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The Potential of Remote Sensing Data for Oil And Gas Exploration in Indonesia: a Review

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ABSTRACT - Oil and gas are important commodities in Indonesia and remain the main source for energy in various sectors. Therefore, the government aim to produce 1 million barrels of oil per day (BOPD) by 2030. To achieve this goal, exploration work is needed to discover new reserves and maintain production in existing fields. This study reviews the experience of oil and gas exploration in Indonesia using remote sensing data and the potential of using remote sensing data for oil and gas exploration through surface anomalies. Surface anomalies are changes or deviations that occur on the surface as the result of the presence of oil and gas underneath. These anomalies included vegetation growing stunted, yellowing or dying, changes in the quantity and composition of clay minerals, iron oxide, increased concentrations of hydrocarbons, helium, radon, carbon dioxide, microbes, and the presence of paraffin dirt formation, as well as geomorphological changes. This study aims to assess and explain the capabilities of remote sensing data in Indonesia for oil and gas exploration. The results show that remote sensing can be used for the initial exploration of oil and gas by delineating areas of potential oil and gas traps based on topographical anomalies and geological mapping integrated with gravity data and increasing confidence in the presence of oil and gas in the subsurface based on surface anomalies. These results are expected that the usefulness of remote sensing can be used to support oil and gas exploration in Indonesia and can be recognized and used for oil and gas activities by utilizing existing methods and discovering methods for data processing and their applications.

Keywords: remote sensing, exploration, oil and gas, geological mapping, surface anomaly

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INTRODUCTION

The development of remote sensing, began with the discovery of infrared wavelengths by Sir William Herschel in 1800, followed by practical photography in 1839. After 1972, remote sensing developed rapidly since the launch of Landsat Campbell and Wynne., (2011). Remote sensing is as a science, art and technology that aims to obtain information about objects and their environment without direct contact using the electromagnetic spectrum, captured by sensors on platforms and analyzed using photo interpretation techniques, image interpretation and advanced image processing systems Campbell and Wynne., (2011), Fussell et al., (1986), Lillesand et al., (2015). There are five elements to explain the remote sensing, namely collecting, obtaining or recording non-contacted data; using the electromagnetic spectrum; using instruments; using platforms; and symbolic transformation of data collected through computer-based interpretation and/or pattern recognition techniques Fussell et al., (1986).

Remote sensing has become a topic interest to scientists in variety of disciplines over the past decade, which remote sensing widely recognized as a significant contributor to several scientific fields Marceau and Hay., (1999). Applications of remote sensing data can be used for land-use and cover mapping, agriculture, soil mapping, urban planning, archaeological, military observation, and geomorphological survey, land cover change studies, deforestation, vegetation dynamics, water quality dynamics, and urban growth Aggarwal., (2004). Remote sensing is an ideal source of data for various activities because it provides information over a large area and at short time intervals Van Westen., (2000). The present of remote sensing data also makes it easier to obtain geologic information over large areas much more quickly than with conventional techniques Goetz and Rowan., (1981). The application of remote sensing in the field of geology is very diverse and broad, including geological mapping and mineral exploration Shirazy et al., (2021).

In the oil and gas sector, remote sensing is highly useful and has proven to be an effective tool for upstream and downstream oil and gas operations, including well planning infrastructure assessment, exploration through area recognition at a regional scale and spectral analysis to assess rock outcrops and oil and gas seeps Lord., (2017). Remote sensing in oil and gas exploration can be used to identify lithological units and geological structures, as well as geomorphological features for supporting the seismic survey and explore the potential of oil and gas deposits and water resources Peña and Abdelsalam., (2006), Shirazy et al., (2021). Remote sensing capabilities that are evolving through new sensors and vectors such as drone based- hyperspectral cameras or other systems, are playing an increasingly important role for application in the oil and gas industry for exploration, production and environmental monitoring Dubucq et al., (2021).

This study was conducted to assess and present the capabilities of remote sensing in the context of oil and gas exploration. This is to provide an overview of the use of remote sensing in oil and gas exploration, particularly in Indonesia and worldwide. It is hoped that in the future, remote sensing will be better known and researched for oil and gas activities so that new methods can be found, both for processing and applying remote sensing data for oil and gas exploration.

Challenges for Future Oil and Gas Exploration

An overview of oil and gas exploration in Indonesia during the period 2000 – 2015 shows an increase in oil and gas exploration areas from 110 in 2003 to 312 in 2015, with a subsequent increase in the number of 2D and 3D seismic surveys, making them the largest in Southeast Asia. In addition, a total of 974 exploration wells were drilled with 310 wells discovering hydrocarbons and a success rate of 46% Satyana., (2016). However, oil and gas production in Indonesia has not increased; in fact, it has decreased every year at a rateof about 4.41% per year Daryanto and Nurfadilah., (2018). However, the use of remote sensing technology for oil and gas has not been used optimally. Remote sensing is only used as supporting data for oil and gas exploration for companies and R&D institutions.

There are 128 sedimentary basins in Indonesia, whereas twenty basins have produced oil and gas, twenty seven basins discovering oil and gas, eight prospecting basins with proven petroleum systems, six basins with hydrocarbon indications, twenty six basins with geological and geophysical data, and forty one basins with no/limited data availability Geological Agency., (2009). The situation leads Indonesia to face challenges in managing energy and oil and gas exploration in the future. There are three challenges that Indonesia must consider in national energy management in the future, namely energy security (the reliability of primary supply to meet energy demand), energy equity (price affordability); and the environment (the release of greenhouse gases from the energy sector) Rahman et al., (2023).

Energy security is the most important issue that must be met to avoid dependence on oil and gas imports, as demand is increasing but oil and gas reserves continue to decline Gunningham., (2013). Efforts to reduce the use of fossil fuels by converting them to electricity are continuing, but the problem is that electrical in Indonesia still uses gas and coal Rahman et al., (2023). Therefore, oil and gas exploration in Indonesia continues by exploring all available opportunities, including heavy oil Susantoro et al., (2022), unconventional hydrocarbon Hakim., (2018), Haris et al., (2018), coalbed methane Harrington., (2016), gas hydrates Ginanjar et al., (2014), and enhancement oil recovery to sustain production in oil and gas fields with polymers, microbial bacteria, surfactants and other ingredients Abidin et al., (2012,Halim et al., 2009).

There indication of oil and gas potential in Indonesia is still large, but unattractive for investors to explore. Moreover, the exploration targets are remote areas, deep sea and marginal fields (Yudi Tryono, 2016). On the other hand, the discovery of oil and gas fields on a large scale is becoming difficult, and the existing oil and gas fields are relatively old and already in the secondary production stage, which leads to a further decline in production (Abdurrahman, 2016). Even though Indonesia still relies on oil and gas energy and hopes to reach production of 1 million barrels of oil per day in 2030 Fitnawan et al., (2021), Hendraningrat et al., (2021).

History of Oil and Gas Exploration in Indonesia Using Remote Sensing

The application of remote sensing for oil and gas exploration in Indonesia began in 1935 with the use of aerial photography for geological mapping in Papua Sudrajat., (1990). The use of remote sensing data is rapidly increasing with the Landsat series and radar data. Several studies conducted using remote sensing data are detailed in Table 1. The use of remote sensing data for oil and gas exploration until 2004 was mainly for geological mapping (lithology and structure/linets) to support seismic activities, geological surveys and the petroleum system concept Table 1. The use of remote sensing data for geologic mapping continued through 2010 with a geologic study conducted by Susantoro., (2009b, 2009a) and Susantoro et al., (2009) in Bojonegoro and surrounding areas, and Suliantara et al., (2010) in Kutai basin.

The use of remote sensing data for oil and gas exploration in Indonesia then developed through surface anomaly studies, beginning with studies of topographic anomalies in the Indramayu region and surrounding areas Crystiana et al., (2014, 2015). This study was followed by the study for oil spectral mapping in the laboratory using a spectrometer Susantoro et al., (2016), vegetation stress anomaly in the Tugu Barat field Susantoro et al., (2017, 2018), clay mineral changes in oil and gas fields Susantoro et al., (2020), and heavy oil exploration in the Central Sumatra Basin Suliantara et al., (20210, Susantoro, et al., (2022). An integrated study of remote sensing and gravity data using a geographic information system was also conducted to identify potential areas for oil and gas exploration in the Memberamo Basin. Susantoro and Suliantara., (2014).

Oil and gas exploration using remote sensing data is becoming increasingly developed complex method to improve the accuracy of oil and gas exploration. These methods include (1) Satellite Based Remote Deep Sensing Survey (SBRDSS), a method of searching for hydrocarbons and minerals using by Russian Satellite based remote sensing methods combined with "POISK" instruments based on field research conducted by the Sevastopol Nuclear Institute; (2) Thermovision Tomography (TVT) is based on processing an image in the thermal infrared wavelength range of 8-14 microns. This allows calculation of the effective density of thermal radiation flux and block-fault structures at a given depth, spatial and temporal dynamics of the normalized stress index of vegetation in correlation with the deep structure of the geological environment; and (3) Sub Terrain Prospecting (STeP) which combines eight independent remote sensing and analysis methods; it is characterized by the processing, and interpretation of satellite, analytical, and cartographic dataStudies using the STeP method were conducted in the Lampung region. The results show that there are prospecting areas that should be followed up with seismic activities Ariadji et al., (2017).

Table 1
Utilization of Remote Sensing Data for Oil and Gas Exploration in Indonesia.

No	Year	Data	Goals	Areas	References
1	1935	Radar & Air photo	Geological mapping	Papua	(Sudrajat, 1990)
2	1976	Landsat	Geological mapping	Rembang (Java)	(Rivereau and Fontanel, 1976)
3	1981	Synthetic aperture radar (SAR)	Structural interpretation	Mahato-Mandian Block, Central Sumatra basin	(Correa, 1981)
4	1983	Shuttle imaging Radar (SIR-A)	Terrain & structural interpretation	Kalimantan & Papua	(Floyd F Sabins, 1983)
5	1985	Shuttle imaging Radar (SIR-A & SIR-B)	Geological mapping	Kendilo river, Kalimantan	(F F Sabins and Ford, 1985)
6	1987	Side-Looking Airborne Radar (SLAR)	Geological mapping	The northwestern part of the Kutai Basin, Kalimantan	(Weerd et al., 1987)
7	1988	Satellite imagery & Aerial photographic	Geological mapping as the basis for further exploration effort	Timor Island	(Kartaadiputra and Samuel, 1988)
8	1988	Synthetic aperture radar (SAR)	Geological Mapping (lineaments)	North Sumatra Basin	(Sosromihardjo, 1988)
9	1989	Landsat TM & Aerial photographic	Geological mapping	Timor island	(Mulhadiono and Simbolon, 1988)
10	1989	Synthetic aperture radar (SAR)	Recognize lithology & topographic feature	East Kalimantan	(Setio et al., 1989)
11	1989	Synthetic aperture radar (SAR)	Morpho-structural interpretation	Upper Kutai basin	(Wain and Berod, 1989)
12	1991	SLAR & Landsat	Geomorphology	Buton island, S. E. Sulawesi	(Davidson, 1991)
13	1991	Airborne Laser Fluorosensor (ALF)	Natural seepage	Sumatra forearc, Java forearc, Biliton, Selayar, Spermonde and North Makassar, Bone, Gorontalo & Halmahera basin	(Thompson et al., 1991)
14	1993	Landsat TM	Geological information	Central & East Java	(Mudjito et al., 1993)
15	1993	Landsat TM and Aerial photographs	Geological Mapping	West Timor, Nusa Tenggara Timur	(Jacobson and Sani, 1993)
16	1993	SLAR, airphotos & satellite imagery	Structural geology	North Irian	(McAdoo and Haebig, 1999)
17	1993	SAR & Landsat	Geological mapping	East Java Basin	(Ardhana, 1993)
18	1998	Landsat TM	Reef complex mapping	Seribu island	(Jordan, 1998)
19	1999	Radarsat & Landsat TM	Fold Mapping	PNG/Irian Jaya and Pakistan	(Insley and Tocher, 1999)
20	1999	Synthetic aperture radar (SAR)	River channel pattern	Wahau river, East Kalimantan	(Darman, 2000)
21	1999	Digital elevation model & SAR	Cross sections schematic of the Makassar straits & geological mapping	Lariang & Karama, Makassar strait	(S. Calvert, 1999; S. Calvert and Robert, 2007)
22	2003	Landsat TM & SAR	Geological Mapping	Lariang & Karama, Makassar strait	(S. J. Calvert and Hall, 2003)
23	2003	Remote sensing data & digital terrain model (DTM)	3D visualization and structural modeling	Gunung Salak geothermal field	(Keetley et al., 2003)
24	2004	Gravity & topographic dataset	Lineament and features for geological mapping	Eastern Indonesia	(Granath et al., 2004)

METHODOLOGY

This research was conducted based on the literature review that focused to summarize the state of the art from previous studies in oil and gas exploration. This paper follows the theory regarding the review paper from Chong and Reinders., (2021) and Munn et al., (2018). The focus of this paper review is remote sensing studies for oil and gas exploration in Indonesia, with data sources from the paper published in Indonesian Petroleum Association Proceedings, Lembaran Publikasi Lemigas, Scientific Contributions Oil and Gas, and papers published by authors in various journals, and proceedings. Based on its characteristics, this research is a systematic literature review, so it tries to provide an overview of the results of available studies on the topic of remote sensing for oil and gas exploration and its potential utilization. This research is also part of a literature review based on the methodological review to provide an overview of oil and gas exploration methods based on remote sensing used in Indonesia. In particular, the research is on the remote sensing application for geological mapping and surface anomalies. Based on the paper review, the chart diagram of the remote sensing application for geological mapping, and anomalies surface mapping using remote sensing can be seen in Figure 1.

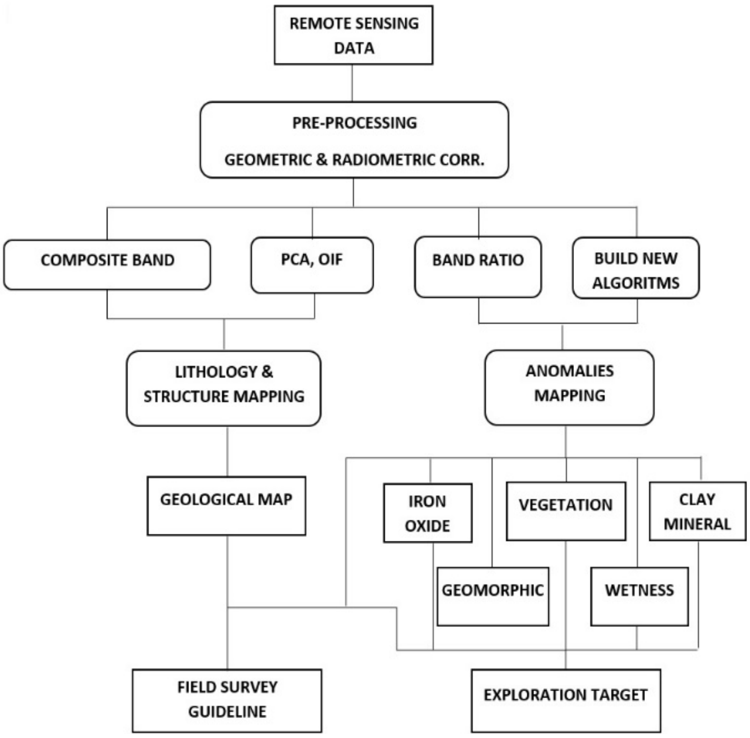

Figure 1
Chart diagram of remote sensing processing and interpretation for geological and surface anomalies mapping

RESULTS AND DISCUSSIONS

Remote Sensing for Geological Mapping

Geological mapping using remote sensing is based on natural phenomena seen on an image that can be identified by landscape (topography and distribution patterns), plant cover and culture Sudrajat., (1990). Alluvium can be interpreted based on the presence of oxbow lakes, and natural dams created by fluvial processes. Hard rock, which can be interpreted based on high topography, stands out from the surrounding rock, with vertical erosional processes playing an important and active role Gupta., (1991) and Sudrajat., (1990). In remote sensing data, geologic features can sometimes be interpreted based on their shape, such as uneroded dome structures, sand dunes, glacial deposits, alluvial fans, ridges, and subclinical folds. Interpretation based on river flow can be based on aspects of the texture of the river, the shape of the valley and the pattern of the flow Miller., 1961). River flow in karst is usually less visible at the surface, in sandy rocks it usually has low density and is a river with a rough texture, while in clay or shale rocks the river density is usually high, because the lithology is impermeable Gupta., (1991). Drainage patterns can also provide an overview of the existence of structures that are developing in an area. For Example, drainage patterns can indicate the presence of faults, anticline and synclines Figure 2.

Relief in remote sensing data reflects the resistance to the rocks to the energy acting in the area. The more resistant rocks such as conglomerate, breccias, intrusive rocks, sandstone, limestone and metamorphic rocks tend to have high relief, whereas the low relief rocks are dominated by mudstone, shale, siltstone, tuff and marl. Igneous rocks tend to form a rounded topography in areas with wet climates, and rough topography in areas with dry climates Havid., (1998) and Setianto., 2003). Sedimentary rocks in the remote sensing data can be interpreted based on the presence of layers with different physical properties, producing a regular appearance, differences in vegetation patterns and existing tributaries Gupta., (1991).

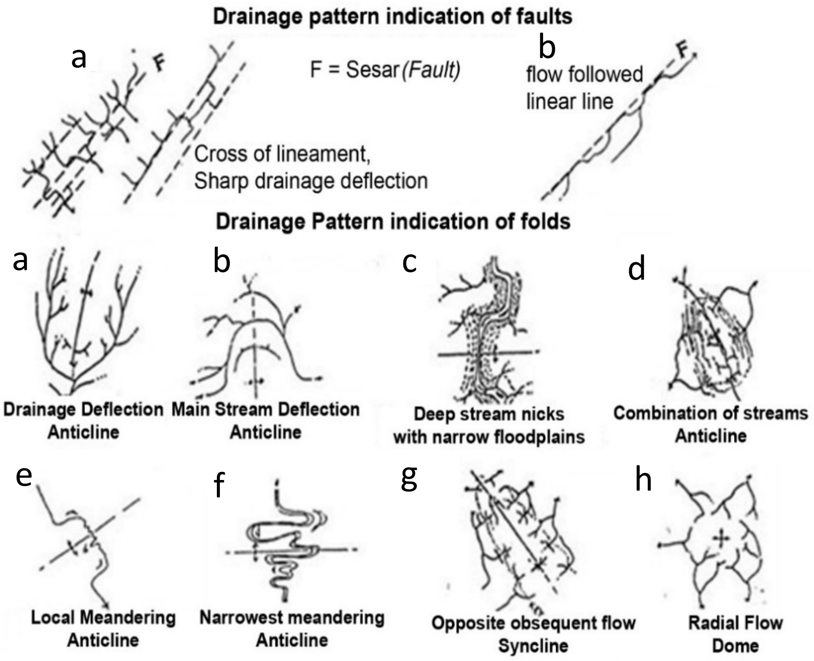

Figure 2
Drainage Pattern Indication of faults and folds (PPPTMGB LEMIGAS-JICA, 1994)

Mapping of rocks using remote sensing data then evolves through the optimum index factor (OIF), principal component analysis (PCA), and band ratio, increasing the ability to detect specific objects. Previous studies have shown that clay, iron oxide, dolomite, carbonate, kaolinite and altered rocks can be mapped using Landsat and ASTER. Combining remote sensing data from band ratio results with SRTM can further confirm the geologic structure and lithological units that exist in the area Figure 3.

The application of PALSAR remote sensing data to geologic mapping in support of oil and gas exploration in the southern Upper Kutai Basin is able to correctly separate the lithologic units and distinguish between the pre-Tertiary basement, sedimentary units and volcanic units. They can also be interpreted as anticlines, synclines, faults and joint structures Suliantara et al., (2010). Investigation of the oil and gas potential in Memberamo Basin boundary using landsat TM data integrated with regional gravity can be used to screen areas, leading to a focus area for oil and gas exploration with the kitchen area likely to be east of the northern part of the study area Susantoro and Suliantara., (2014).

Remote Sensing for Surface Anomaly Mapping

The results of the studies from 1996 to present show that there is a relationship between the presence of oil and gas in the reservoir and the conditions at the surface. One of the methods used to demonstrate this is the soil gas geochemical method. The results of a study of geochemical surveys at 139 sites showed that in 43 wells with negative anomalies, 41 wells found no hydrocarbons, while in 98 wells with positive anomalies, 37 wells were commercially successful Potter II et al., (1996). The anomalies that occur at the surface due to microseepage migration were demonstrated by Schumacher., (1996), where near the surface of the soil and sediment above the reservoir there is an increase in the concentration of light hydrocarbons and hydrocarbon-oxidizing microbes; a sharp change in the ratio and concentration of light hydrocarbons at the edges of the surface projection of reservoirs; a ratio of stable carbon isotopes for methane and light hydrocarbons in soil gasses to those found in reservoirs; loss and occurrence of soil gas and microbial anomalies in response to reservoir depletion and post-compaction. The presence of soil surface geochemical anomalies also shows a high correlation with the relative intensity of hydrocarbons detected in oil and gas well records Sechman et al., (2018). Migration of hydrocarbons above the gas source point in the caprock follows the mechanism of diffusion and infiltration (buoyancy) so that vertical gas flows are found in the form of plumes along the hydrocarbons as microseepage WANG et al., (2016).

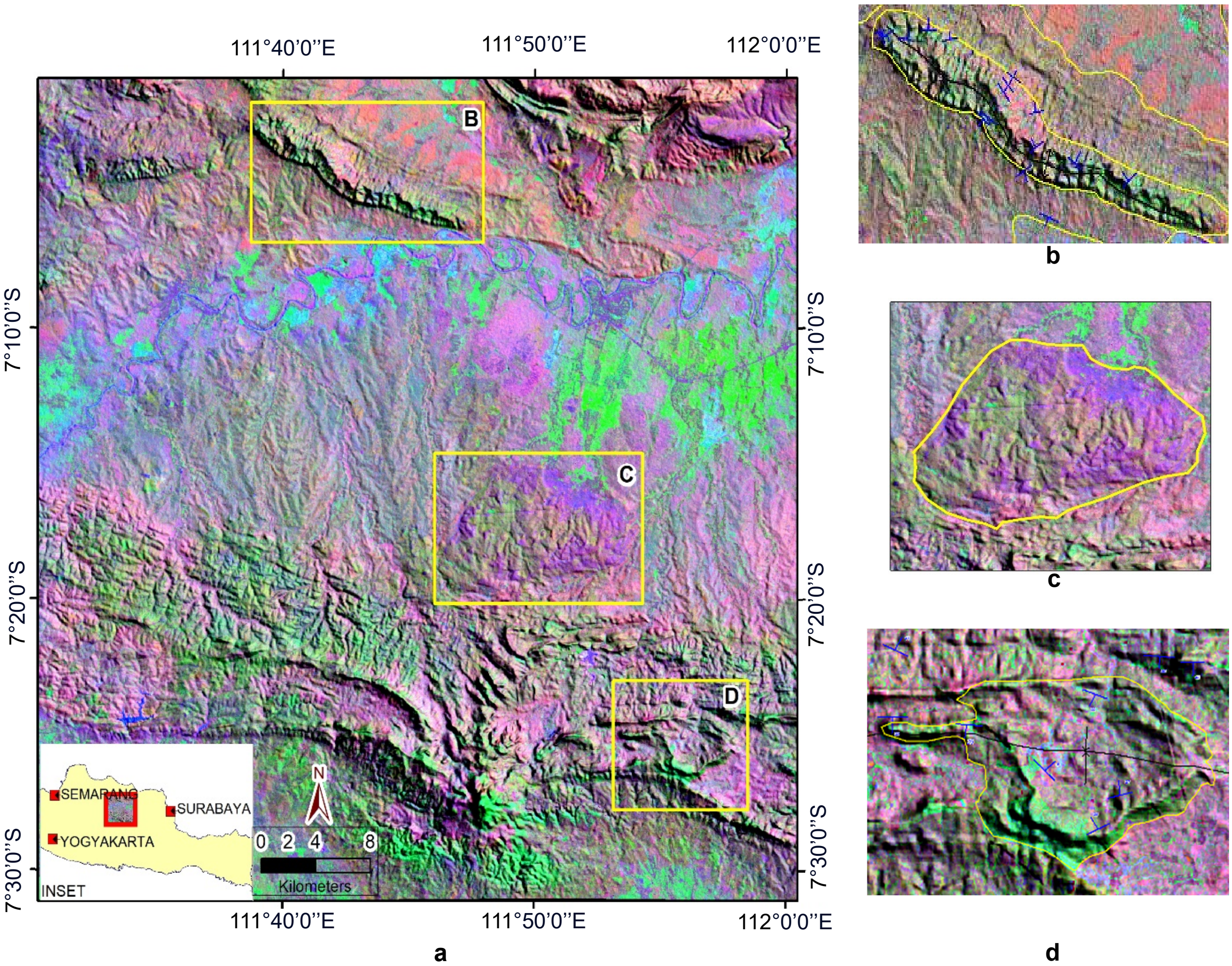

Figure 3
Landsat 7ETM+ and SRTM Processed Imagery. a. The appearance of the combined Landsat 7ETM+ image band ratio 3/1, 5/7, 3/5 (RGB) with SRTM; b. anticline structure; c. limestone lithology; and d. syncline structure Susantoro., (2009a) and Susantoro et al., (2009).

Surface manifestations describing the presence of hydrocarbon microseepage include: hydrocarbon concentration anomalies in soil, sediment, water and atmosphere; microbiological anomalies; minerals changes in the form of calcite, pyrite, uranium, elemental sulfur, magnetic iron oxides and sulfides; red bed bleaching; clay mineral changes; acoustic anomalies; geomorphic anomalies; electrochemical changes; biogeochemical changes and geobotanical anomalies Hong., (1999), Noomen et al., (2012), Schumacher., (1996), Schumacher and LeSchack., (2002). In general, the goal of exploration based on surface anomalies is to find seepage Figure 5, and then map the seepage to relate it to subsurface prospects and characterize the type of oil seen in play's seeps Sundberg., (1994). There are not many studies on surface anomalies specifically for oil and gas exploration in Indonesia. However, Crystiana et al., (2014) conducted studies on topographical anomalies to identify potential areas (RPA) for oil and gas exploration via remote sensing. The evaluation of topographic anomalies is based on a manual interpretation that identifies areas that are higher than surrounding areas. The analysis is then continued by integrating lineaments and flow patterns. The results identified 84 RPAs, 44% of which are oil and gas structures that have been shown to produce hydrocarbons Figure 4. The presence of this topographic anomaly is confirmed by research conducted by Susantoro et al., (2022) to map existing oil and gas fields that show topographic anomalies based on soil grain roughness and wetness index. The results showed that at the peak anticline are characterized by coarse soil grain size and low wetness index values than in the edge of oil and gas field.

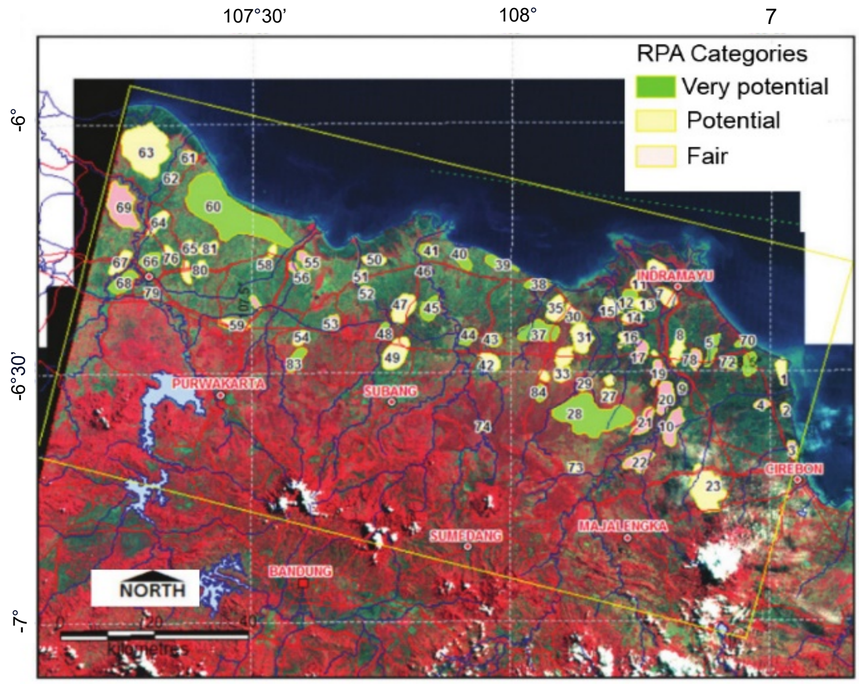

Figure 4
Remote sensing potential areas for hydrocarbon exploration based on topographic anomalies, where the potential areas showed by higher topographic than surrounding areas Crystiana et al., (2014).

Evidence of geobotanical anomalies was reported by by Susantoro et al., (2017) in Tugu Barat field, who noted the presence of sugarcane stress around the hydrocarbon field. This is confirmed by Noomen., (2007) who conducted studies in which gas was injected into the soil around maize (Zea mays) and wheat (Triticum aestivum) plants, causing stunting of these plants and hindering their photosynthetic process. Geobotanical anomalies in plants due to hydrocarbon leakage can be characterized by the characteristic yellowish leaves, lower fertility, and can be widespread up to 100 meters around the oil and gas field Naudé et al., (2011), Yu et al., (2015). Studies of clay mineral alteration at the surface of oil and gas fields show an anomaly; in which a crest neck pattern occurs in which concentrations of clay and smectite tend to be higher in the center of the oil and gas field and then decrease at the edges (Figure 5). Kaolinite concentration tends to be low in the center of the oil and gas field and high at the edges Susantoro et al., (2020). Factors that cause hydrocarbons to seep from the reservoir to the surface include enhanced fracturing at the structure margins, vapor migration, stack columns, diffusion, and microbubble upwelling Saunders et al., (1999), Schumacher., (1996), Sikka and Shives., (2001), Tedesco., (1995), Zuhui et al., (1993). Figure 5 shows changes in total clay content and kaolinite content in Tugu Barat field Susantoro et al., (2020).

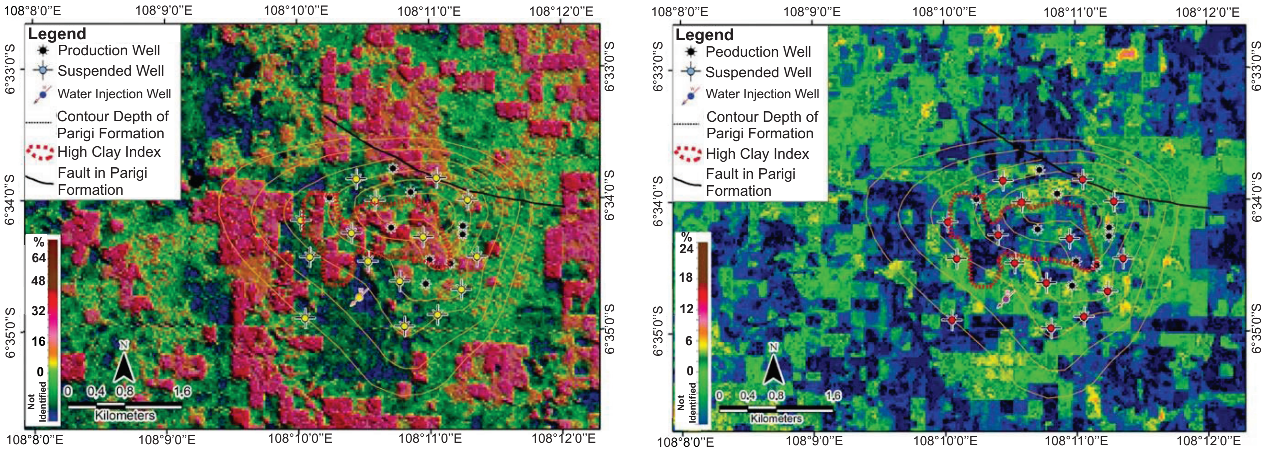

Figure 5
Surface anomaly patterns in oil and gas fields. a. total clay minerals showing high concentrations in the middle and decreasing at the edges field as the indication of higher microseepage than in the middle; and b. kaolinite concentrations tend to be low in the middle and high at the edges field as the indication of higher microseepage than in the middle Susantoro et al., (2020).

Remote sensing is expected to become a tool for oil and gas exploration in the near future through advanced processing and machine learning. Several studies have already been conducted using machine learning, which have proven that they can support oil and gas activities, but have not yet relied on remote sensing data. The methods used in remote sensing are also developing and being used for general studies in oil and gas sector, such as the analysis of rock unit and total organic carbon in oil and gas wells using machine learning. The machine learning-based study includes lithological predictions using the K-nearest neighbor (KNN) algorithm in the Upper Cibulakan Formation Rafi., (2023). Prediction of total organic carbon (TOC) based on models created using various machine learning algorithms from existing wells such as: Artificial Neural Network, K-Nearest Neighbors, Support Vector Regression, Decision Tree, and Random Forest Wardhana et al., (2021) and use of machine learning to estimate shear wave velocity to determine rock physical properties (Wardhana et al., (2022).

CONCLUSIONS

The results of the study show that remote sensing has been used for oil and gas exploration since before 1945, especially for exploration in frontier areas. Remote sensing data are used in oil and gas exploration to interpret lithology and geologic structure to support seismic activity and initial screening of oil and gas exploration areas. The use of remote sensing data for oil and gas exploration which was originally conducted conventionally through manual interpretation then evolved through digital interpretation with band ratios and surface anomalies. The remote sensing technology for oil and gas exploration is divided into two types, (1) regional scale for geological survey and mapping, supporting seismic survey and finding of exploration areas target; and (2) detail scale for evaluation of prospect area before conducted for the drilling program. Based on the study showed that remote sensing has great potential to be used optimally for oil and gas exploration. This can be achieved by developing advanced processing methods for surface anomalies and machine learning.

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GLOSSARY OF TERMS

Symbol	Definition	Unit
2D	2 Dimensional	
3D	3 Dimensional	
ALF	Airborne Laser Fluorosensor	
ASTER	Advanced Spaceborne Thermal Emission and Reflection	
BOPD	Barrels of oil per day	
DTM	Digital Terrain Model	

ETM+	Enhanced Thematic Mapper Plus
F	Fault
KNN	K-Nearest Neighbor
OIF	Optimum index factor
PALSAR	The Phased Array L-band Synthetic Aperture Radar
PCA	Principal Component Analysis
RGB	Red Green Blue
RPA	The Potential Areas
SBRDSS	Satellite Based Remote Deep Sensing Survey
STeP	Sub Terrain Prospecting
SAR	Synthetic Aperture Radar
SIR	Shuttle imaging Radar
SLAR	Side-Looking Airborne Radar
SRTM	Shuttle Radar Topographic Mission
TM	Thematic Mapper
TOC	Total Organic Carbon
TVT	Thermovision Tomography

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