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Deep Neural Remote Sensing and Sentinel-2 Satellite Image Processing of Kirkuk City, Iraq for Sustainable Prospective

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Abstract: Sentinel-2 satellites, equipped with board-mounted multispectral payloads, provide images of the Earth in the wavelengths of the electromagnetic spectrum. These sensors can be used on Earth's surface to observe it with a very high spatial resolution, and there is a wide range of near-infrared and non-infrared spectral bands. These spectral ranges allow for a wide array of purposes, like assessing vegetation health land use and land cover changes, coastal and inland water quality assessment, and making disaster maps. In this case study, we mapped and analyzed different types of Sentinel-2 images that imaged Kirkuk city landscape in Iraq. The methodology is based on Artificial Intelligence (AI) analyzing patterns of Sentinel hub data and Geographic Information Systems (GIS)-based mapping. Furthermore, minimum noise fraction (MNF) and pixel purity index (PPI) were applied on each image to enhance the spectral unmixing accuracy which provides higher precise endmember spectra. A deep neural remote sensing has been used for 10 m resolution Sentinel-2 image segmentation of Kikuk. This produces such a result where features are exactly distinguished and identified. This is performed by automatically detecting and classifying features on the image to provide better identification and estimation. Analyzing received data through Sentinel-2 provides us with the basis to identify such patterns, trends, and insights as key facts supporting urban planning, environmental sustainability, and so much more.

Keywords: Sentinel-2, electromagnetic spectrum, geographic information systems, minimum noise fraction, pixel purity index, sentinel hub

1. Introduction

The progress made in remote sensing technology via satellites has revolutionized the methods of monitoring the Earth's surface [1]. Modern airborne and space-borne satellites can capture surface area's surface with the help of their multispectral and hyperspectral sensors which are exactly located inside the satellites to give exact and digital data of the features present there [2].

The electromagnetic waves are reflected and absorbed at preset wavelengths by different materials. Each material is spectrally distinguishable in images according to their spectral signatures captured by the sensors. They can be adequately identified by spectral signatures [3].

Scientists in the last several years have been using a lot of hyperspectral observations and remote sensing methods to obtain land products, as well as analysis and applications. As hyperspectral investigative sensors demonstrate their capabilities, the Sentinel-2 multispectral satellites provide free, open, global, and systematic high-resolution visible and infrared imagery, both day and night, with a short revisit time, allowing access to these images at no cost [4].

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To differentiate the wavelengths (around RGB and NIR) from thermal infrared (TIR) and moisture content (hydrants), the remote sensing instruments used include digital cameras, multi-exposure infrared cameras, hyperspectral instruments, microwave sensors, and Lidars. Some sensors that you may probably meet up with include the ones used on aircraft, UAVs (Unmanned Aerial Vehicles), satellites, and other objects [5].

The European Space Agency (ESA) developed the Copernicus program which produces Sentinel-2 multispectral products whose primary goal is to provide high-resolution satellite data for land cover/land-use monitoring, climate change, and disaster monitoring, as well as to complement other satellite missions such as Landsat [1]. The key mission objectives for Sentinel-2 are as follows: (1) catering to the acquisition of high-resolution images with minimal gaps in imaging, (2) maintaining the existing levels of service assured by SPOT satellites which capture multispectral imagery, and (3) providing information for upcoming operational products such as land-use maps, land cover change detection maps, and physical features data. Furthermore, Sentinel-2 will be the most valuable and actively used instrument by these three services [6].

Sentinel-2 general operation is to supply super-spectral, medium spatial resolution payload within a broad field of view (290 km) with a very frequent revisit (5 days) and excellent resolutions (10, 20, and 60 m) and a pretty large spectral band set

(13 spectral bands) to ensure the continuous global coverage [7, 8]. The installment is put in place to ensure continuity in the SPOT/ Landsat missions and fill the existing data gap with operational products such as land cover maps, land-change detection maps, and geochemical/physical variables [9]. A Sentinel mission is based on a dual satellite configuration where the two satellites orbit within a given constellation. This has led to a drastic improvement in the information revisiting time. The Sentinel operation has three phases pre-operation between 2008 and 2010, initial operation during 2011–2013, and continuous operation since 2014. In response to the strategic plans for the Copernicus program, Sentinel-4 was launched, and beyond Sentinel 6 will be considered the next evolutionary satellite for air quality [1].

Sentinel-2A set off in June 2015 and Sentinel-2B was out in March 2017. It covers an area with the same viewing conditions every five days at the Equator and every two days at mid-latitudes. This spacecraft looks down on the surface of Earth in more detail than previously possible with a wide field of view and high spatial resolution [10].

The sensing technology like hyper-/multispectral technology is based on the same physical principle. They both capture radiance in the visible to near Infrared region (VNIR) spanning the range of 400–1000 nm and short wave infrared region (SWIR) 1000–2400 nm. In comparison to multispectral sensors like Landsat-8 (11 bands), which record in a fairly narrow range (4–20 bands), hyperspectral sensors comprise a very high number of adjacent and extremely narrow spectral bands of 5–15 nm [6]. Hyperspectral observations certainly provide an improved involved-scene description and the monitoring of the earth's surface and other planets, with the highest precision compared to multispectral imaging [11–13]. Currently, both Sentinel-1 and Sentinel-2 satellite images serve as sources of data for stand-alone deep-learning models for disparate, specific detection, and use [14].

The Sentinel-2 data are not only valuable for land cover change detection, evaluation of geochemical and physical properties, vegetation monitoring, and natural catastrophe management but also help in other applications. As it is clear from the case of mineral exploration, the Sentinel-2 data have also demonstrated their ability for mapping the improved absorption feature (iron). It is worth noting that the spectral features, including the high or even higher spectrum range, and VNIR part are similar to the Landsat series and/or SPOT [15]. Space-based hyperspectral sensors could be valuable in many applications. They are equipped with high spatial and spectral resolutions, and their performance is not drastically affected by the atmospheric changes. This approach has been entirely paramount to hyperspectral science and application-based developments [16, 17].

The current case study in Kirkuk city aims to analyze Sentinel-2 data that imagines Kirkuk's surface land. In this study, we used Sentinel hub images of Sentinel-2_L2A based on ArcGIS mapping and Quantum Geographic Information System (QGIS) analysis. MNF and PPI were applied using the Envi program for improving the accuracy of spectral unmixing. A deep-learning approach was used for image segmentation.

With this methodology, it is intended to get a comprehensive understanding of the region and, thus, provide great prospects for different applications, including urban planning, environmental monitoring, and resource management.

With Sentinel-2 data analysis, the study aims to see the patterns, trends, and insights that may influence development planning and sustainability. Such activity consists of studying land-use alteration, detecting vegetation health, and creating hazardous-area maps, among others. Summarizing, the study stands out as a result of merging innovative remote sensing technologies with AI analysis and GIS mapping methods for Kirkuk city that is focusing on providing detailed information for a great number of fields including urban planning and environmental management.

2. Literature Review

Sentinel-2 particularly captures images with the visible spectrum (400–700 nm) observation, and it produces high-resolution pictures that enable exquisite class-making of the surface features [9]. The multispectral channels such as the Red, Green, and Blue bands facilitate an accurate rendition of the condition of terrestrial surfaces. In addition to the visible spectrum, NIR image, (700–1400 nm) is another important domain of the Sentinel-2 sensors for biomass monitoring and assessment of vegetation status, as addressed by Clewley et al. [18] where important NIR bands are B8A and B8 from which full information about vegetation reflectance can be attained to calculate vegetation indices such as Normalized Difference Vegetation Index (NDVI). The imaging capability of Sentinel-2 images extends into the shortwave infrared with the spectrum of (1400–3000 nm), which permits the detection of some essential features on the land surface. Infrared images from greater resolution sources like Sentinel-2 are a means of furthering oil spill cartography.

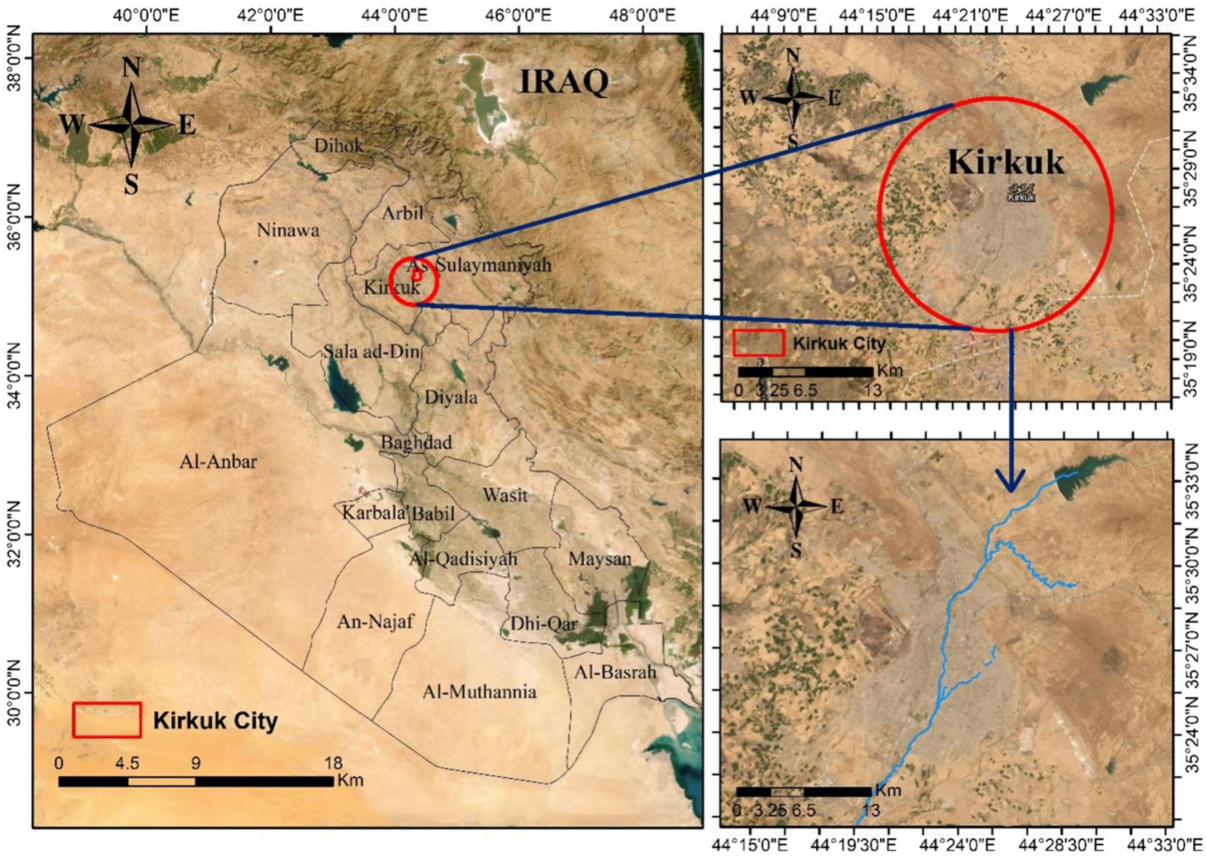
These sensors are known to result in data at 20–60 m resolution at different NIR-SWIR bands and provide us with a datum to classify oil slick conditions [19].

To enhance the observations' accurateness across the electromagnetic spectrum, there is the need to correct the data captured for atmospheric conditions given that Sentinel-2 data commonly undergo atmospheric correction adherence. However, in this way, the technical barrier of the saturation is mitigated and the amount of monitored features improves dramatically [20]. Radiometric accuracy testing is of utmost importance for Sentinel-2 imagery to be identical in terms of precision and accuracy. Through calibration, algorithms guarantee sensor measurements stay stable over time; hence, acquisitions of long-term time series and trend analysis of the dynamics of the surface of the Earth are made possible [21].

Through the continuance in the improvement of sensor technology, techniques related to data processing, and machine learning, the potential of the Sentinel-2 satellite's ability in Earth imaging across the electromagnetic spectrum is anticipated to be considerably enhanced. Extending the capabilities of Sentinel 2 data to cover a wide range of applications such as agriculture, forestry, emergency response, water, and environment monitoring among others will be the thrust of future research directions including integrating visual and geospatial intelligence data with advanced fusion methods [22].

Fusing data from a Sentinel-2 sensor along with other satellite observations, for instance, those made by the Landsat series improves the saturation and spectral resolution of the earth observation data set. Various sensors working together provide an enhancement in the performance of land/cover map making and also dealing with disaster warning systems [23, 24]. According to Alshari and Gawali [25], machine learning algorithms are a phenomenal tool for retrieving significant information from Sentinel-2's imagery at different frequencies of electromagnetic radiation. Technologies like deep learning allow automatic feature extraction and classify large amounts of data very fast, therefore, the analysis of Earth observation data. Sentinel-2 satellites provide a broad image of our planet by emitting an electromagnetic spectrum, that is one of their key qualities when explaining why so many domains can benefit from it, from land cover monitoring to disaster response.

Figure 1
Study area map of Kirkuk city in Iraq



Based on Sentinel-2 data, many studies have been conducted using different indices, such as NDVI and Normalized Burn Ratio Index applied by Mahmood and Jumaah [26], and Normal Difference Water Index by Jumaah et al. [27], Qader et al. [28], and Radeloff et al. [29]. Sentinel-2's global coverage coupled with its open data policy creates an environment in which the use of Earth observation data becomes even and free thus making way for research and applications to be used by people across the globe Orusa et al. [30]. Therefore, we aim to improve the integration of free satellite data into the standard administrative workflow. According to Aziz et al. [8], Sentinel-2 has capabilities that include detailed forest analysis, change detection, and feature analysis. A set of procedures takes the uncertainty out of remote sensing; therefore, the results from detecting and estimating different forest types manifest the picture of health and maturity where needed. While the Sentinel satellite images integrated into one dataset by Dang et al. [14] present a potential resource for model development, they specifically serve as a source of big data for deep learning models used in landslide detection.

The two outstanding features of Sentinel-2—its multispectral properties and advanced data processing techniques—make it a pillar in the field of Earth observation and a major contributor to scientific advancement and societal benefits.

3. Research Methodology

3.1. Study area

Kirkuk city is bonded between coordinates (35°18′ N to 35°32′ N) and (44° 14′ E to 44° 28′ E) as shown in Figure 1. The study area lies north of Iraq and its weather is almost dry, very hot, and hot semi-arid during summer whereas is cold in the winter. The rainy months are from October to April. The annual average rainfall is about 342.7 mm. The annual average temperature ranges from 3 °C to 43 °C [31].

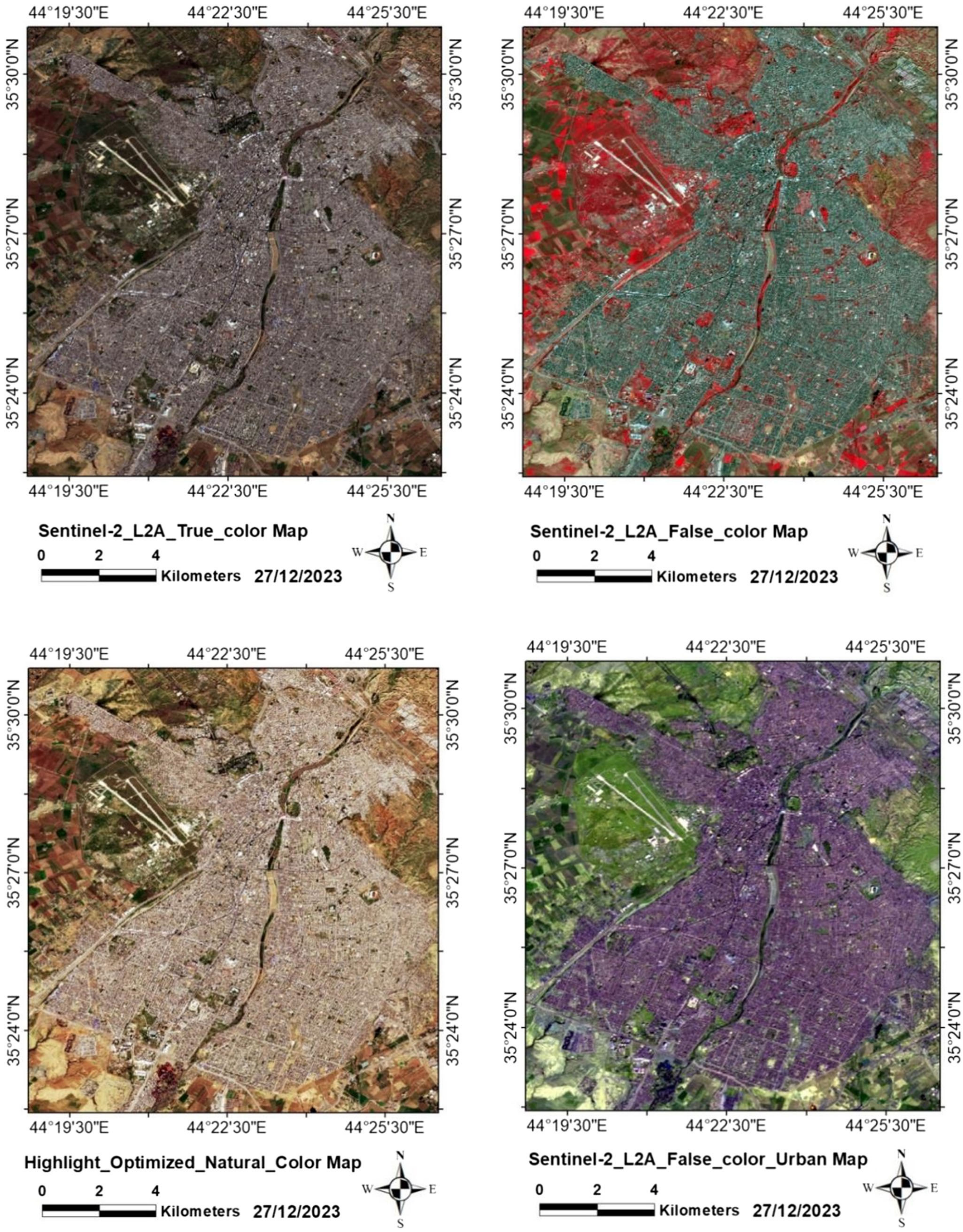
3.2. Sentinel-2 data

Sentinel-2_L2A of four different types of images acquired on 27-12-2023 and 25-04-2024 were downloaded, analyzed, and mapped. Table 1 represents the mean details of used Sentinel-2 images. The images represented Sentinel-2 true color, Sentinel-2 false color, Sentinel-2 highlight optimized natural color, and Sentinel-2 false color urban. A 10 m resolution Sentinel-2_L2A image was used for deep learning downloaded from Copernicus. All other images were downloaded from the Sentinel hub Earth Observation EO browser with high resolution and cloudless with the coordinate system of WGS1984.

Table 1
Mean details of used Sentinel-2 data

Sentinel-2 info	Image 1 details	Image 2 details
Type of image	Sentinel-2_L2A	Sentinel-2_L2A
Acquisition date	27/12/2023	25/04/2024
Image format	TIFF(32-bit float)	TIFF
Image resolution	1627 × 1984 px	10 m
Cloud cover	0%	0.5%
Coordinate system	WGS 1984	WGS 1984

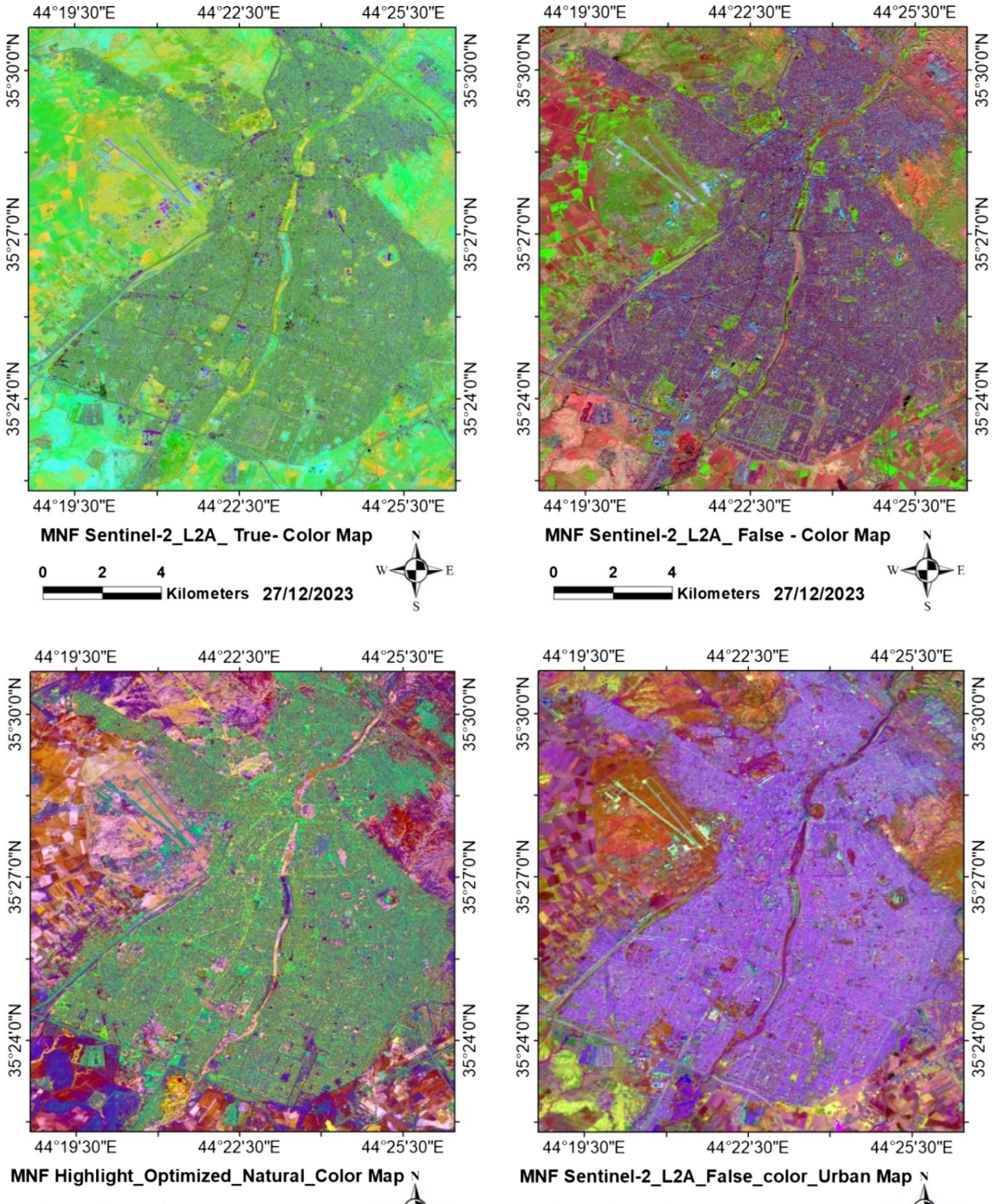
Figure 2
Sentinel-2 maps of different data



3.3. Images processing

Sentinel hub EO browser allows you to browse and download different types of Sentinel images of full resolution with different visualizations or you can make your own visualization based on the used index and bands. Using ArcGIS10.8, we analyzed and mapped four maps based on the downloaded data types (Sentinel-2 true color image, Sentinel-2 false color image, Sentinel-2 highlight optimized natural color image, and Sentinel-2 false color urban image). Sentinel Hub EO Browser integrates machine learning ML and artificial intelligence AI, enabling advanced image analysis and providing the best-derived information from EO data. We explored different spectral bands by applying different visualization techniques with adjusting for better visualization. Two processes using ENVI 5.3 were applied (MNF and PPI). Forward MNF noise statistics from dark data were used to reduce the manifestation of noise and thus enhance the signal-to-noise ratios in hyperspectral imagery. In the remote sensing

Figure 3
MNF Sentinel-2 maps of different data

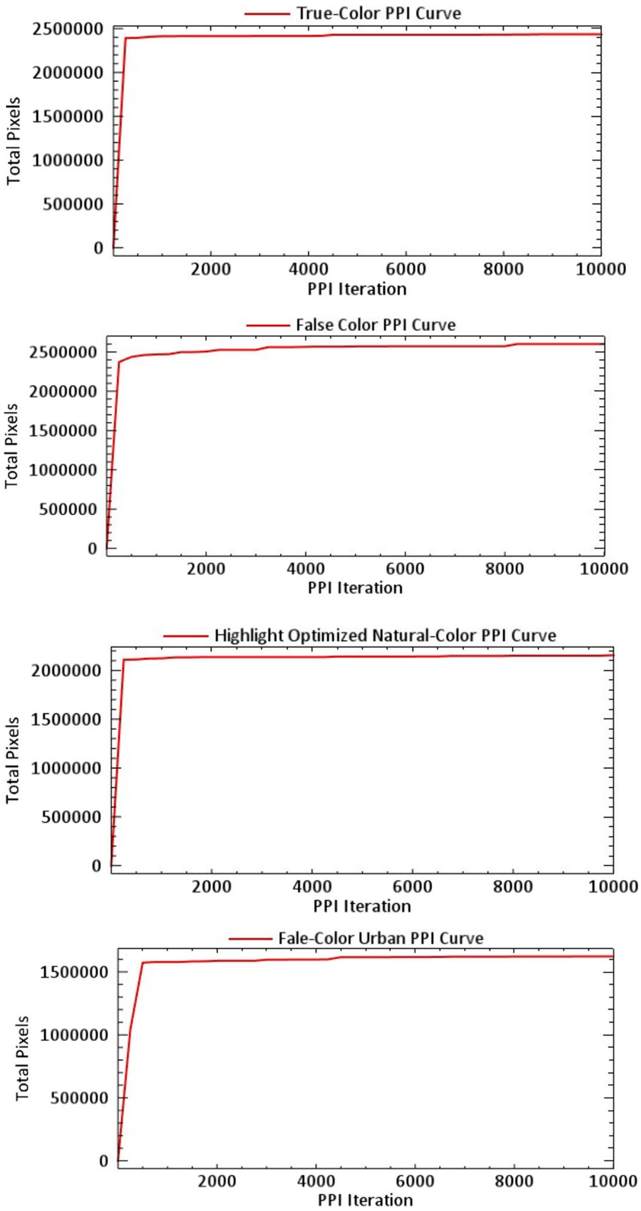


context, dark data may refer to spectral bands or channels that are either null used, underutilized, or not utilized at all by sensors. Because these bands can refer to vital information, but at the same time their potential is ignored and no processing is applied due to the lack of adequate understanding or technique. The Pixel Purity Index (PPI) existing output band was used to choose endmembers in spectral unmixing.

For applying PPI, the image will be selected and PPI parameters should be determined for example; the number of iterations, iterations per block, and threshold factor. To apply PPI in ENVI software, first use the definite hyperspectral sentinal-2 image and open it in the software for analysis. Navigate to the used tool for spectral unmixing and then use the PPI algorithm. The number of endmembers (pure spectra) should be determined, and once all parameters are defined, the spectral signatures in the image will be analyzed, and ENVI software will identify the pixels that display spectral purity, presenting features as pure materials or endmembers.

There is an optional refinement in ENVI where you might decide to make some more fine-tuned adjustments to the PPIs you got as per the outcomes of your detailed analysis. This might include manually selecting or adjusting the defined endmembers.

Figure 4
PPI graph of different Sentinel-2 images



To reduce processing time a spectral subset of the image can be chosen, this will be based on the size of the hyperspectral image and the availability of computational means.

Also to refine the PPI results, thresholding and filtering techniques can be applied. These may, among other possibilities, consist of specifying the lowest value for the spectral purity or shifting the pixels which not conform to certain criteria. The resultant PPI can then be reviewed to get assurance that the endmembers obtained are pure spectral signatures. The visualization and cross-checking with the ground truth data might work as good enough for the validation.

Applying further parameters of the PPI algorithm to implement improvements optimizing parameters, for example, the number of the end members must be characterized, as well as the spectral purity threshold. Changing these settings can influence the precision and efficiency of the process altogether.

Applying the mentioned refinements and improvements allows us to deal with large amounts of data, and the results can be made more precise thus making the hyperspectral data analysis approach with ENVI the best one.

Furthermore, a segmentation process of deep neural remote sensing has been applied to Sintenel-2 image of 10 m resolution downloaded from Copernicus. The deepness plugin in QGIS permits the easy performance of image segmentation and detection with custom neural network models based on Python packages. We based our segmentation on the Eurosat dataset model, which uses thirteen spectral bands across different classes.

4. Results

Figure 2 represents the mapped images of Sentinel-2 of true color, false color image, highlight optimized natural color, and false color urban, respectively.

Sentinel-2 true color map describes the true color composite of the Kirkuk landscape. Where each area in the spectrum is represented by visible light bands (B04, B03, and B02), these correspond to red, green, and blue parts of the spectrum in the corresponding R, G, and B color channels, performing a good representation of the natural color of the Earth as can be seen naturally.

The Sentinel-2 false color map describes the false color composite to image the Kirkuk landscape based on one non-visible wavelength. The false color composite uses near-infrared, red, and green bands. In this map, plants and vegetation absorb red and reflect near-infrared and green. The exposed lands are reflected as gray or tan, and the waterbodies appear in blue or black color. Sentinel-2 false color map applications are most highly used for plant density and health assessment. The Sentinel-2 bands in this map are B08, B04, and B02.

The optimized natural color map from Sentinel-2 beautifully displays the Kirkuk landscape. In order to avoid burn-out pixels, and to even out the exposure, highlight optimization is used. The Sentinel-2 bands in this map are B04, B03, and B02.

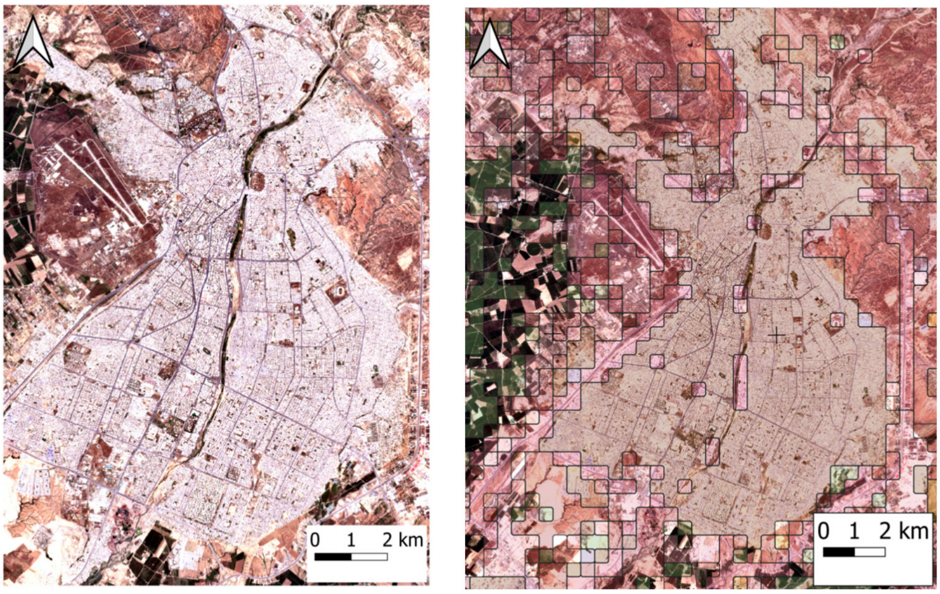
Sentinel-2 false color urban map visualizes urbanized areas of the Kirkuk landscape more clearly. Here, the urbanized areas were represented by purple color, white, and gray. Moreover, plants and vegetation appear in shades of green, while a variety of colors represent soils, sand, and minerals. Waterbodies can be seen in black or blue color. Snow and ice will appear also as dark blue. Furthermore, the flooded areas can be seen in black or very dark blue. The application of this composite is beneficial in wildfire detection as they are represented as shades of red and yellow. The map is based on the bands of B12, B11, and B04.

Figure 3 represents the MNF of Sentinel-2 of true color, false color image, highlight optimized natural color, and false color urban, respectively. If dark information data MNF are analyzed, it is important to consider the noise statistics inherent to the information. This involves elucidation of what noises or backgrounds exist in the ranking of the unused spectral bands and then the incorporation of this information into the MNF (multivariate spatial analysis) processing section.

Figure 4 represents the PPI of each MNF Sentinel-2 map of true color, false color, highlight optimized natural color, and false color urban images, respectively. Spectral unmixing is a primary objective being pursued by remote sensing which involves splitting a mixed pixel's spectral signature into additive endmembers which constitute the entirety of the pixel's spectral signature and also their abundance fractions within the pixel.

Figure 5 represents deep neural remote sensing segmentation of 10 m resolution Sentinel-2 image.

Figure 5
Deep neural remote sensing segmentation of 10 m resolution Sentinel-2 image



5. Conclusion

By using different types of sentinel-2 data and implementing GIS and Envi-based analysis, we have been able to learn in detail of the region of interest.

The true color map reveals the character of the colors of the surface of the Earth, so the viewer can see a natural landscape. On one side, the false color map, utilizing near-infrared, red, and green bands, observes vegetation density and health, and clear differentiation of land cover types becomes possible. Highlight-optimized natural color maps present an enhanced visual representation of land by minimizing burn-out pixels. Moreover, the false color urban map imparts useful information about urbanized areas which even helps us to distinguish different types of land cover like vegetation, water bodies, and even built-up areas very easily.

The use of sophisticated processing methods like MNF and PPI has also enriched the effectiveness by making it possible to reduce the noise of the multispectral data and identify end members, respectively. These reconstruction methods have helped make hyperspectral imagery with a high signal-to-noise ratio and particularly useful information from spectral bands that were nonexistent before.

Generally, the utilization of sophisticated satellite imaging techniques, the latest processing methods, and machine learning tools have emerged to serve the demand for comprehensive analyses and earth mappings of Kirkuk City. Such analyses are priceless not only for purposes of change detection but also for assessing the condition of natural habitats, urban planning, and natural disaster preparedness.

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data are available from the corresponding author upon reasonable request.

Author Contribution Statement

Huda Jamal Jumaah: Conceptualization, Methodology, Formal analysis, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Aydin Adnan Rashid:** Software. **Serri Abdul Razzaq Saleh:** Validation. **Sarah Jamal Jumaah:** Investigation.

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