ VNIR/SWIR bands have a spatial resolution of 30 m, while the thermal band has a resolution of 100 m. For limestone studies, the VNIR and SWIR bands are utilized to perform ratios, color composites, and NDVI calculations. This study employed Landsat 8 data from Path 112/ Row 64, captured on December 10, 2015. The imagery underwent geometric correction and georeferencing to the UTM (51 South Zone) projection using the WGS-84 datum.

Table 1. The Spectral Characteristics and Spatial Resolution of Landsat Band 8

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December 10, 2015

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	No Band	**wavelength (µm)**	**Spatial Resolution (m)**	**Band**
VNIR	1	0,43-0,45	30	Ultra-Blue (Coastal/Aerosol)
	2	0,45-0,51		Blue
	3	0,53-0,59		Green
	4	0,64-0,67		Red
	5	0,85-0,88		NIR
	8	0,50-0,68	15	Panchromatic
SWIR	9	1,36-1,38	30	Cirrus
	6	1,57-1,65		SWIR 1
	7	2,11-2,29		SWIR 2
TIR	10	10,60-11,19	100	TIR 1
	11	11,50-12,51		TIR 2

2.3. Pre-Processing and Processing Landsat 8

~~This study employed Landsat 8 to examine the spectral properties, color, and NDVI values of limestone~~ . The most sensitive bands for limestone detection were identified using Landsat 8 bands. To create more interpretable images for limestone identification in the study area, these selected spectral bands were used in ratio calculations, composite color image generation, and NDVI computations. Before analyzing limestone presence with Landsat 8 data, it was crucial to conduct pre-processing steps using ENVI software, specifically focusing on radiometric and atmospheric corrections. This pre-processing phase eliminated atmospheric interference effects, yielding more accurate measurements of reflectivity, emissivity, surface physical properties, and surface temperature (Muchsin et al., 2018). The process of radiometric correction involves converting Digital Numbers (DN) to radians and/or reflectance, followed by atmospheric adjustment using the FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) tool within ENVI software. Subsequently, the Landsat image is trimmed to match the study area's boundaries.

The band ratio, color composite, and NDVI processes are the next processes after data preprocessing is complete. This process is a technique for improving the image quality for clearer interpretation targets, especially for improving the image quality targets in limestone lithology mapping. In remote sensing analysis, the band ratio technique compares two spectral bands for a single color in the RGB (Red, Green, Blue) system, resulting in a specific rock surface appearance. Following this, a color composite process is employed, which combines three colors to map lithological zones. The final step in processing Landsat 8 imagery involves generating an NDVI (Normalized Difference Vegetation Index) map by applying the NDVI algorithm to the appropriate Landsat 8 image bands.

3. Results and Discussion

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The methodology is not clear and the methodology paragraph is missing. A special paragraph should be added to explain the methodology followed to reach the results.

3.1. Band Ratio (BR)

The Band Ratio method is the remote sensing enhancement method applied in this study. The Band ~~Ratio technique enhances color differences by calculating the ratio of brightness values at the peaks and valleys of the spectral reflectance curve.~~ This approach is particularly effective in identifying features or materials that are not easily discernible in the original band. Additionally, the band ratio transformation proves valuable in detecting minerals associated with hydrothermal alteration processes.(Pour et al., 2011; Rockwell & Hofstra, 2008; Di Tomasso & Rubinstein, 2007). Two band ratios for RGB images have been used for mapping lithology and hydrothermal alteration: Sabin ratios (4/2, 6/7, and band 10 as RGB and 4/2, 6/5, and 6/7 as RGB) (Sabins, 1999). The mineralized limestone spectrum shows high reflectance in band 6 Landsat 8 OLI and low reflectance in band 7, which is due to weak alteration of gypsum and clay. Therefore, the ratio (7/6) of Landsat 8 OLI can be used to extract mineralized limestone (Amer et al., 2010; Bedini, 2011). The two bands compared for each RGB color were chosen to better extract the lithological units. The ratios of the two bands used in this research to extract limestone were R5/4, G6/5, and B7/2, and the second band ratios used in this research were R6/5, G 7/6, and B 4/7 (Fig. 2). Figure 2 shows color variations for unmined and mined limestone outcrops, in addition to colors for non-limestone or identified as forest or vegetation.

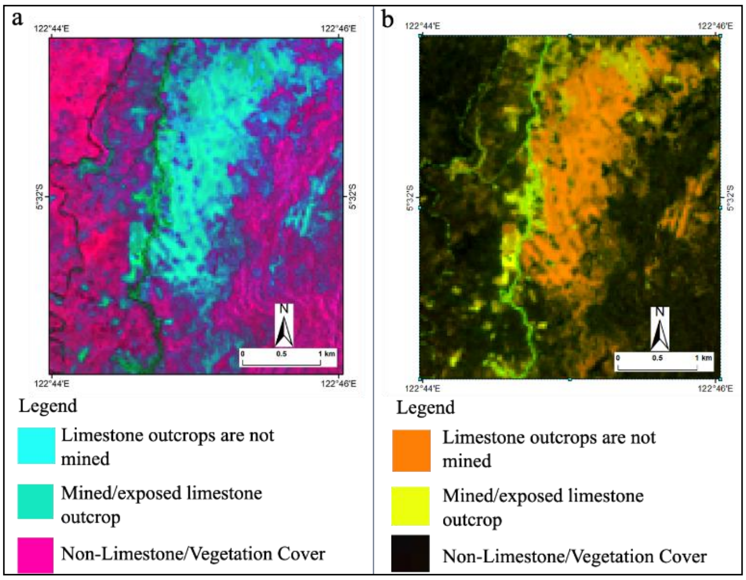

Fig. 2. a) R5/4, G6/5, and B7/2 band ratio results and b) R6/5, G7/6, and B 4/7 band ratio of Landsat 8 image

3.2. Color Composite

The generation of color composites depends on the spectral properties of modified rocks and minerals. Clay and carbonate minerals exhibit absorption features in the 2.1 to 2.4 m range, while reflectance is noted between 1.5 and 1.7 m (Ourhzif et al, 2019). Following an analysis of various band ratio combinations, two RGB color composite schemes were chosen to improve the detection of existing lithological units and mineralization areas (Amer et al., 2010; Crouvi et al., 2006; Moghtaderi & Zadeh,

Commented [A10]: The BR method enhances the contrast between targets or features based on dividing the reflectance for the one band pixels by the same pixels in other bands [AMER et al. 2010; RAJENDRAN, NASIR 2014].

Commented [A11]: Rocks have different reflectivity due to different mineral components, as well as different wavelengths, as they can have high reflectivity in a certain part of the wavelength and low reflectivity in another part (Bety, 2023).

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2007; Di Tomasso & Rubenstein, 2007). Landsat 8 OLI employs bands R4, G3, and B2 for natural RGB color composites. This research utilized an RGB color composite of 753 to identify limestone (Fig. 3a). The wavelength ranges for these bands are: 2.11-2.29 µm for band 7 (SWIR 2), 0.85-0.88 µm for band 5 (Near Infrared), and 0.53-0.59 µm for band 3 (Green). Additionally, an alternative RGB color composite of 762 was used to detect limestone presence (Fig. 3b), band 7 (SWIR 2) has a wavelength of 2.11-2.29 µm, band 6 (SWIR 1) has a wavelength of 1.57-1.65 µm, and band 2 (Blue) has a wavelength of 0.45-0.51 µm (Heriansyah et al, 2022).

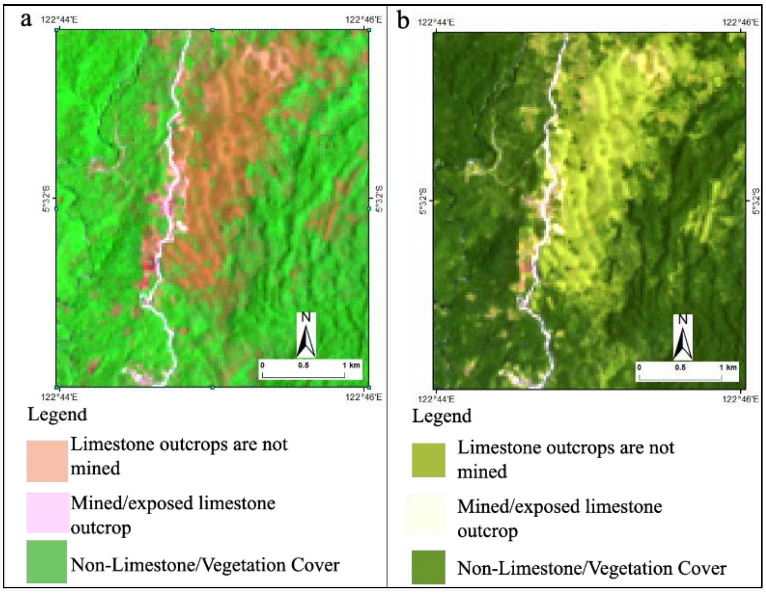

Fig. 3. a) Colour composite results of RGB: 753 and b) RGB: 762 Landsat 8 images

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The identification of the color of limestone outcrops based on band ratios and color composites shows varied and significant color differences from non-limestone outcrops. Apart from being based on band ratios and color composites, spectral identification in Landsat 8 images was performed to show the spectral characteristics of each band of Landsat 8 images. The limestone spectrum has high reflectance in band 6 (1.57-1.65 µm) and low reflections. low in band 7 (2.11-2.29 µm) in unmined limestone (Fig. 4a) and mined limestone (Fig. 4b). Non-limestone or vegetation showed the opposite reflectance, that is, low in band 6 (Fig. 4c).

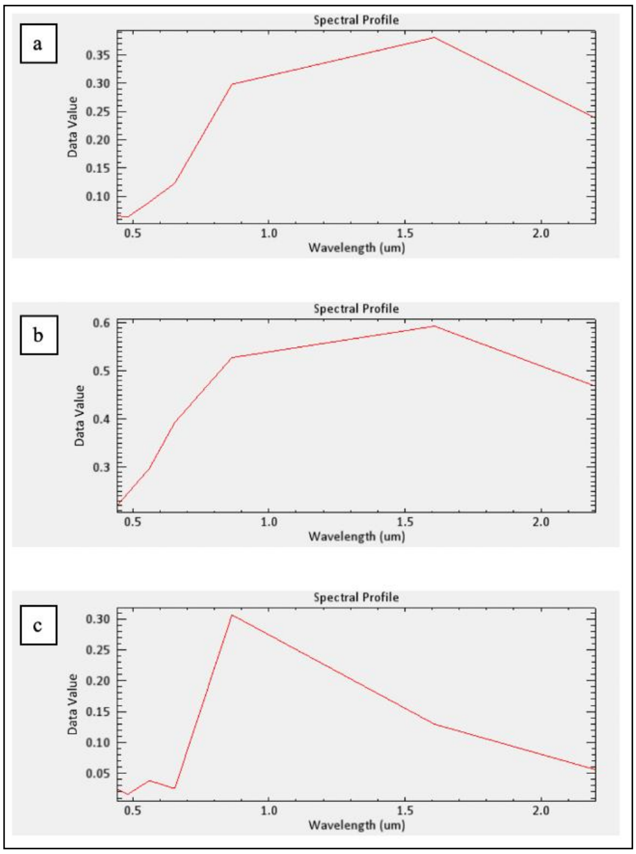

Fig. 4. a) Spectral curve of unmined limestone, b) spectral curve of mined or exposed limestone, and c) spectral curve of non-mined limestone.

3.3. NDVI (Normalized Differenced Vegetation Index)

Since the 1970s, researchers have employed the NDVI to extract vegetation index values from remote sensing data. Many scientists have utilized NDVI with the increasing availability of satellite and Unmanned Aerial Vehicle (UAV) remote sensing imagery (Venkata et al., 2022). Vegetated and non-vegetated areas can be distinguished using NDVI (Somayajula et al. 2021). NDVI values between -1 and +1. Water bodies had negative NDVI values (values close to -1). Values close to zero (-0.1 to 0.1) indicate barren sand and rock. NDVI values from 0.1 to 0.2 indicate the surface of the land or open land. Low NDVI with a value of 0.2-0.4 indicates bushes, grasslands, and NDVI values between 0.6 to 1.0 indicate dense vegetation in tropical rainforests.

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NDVI analysis of operational limestone quarries revealed values ranging from -0.1 to 0.05. The likelihood of limestone presence increases as NDVI values decrease, corresponding to the naturally white appearance of the mineral (Venkata et al., 2022). The NDVI threshold value for determining active mining limits ranges from -0.1 to 0.05 (Kotaridis et al, 2020). The formula used to calculate the

NDVI value through the red (red) and near-infrared (NIR) bands from the Landsat 8 spectral is as follows:

$$NDVI=Indeks(NIR,Red)=\frac{NIR-Red}{NIR+Red} \quad (1)$$

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The NDVI values in this research area show several types of land cover, namely, water bodies, open land, vegetated land, and limestone. Unmined limestone outcrops show a value of 0.3-0.5, mined or exposed limestone outcrops show an NDVI value of 0.1-0.2 and non-limestone or vegetation NDVI values of 0.6-1.0 (Fig. 5). Limestone areas that have been mined or exposed show low NDVI values, which shows that the land or vegetation cover has been disturbed by mining activities.

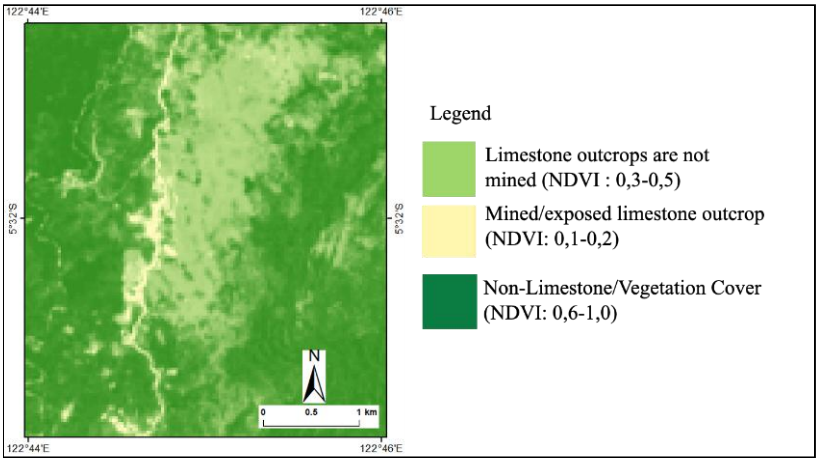

Fig. 5. NDVI of the study area

3.4. Field and Laboratory Studies

Field data were collected to validate the capability of Landsat 8 imagery to interpret and distribute limestone. Five locations were spread across the research area. ST.01 (Fig. 6a and 6b) is a limestone outcrop on the side of the road, based on observations in the field of greyish-white limestone. The thickness of the limestone at location ST. 01 was approximately 2-5 meters along the roadside (Fig. 6a). ST.02 (Fig. 6c and 6d) and ST.03 (Fig. 6e and 6f) are former community mining locations or limestone mining openings. The limestone at ST.02 (Fig. 6d) has the same color, namely, brownish white, and the exposed limestone is 2-5 meters thick. At ST.03 the limestone is up to 20 meters thick and has a brownish-white colour (Fig. 6f).

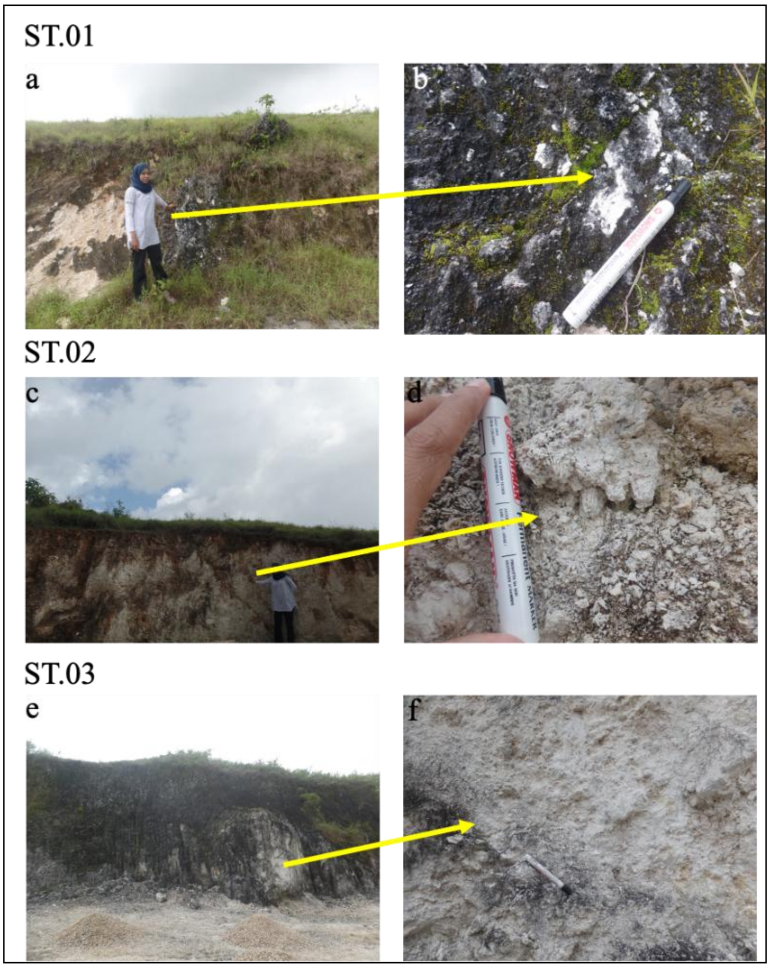

Fig. 6. Limestone outcrops in the study area ST 01 unmined limestone location, ST 02 and ST 03 mined limestone locations.

ST.04 (Fig. 7a and 7b) is a former limestone mine and the land used to extract heaped rock for building materials. The limestone outcrop at ST.04 is up to 15 m thick and brownish--white in color. At ST.05 (Fig. 7c and 7d), the limestone outcrop is located at a limestone mine operated by the local community. The opening of the limestone mine contained rock excavation holes. The limestone outcrop at ST.05 is grayish-brown-white with a thickness of 10-20 meters.

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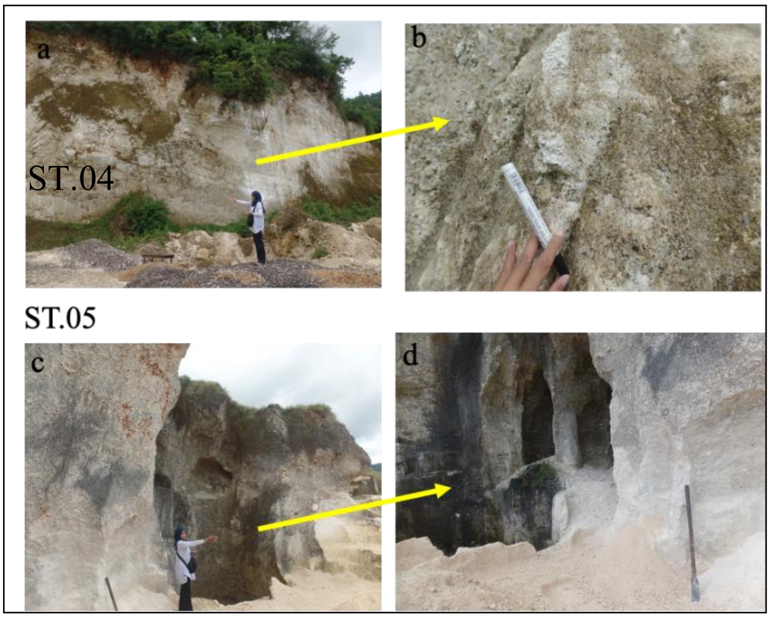

Fig. 7. Limestone outcrops in the ST 04 and ST 05 research areas at the mined limestone location

The laboratory analysis used in this study was X-Ray Fluorescence (XRF) analysis to determine the chemical content of each sample. For (XRF) the rock samples were ground and crushed to a powder (Alrawi et al., 2023; Salih et al, 2023). Table (2) shown t~~T~~he XRF results. ~~are shown in the following table~~

Table 2. Results of XRF analysis of limestone in the study area

No	Location	Minerals	Quantitative (%)
1	ST.01	CaO	98,36
		K_2O	0,66
		Ru_2O	0,45
		Fe_2O_3	0,41
		Ag_2O	0,05
		SrO	0,03
		CuO	0,02
2	ST.02	CaO	99,30
		Ru_2O	0,43
		Fe_2O_3	0,19
		Ag_2O	0,03
		CuO	0,02
3	ST.03	CaO	99,40

		Ru_2O	0,44
		Ag_2O	0,07
		4SrO	0,04
		CuO	0,02
4	ST.04	CaO	98,80
		K_2O	0,68
		Ru_2O	0,42
		Ag_2O	0,05
		CuO	0,02
5	ST.05	CaO	98,94
		K_2O	0,42
		Fe_2O_3	0,61
		CuO	0,02

The limestone sample analysis showed the presence of a high CaO content (>97%). The limestone is identified as coral seamount rock with a number of fossil fragments, and the limestone shows the presence of coral reefs rich in calcite minerals with fossil skeletons observed in limestone from shallow marine facies. XRF analysis of the samples confirmed reef limestone mineralization.

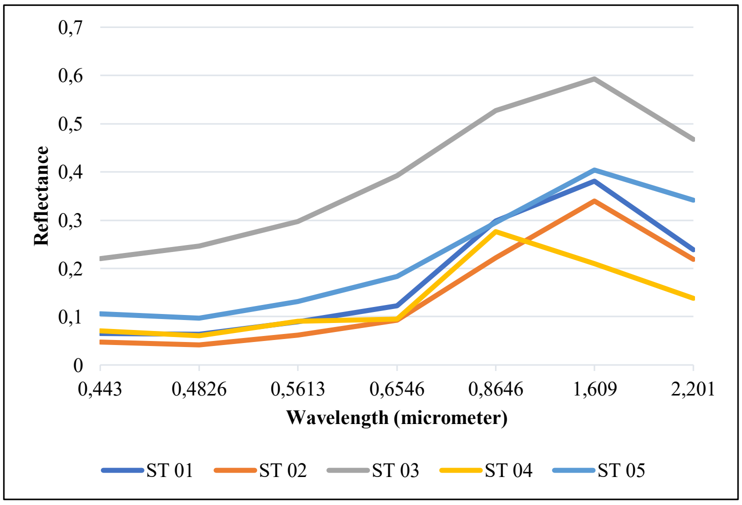

Fig. 8. Spectral graph of limestone at sampling locations in the field

The Limestone Spectral Analysis at each sampling location is shown in the graph (Fig. 8). The spectra show the differences in the reflectance of the chemical content of each sample. The dominant CaO content in the calcite minerals showed a different reflectance. Although the differences are not very significant in each sample, ST 04, which contains CaO 98.80 %, shows a decrease in reflectance at 6 (wavelength 1.57-1.65 μm), which is inversely proportional to ST 01, ST 02, ST 03 and ST 05 which shows high reflectance in band 6.

4. Conclusions

This research uses Landsat 8 to identify the distribution and potential of limestone in South Buton, Southeast Sulawesi Province, using the band ratio, color composite, and NDVI methods. The research results based on remote sensing data from Landsat 8 imagery divided the characteristics of limestone into three types: unmined limestone, mined limestone, and non-limestone. The color characteristics displayed from the band ratio and color composite results show significant color differences from limestone outcrops in the study area. The NDVI method shows land or areas that are disturbed by limestone mining activities, so the NDVI value is low because the vegetation value is low or the vegetation cover is disturbed due to mining activities in the research area. The spectral curve of each Landsat 8 image band showed high reflectance in band 6 for limestone and low reflectance in band 6 for non-limestone.

The results of the XRF analysis of limestone samples taken in the research area show a high CaO content, which indicates a dominant calcite mineral content. The spectral curve of each Landsat 8 image band was different for each CaO content in the limestone sample. However, the difference was not significant, indicating that the CaO content was not significantly different in each sample.

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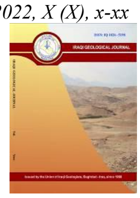

Characteristics of Limestone Outcrops Based on Landsat 8 Image and Geochemical Analysis in South Buton Regency, Southeast Sulawesi Province, Indonesia

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Abstract

Identification of limestone outcrops aims to determine the potential location, distribution, and quality of limestone. With advances in remote sensing technology, limestone identification can be carried out using Landsat 8 OLI satellite imagery data. This study aims to identify the characteristics of the limestone potential area with the Landsat 8 image processing method used is band ratio, color composite and NDVI. Each result of the Landsat 8 image processing method can show the characteristics and distribution of limestone outcrops based on color and spectral differences from Landsat 8 image data. Spectral analysis of Landsat 8 image data was carried out to see the reflectance level of each band which can show differences in unexposed limestone outcrops, or unmined and exposed or mined limestone. The NDVI method can show potential locations of limestone whose vegetation has been disturbed by mining activities. The chemical characteristics of limestone can be determined by geochemical testing of X-Ray Fluorescence (XRF) limestone samples. Of geochemical analysis, XRF is carried out in the laboratory to determine the main chemical elements and trace elements of the rock. This research will help industrial engineers to explore the potential of limestone in south Buton.

Keywords: limestone; Landsat-8; Band Ratios; Colour Composite; NDVI

1. Introduction

Limestone in the South Buton area is widespread and clearly exposed. One of the exposed limestone is the Rongi Hill, which is included in the reef limestone Wapulaka Formation. Southeast Sulawesi Province is one of the prospective areas for limestone exploration and mining. The area is marked by the existence of two mining business permit areas located in South Buton. As infrastructure, population, and regional development increase, the exploitation of limestone is increasingly supporting the government and society to meet infrastructure needs. Limestone is the primary raw material required for drainage and infrastructure (Soni and Nema, 2021).

Geological mapping is important for any geological work and provides vital information about the geology of the area, such information can be used for several proposes (Bety, 2022). Remote sensing is the initial method used for geological mapping that covers a large area. This method is inexpensive and time consuming for obtaining surface rock information (Abdelmalik, 2020). The rapid advancement of remote sensing techniques and technologies is increasingly beneficial to researchers across various disciplines. A significant use case can be found in geological studies, where these techniques are

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employed for mapping structural features and rock types, as well as identifying and locating economically significant mineral deposits (Amer et al, 2010; Gad, S., and Kusky, T., 2006). The processing of remote sensing data requires many algorithms and mathematics/statistics that have been developed and used to improve the interpretation of geological features/targets. In the fields of lithology mapping and mineral exploration, two techniques stand out as the most effective and widely used: band ratio and principal component analysis (PCA) (Abdelmalik, 2020; Bety et al, 2024). Spectral integration of remote sensing data from each studied target stands as the most crucial remote sensing technique. The spectral curve of remote-sensing data contains information that reveals the physical and chemical properties of each object, target, or rock under examination. Studies have demonstrated that the distinctive spectral patterns of rocks and minerals are produced by mechanisms linked to electron movement and transition (Hunt, 1977). The spectral signature of remote sensing data is influenced not only by the rock's chemical makeup but also by its physical characteristics, such as porosity and grain size (Hunt, 1977). The distribution of rocks and minerals on the surface was determined and interpreted using these characteristic spectral patterns (Salih, 2023)

The Landsat 8 OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor) were introduced in 2013, marking the recent enhancements to the Landsat satellite program. This iteration of Landsat features decreased bandwidth and incorporates two new spectral bands. Multiple studies have shown Landsat 8's capability in delineating geological structures and detecting zones of hydrothermal alteration (Benaissi et al., 2022; Lu and He, 2022, Osinowo et al., 2021; Salih, 2023), which show that the spectral data from the Landsat 8 band are very helpful in lithology mapping. Regional geological mapping was performed by Pour and Hashim (2011) utilizing Landsat 8 and ASTER satellite imagery, employing the band-ratio index technique. In lithology mapping, the textural characteristics of Landsat 8 images prove beneficial (Wei et al., 2016). In addition to the band ratio method, the color combination method can be used for geological mapping, as was done by Pour et al. for hydrothermal alteration mapping using Landsat 8 (Beiranvand & Hashim, 2023).

Limestone mining locations usually experience land cover changes that impact long-term land and environmental conditions. The normalized differential vegetation index (NDVI) method can be used to assess changes in vegetation cover due to changes in land cover caused by active limestone mines. Venkata et al. used Landsat 8 to calculate the NDVI value to detect limestone mining locations and their impact on environmental changes (Venkata et al., 2022).

The research sought to evaluate limestone potential in South Buton, Southeast Sulawesi Province, utilizing Landsat 8 imagery through the application of band ratio, color combination, and NDVI techniques. This research was also carried out by field studies to obtain several limestone samples from locations that were not limestone mining locations and limestone samples from active or former limestone mining sites. Spectral analysis was performed to determine the reflection level of each band indicated by the limestone at the study site. This research is expected to yield results that will prove valuable to researchers, industry professionals, and the environment in the areas of limestone exploration and ecological conservation. By contributing to the development of eco-conscious mining sites, this study aims to promote long-term sustainability in the sector.

2. Materials and Methods

2.1. Study Area

The research area was the South Buton Regency, Southeast Sulawesi Province. The selected area is the Wapulaka Formation, which is a limestone formation of algae and coral reefs. The age of formation is late Pliocene to Pleistocene and consists of bioclastic limestone (Sikumbang, 1995). The limestone in the study area is characterized by coastal steps that rise to the surface because the geology of the southern island of Buton is bordered by the Flores Sea (Figure 1). Based on ESDM (Energy and

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Mineral Resources) data at https://geoportal.esdm.go.id/minerba/ there are two limestone IUPs (Mining Business Permits) for industries located in South Buton Regency. The IUP remained in the exploratory stage. The research area was located at geographical coordinates 122°40' – 122°55' East Longitude and 5°45'-5°25' South Latitude.

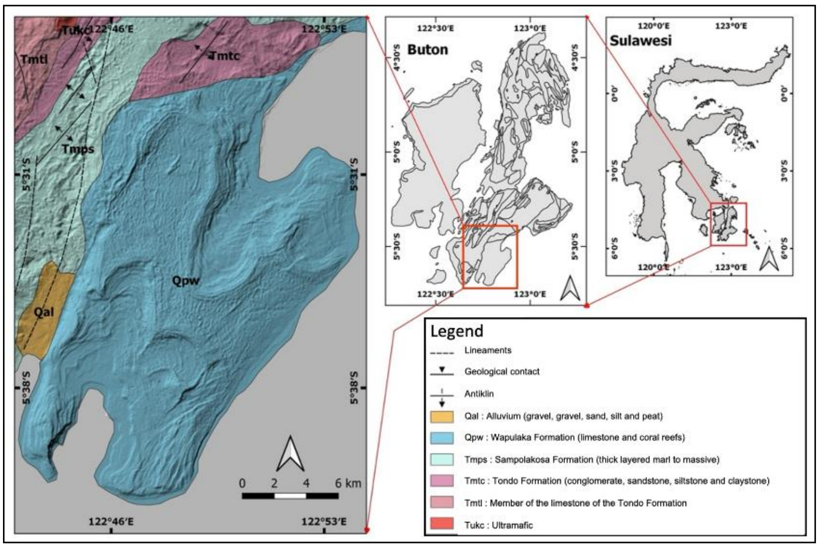

Fig. 1. Geological map of the research area in South Buton, Southeast Sulawesi Province

2.2. Data

For this study, the geospatial information was acquired from the United States Geological Survey (USGS) Earth Explorer platform, accessible at https://earthexplorer.usgs.gov/. This satellite features 11 bands, encompassing visible, infrared, and thermal ranges. Table 1 shos the spectral specifications and spatial resolution of the Landsat-8 OLI (Operational Land Imager). VNIR and SWIR bands have a spatial resolution of 30 m, while the thermal band has a resolution of 100 m. For limestone studies, the VNIR and SWIR bands are utilized to perform ratios, color composites, and NDVI calculations. This study employed Landsat 8 data from Path 112/ Row 64, captured on December 10, 2015. The imagery underwent geometric correction and georeferencing to the UTM (51 South Zone) projection using the WGS-84 datum.

Table 1. The Spectral Characteristics and Spatial Resolution of Landsat Band 8

	No Band	**wavelength (µm)**	**Spatial Resolution (m)**	**Band**
VNIR	1	0,43-0,45	30	Ultra-Blue (Coastal/Aerosol)
	2	0,45-0,51		Blue
	3	0,53-0,59		Green
	4	0,64-0,67		Red
	5	0,85-0,88		NIR
	8	0,50-0,68	15	Panchromatic
SWIR	9	1,36-1,38	30	Cirrus
	6	1,57-1,65		SWIR 1
	7	2,11-2,29		SWIR 2
TIR	10	10,60-11,19	100	TIR 1
	11	11,50-12,51		TIR 2

2.3. Pre-Processing and Processing Landsat 8

This study employed Landsat 8 to examine limestone's spectral properties, colour composite, and NDVI values. The most sensitive bands for limestone detection were identified using Landsat 8 bands. To create more interpretable images for limestone identification in the study area, these selected spectral bands were used in ratio calculations, composite color image generation, and NDVI computations. Before analyzing limestone presence with Landsat 8 data, it was crucial to conduct pre-processing steps using ENVI software, specifically focusing on radiometric and atmospheric corrections. This pre-processing phase eliminated atmospheric interference effects, yielding more accurate measurements of reflectivity, emissivity, surface physical properties, and surface temperature (Muchsin et al., 2018). The process of radiometric correction involves converting Digital Numbers (DN) to radians and/or reflectance, followed by atmospheric adjustment using the FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes) tool within ENVI software. Subsequently, the Landsat image is trimmed to match the study area's boundaries.

The band ratio, color composite, and NDVI processes are the next processes after data preprocessing is complete. This process is a technique for improving the image quality for clearer interpretation targets, especially for improving the image quality targets in limestone lithology mapping. In remote sensing analysis, the band ratio technique compares two spectral bands for a single color in the RGB (Red, Green, Blue) system, resulting in a specific rock surface appearance. Following this, a color composite process is employed, which combines three colors to map lithological zones. The final step in processing Landsat 8 imagery involves generating an NDVI (Normalized Difference Vegetation Index) map by applying the NDVI algorithm to the appropriate Landsat 8 image bands.

These techniques collectively enhance the visual interpretation of geological features and vegetation cover. The band ratio method highlights specific rock compositions, while color composites provide a comprehensive view of lithological variations. NDVI mapping further complements the analysis by quantifying vegetation density and distribution, which can indirectly inform about underlying geological conditions.

The next stage is to identify the chemical content of limestone samples taken in the field using XRF. The XRF analysis will provide detailed information on the elemental composition of the limestone, allowing for a more comprehensive understanding of its geological characteristics. This data can then be correlated with the BR, CC and NDVI mapping results to establish potential relationships between vegetation patterns and specific mineral content in the outcrop limestone. By integrating these multiple lines of evidence, researchers can develop a more robust model of the geological landscape and its influence on surface vegetation.

3. Results and Discussion

3.1. Band Rasio (BR)

The Band Ratio method is the remote sensing enhancement method applied in this study. The BR method enchances the contrast between targets or features based on dividing the reflectance for the one band pixels by the same picels in other band (Amer et al. 2010; Nasir et al. 2014). This approach is particularly effective in identifying features or materials that are not easily discernible in the original band. Additionally, the band ratio transformation proves valuable in detecting minerals associated with hydrothermal alteration processes.(Pour et al., 2011; Rockwell & Hofstra, 2008; Di Tomasso & Rubinstein, 2007). Two band ratios for RGB images have been used for mapping lithology and hydrothermal alteration: Sabin ratios (4/2, 6/7, and band 10 as RGB and 4/2, 6/5, and 6/7 as RGB) (Sabins, 1999). The mineralized limestone spectrum shows high reflectance in band 6 Landsat 8 OLI and low reflectance in band 7, which is due to weak alteration of gypsum and clay. Therefore, the ratio (7/6) of Landsat 8 OLI can be used to extract mineralized limestone (Amer et al., 2010; Bedini, 2011). The two bands compared for each RGB color were chosen to better extract the lithological units. The ratios of the two bands used in this research to extract limestone were R5/4, G6/5, and B7/2, and the second band ratios used in this research were R6/5, G 7/6, and B 4/7 (Fig. 2). Figure 2 shows color variations for unmined and mined limestone outcrops, in addition to colors for non-limestone or identified as forest or vegetation.

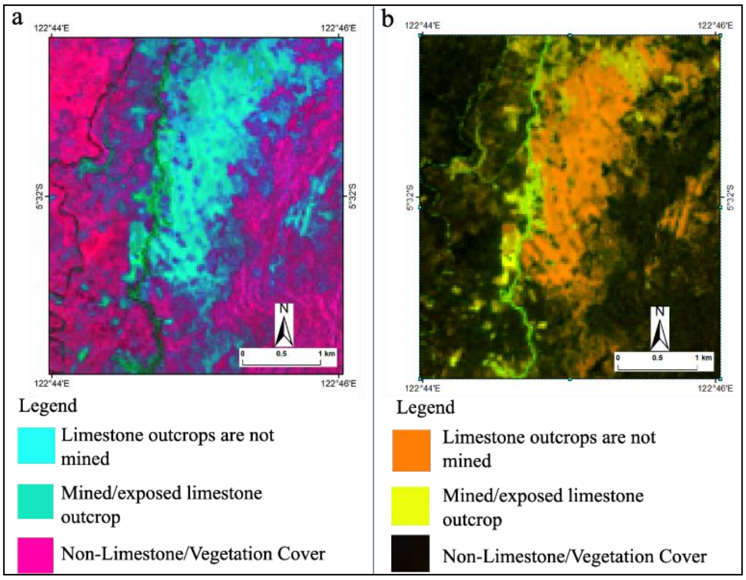

Fig. 2. a) R5/4, G6/5, and B7/2 band ratio results and b) R6/5, G7/6, and B 4/7 band ratio of Landsat 8 image

3.2. Color Composite (CC)

The generation of color composites depends on the spectral properties of modified rocks and minerals. Clay and carbonate minerals exhibit absorption features in the 2.1 to 2.4 µm range, while reflectance is noted between 1.5 and 1.7 µm (Ourhzif et al, 2019). Following an analysis of various band ratio combinations, two RGB color composite schemes were chosen to improve the detection of existing lithological units and mineralization areas (Amer et al., 2010; Crouvi et al., 2006; Moghtaderi & Zadeh, 2007; Di Tomasso & Rubenstein, 2007). Landsat 8 OLI employs bands R4, G3, and B2 for natural RGB color composites. This research utilized an RGB color composite of 753 to identify limestone (Fig. 3a). The wavelength ranges for these bands are: 2.11-2.29 µm for band 7 (SWIR 2), 0.85-0.88 µm for band 5 (Near Infrared), and 0.53-0.59 µm for band 3 (Green). Additionally, an alternative RGB color composite of 762 was used to detect limestone presence (Fig. 3b), band 7 (SWIR 2) has a wavelength of 2.11-2.29 µm, band 6 (SWIR 1) has a wavelength of 1.57-1.65 µm, and band 2 (Blue) has a wavelength of 0.45-0.51 µm (Heriansyah et al, 2022).

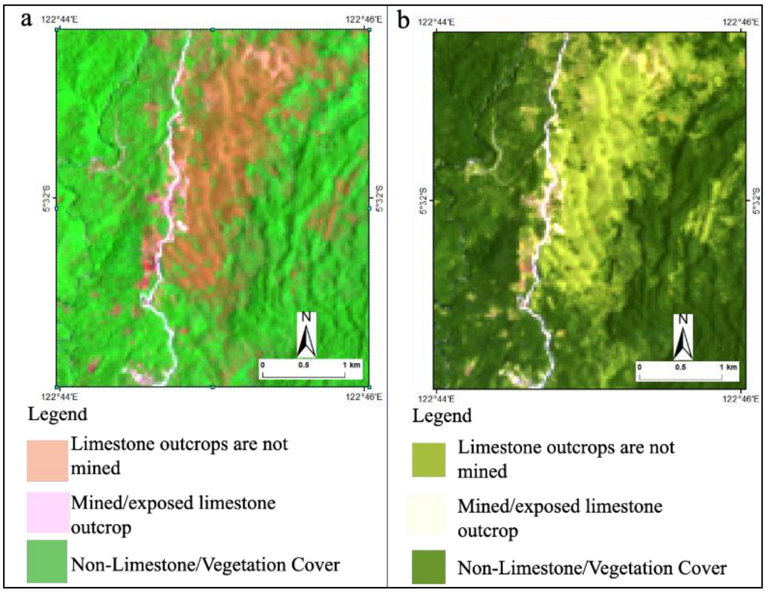

Fig. 3. a) Colour composite results of RGB: 753 and b) RGB: 762 Landsat 8 images

The identification of the color of limestone outcrops based on band ratios and color composites shows varied and significant color differences from non-limestone outcrops. Apart from being based on band ratios and color composites, spectral identification in Landsat 8 images was performed to show the spectral characteristics of each band of Landsat 8 images. The limestone spectrum has high reflectance in band 6 (1.57-1.65 μm) and low reflections. low in band 7 (2.11-2.29 μm) in unmined limestone (Fig. 4a) and mined limestone (Fig. 4b). Non-limestone or vegetation showed the opposite reflectance, that is, low in band 6 (Fig. 4c).

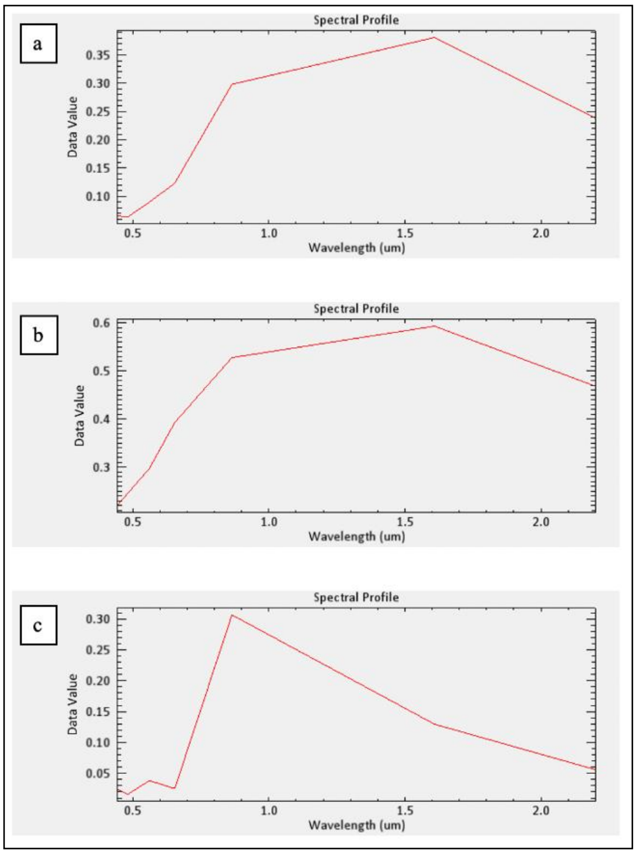

Fig. 4. a) Spectral curve of unmined limestone, b) spectral curve of mined or exposed limestone, and c) spectral curve of non-mined limestone.

3.3. NDVI (Normalized Differenced Vegetation Index)

Since the 1970s, researchers have employed the NDVI to extract vegetation index values from remote sensing data. Many scientists have utilized NDVI with the increasing availability of satellite and Unmanned Aerial Vehicle (UAV) remote sensing imagery (Venkata et al., 2022). Vegetated and non-vegetated areas can be distinguished using NDVI.(Somayajula et al. 2021). NDVI values between -1 and +1. Water bodies had negative NDVI values (values close to -1). Values close to zero (-0.1 to 0.1) indicate barren sand and rock. NDVI values from 0.1 to 0.2 indicate the surface of the land or open land. Low NDVI with a value of 0.2-0.4 indicates bushes, grasslands, and NDVI values between 0.6 to 1.0 indicate dense vegetation.

NDVI analysis of operational limestone quarries revealed values ranging from -0.1 to 0.05. The likelihood of limestone presence increases as NDVI values decrease, corresponding to the naturally white appearance of the mineral (Venkata et al., 2022). The NDVI threshold value for determining active mining limits ranges from -0.1 to 0.05 (Kotaridis et al, 2020). The formula used to calculate the

NDVI value through the red (red) and near-infrared (NIR) bands from the Landsat 8 spectral is as follows:

$$NDVI=Indeks(NIR,Red)=\frac{NIR\text{-}Red}{NIR+Red}=\frac{(B5-B4)}{(B5+B4)} \tag{1}$$

The NDVI values in this research area show several types of land cover, namely, water bodies, open land, vegetated land, and limestone. Unmined limestone outcrops show a value of 0.3-0.5, mined or exposed limestone outcrops show an NDVI value of 0.1-0.2 and non-limestone or vegetation NDVI values of 0.6-1.0 (Fig. 5). Limestone areas that have been mined or exposed show low NDVI values, which shows that the land or vegetation cover has been disturbed by mining activities.

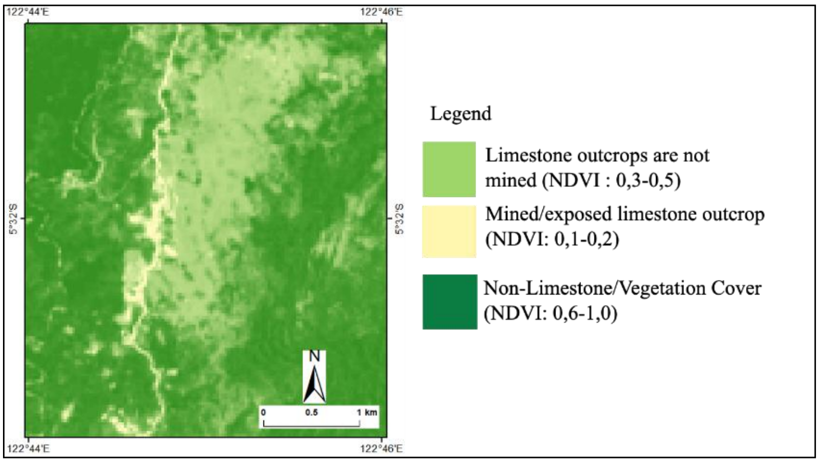

Fig. 5. NDVI of the study area

3.4. Field and Laboratory Studies

Field data were collected to validate the capability of Landsat 8 imagery to interpret and distribute limestone. Five locations were spread across the research area. ST.01 (Fig. 6a and 6b) is a limestone outcrop on the side of the road, based on observations in the field of greyish-white limestone. The thickness of the limestone at location ST. 01 was approximately 2-5 meters along the roadside (Fig. 6a). ST.02 (Fig. 6c and 6d) and ST.03 (Fig. 6e and 6f) are former community mining locations or limestone mining openings. The limestone at ST.02 (Fig. 6d) has the same color, namely, brownish white, and the exposed limestone is 2-5 meters thick. At ST.03 the limestone is up to 20 meters thick and has a brownish white colour (Fig. 6f)

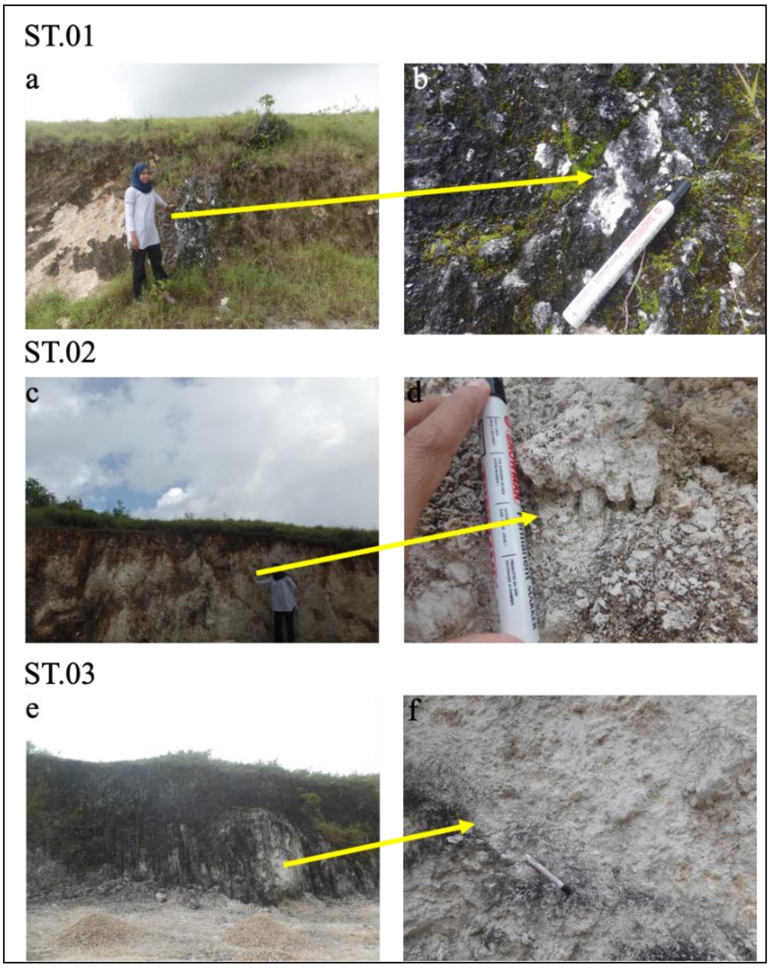

Fig. 6. Limestone outcrops in the study area ST 01 unmined limestone location, ST 02 and ST 03 mined limestone locations.

ST.04 (Fig. 7a and 7b) is a former limestone mine and the land used to extract heaped rock for building materials. The limestone outcrop at ST.04 is up to 15 m thick and brownish white in colour. At ST.05 (Fig. 7c and 7d), the limestone outcrop is located at a limestone mine operated by the local community. The opening of the limestone mine contained rock excavation holes. The limestone outcrop at ST.05 is grayish-brown-white with a thickness of 10-20 meters.

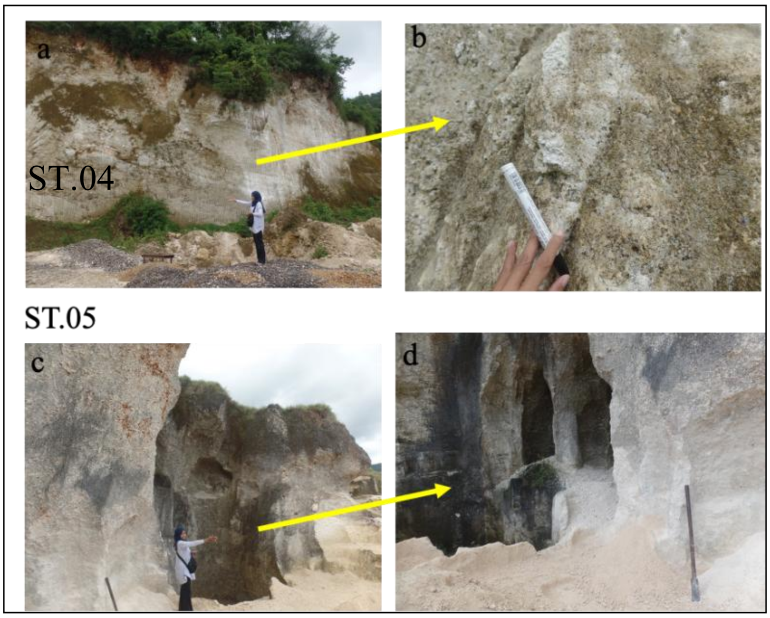

Fig. 7. Limestone outcrops in the ST 04 and ST 05 research areas at the mined limestone location

The laboratory analysis used in this study was X-Ray Fluorescence (XRF) analysis to determine the chemical content of each sample. For (XRF) the rock samples were ground and crushed to a powder (Alrawi et al., 2023; Salih et al, 2023). Table (2) shown the XRF results.

Table 2. Results of XRF analysis of limestone in the study area

No	Location	Minerals	Quantitative (%)
1	ST.01	CaO	98,36
		K_2O	0,66
		Ru_2O	0,45
		Fe_2O_3	0,41
		Ag_2O	0,05
		SrO	0,03
		CuO	0,02
2	ST.02	CaO	99,30
		Ru_2O	0,43
		Fe_2O_3	0,19
		Ag_2O	0,03
		CuO	0,02
3	ST.03	CaO	99,40
		Ru_2O	0,44

		Ag_2O	0,07
		4SrO	0,04
		CuO	0,02
4	ST.04	CaO	98,80
		K_2O	0,68
		Ru_2O	0,42
		Ag_2O	0,05
		CuO	0,02
5	ST.05	CaO	98,94
		K_2O	0,42
		Fe_2O_3	0,61
		CuO	0,02

The limestone sample analysis showed the presence of a high CaO content (>97%). The limestone is identified as coral seamount rock with a number of fossil fragments, and the limestone shows the presence of coral reefs rich in calcite minerals with fossil skeletons observed in limestone from shallow marine facies. XRF analysis of the samples confirmed reef limestone mineralization.

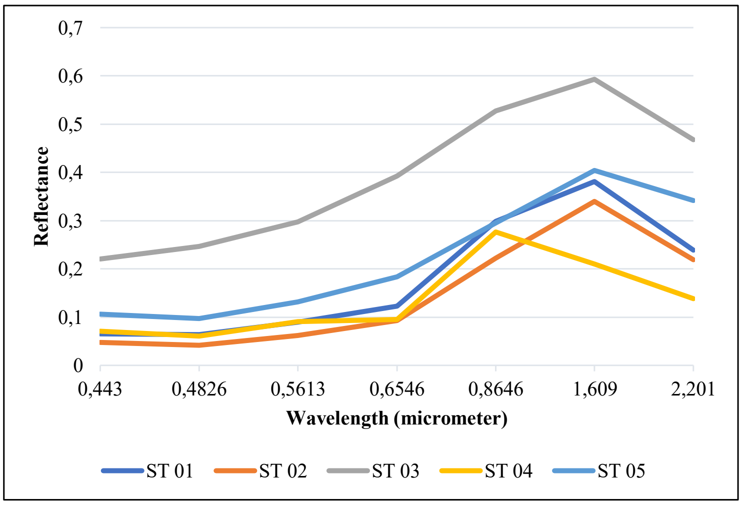

Fig. 8. Spectral graph of limestone at sampling locations in the field

The Limestone Spectral Analysis at each sampling location is shown in the graph (Fig. 8). The spectra show the differences in the reflectance of the chemical content of each sample. The dominant CaO content in the calcite minerals showed a different reflectance. Although the differences are not very significant in each sample, ST 04, which contains CaO 98.80 %, shows a decrease in reflectance at 6 (wavelength 1.57-1.65 μm), which is inversely proportional to ST 01, ST 02, ST 03 and ST 05 which shows high reflectance in band 6.

4. Conclusions

This research uses Landsat 8 to identify the distribution and potential of limestone in South Buton, Southeast Sulawesi Province, using the band ratio, color composite, and NDVI methods. The research results based on remote sensing data from Landsat 8 imagery divided the characteristics of limestone into three types: unmined limestone, mined limestone, and non-limestone. The color characteristics displayed from the band ratio and color composite results show significant color differences from limestone outcrops in the study area. The NDVI method shows land or areas that are disturbed by limestone mining activities, so the NDVI value is low because the vegetation value is low or the vegetation cover is disturbed due to mining activities in the research area. The spectral curve of each Landsat 8 image band showed high reflectance in band 6 for limestone and low reflectance in band 6 for non-limestone.

The results of the XRF analysis of limestone samples taken in the research area show a high CaO content, which indicates a dominant calcite mineral content. The spectral curve of each Landsat 8 image band was different for each CaO content in the limestone sample. However, the difference was not significant, indicating that the CaO content was not significantly different in each sample.

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