

Comparison in hyperspectral and multi-spectral remote sensing data for land cover classification in Samara, Russia

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Abstract. The main aim of this study is to evaluate k -nearest neighbor algorithm (KNN) supervised classification with migrating means clustering unsupervised classification (MMC) method on hyperspectral and multispectral imagery to discriminating land-cover classes. Accuracy assessment of the derived thematic maps was based on the analysis of the classification confusion matrix statistics computed for each classification map, using for consistency the same set of validation points. We used Earth Observing-1 (EO-1) Hyperion hyperspectral data to Landsat 8 Operational Land Imager (OLI) and Advance Land Imager (ALI) multispectral data. Results indicate that KNN (95, 94, 88 overall accuracy and .91, .89, .85 kappa coefficient for Hyp, ALI, OLI respectively) shows better results than unsupervised classification (93, 90, 84 overall accuracy and .89, .87, .81 kappa coefficient for Hyp, ALI, OLI respectively). In addition, it is demonstrated that the hyperspectral satellite image provides more accurate classification results than those extracted from the multispectral satellite image. The higher classification accuracy by KNN supervised was attributed principally to the ability of this classifier to identify optimal separating classes with low generalization error, thus producing the best possible classes' separation.

Keywords: Hyperspectral and multispectral satellite data, land use/cover, Remote sensing, Supervised and unsupervised classification.

1. Introduction

Remote sensing data are commonly used for land cover classification and mapping, and its replaced traditional classification methods, which is expensive and time consuming. Since the early 1970s, multispectral satellite data have been widely used for land cove classification. Multispectral remote sensing technologies, in a single observation, collect data from three to six spectral bands from the visible and near-infrared region of the electromagnetic spectrum. This crude spectral categorization of the reflected and emitted energy from the earth is the primary limiting factor of multispectral sensors either spatially or spectrally to monitor sub-class level classification because they have very similar

characteristics. Increasing the number of “pure pixels” through improved spatial resolution removes a large source of error in the remote sensing analysis [1]. Species level mapping works well for monotypic stands, which occur in large stratifications. Where species are more randomly distributed or patchy at fine scales (grain), accurate map classifications are difficult to obtain. So over the past 2 decades, the development of airborne and satellite hyperspectral sensor technologies has overcome the limitations of multispectral sensors [2].

Hyperspectral sensors collect several, narrow spectral bands from the visible, near-infrared, mid-infrared, and short-wave infrared portions of the electromagnetic spectrum. These sensors typically collect more than 200 spectral bands, enabling the construction of an almost continuous spectral reflectance signature. These bands are so sensitive to ground features that it is possible to record detailed information about earth surface. In addition, materials which have similar spectral features are possible to be discriminated [3]. Furthermore, narrow bandwidths characteristic of hyperspectral data permit an in-depth examination of earth surface features which would otherwise be ‘lost’ within the relatively coarse bandwidths acquired with multispectral data [4].

Many studies have reviewed the application of hyperspectral and multispectral imagery in the classification and mapping of land use in particular water, urban, transportation and vegetation species level by detecting biochemical and structural differences. The main aim of this study is to evaluate k -nearest neighbor algorithm(KNN) supervised classification with migrating means clustering unsupervised classification (MMC) method on hyperspectral and multispectral imagery to discriminating land-cover classes [5]. For this purpose, a test site was selected an area located in the mainland of Samara region, Russia for which hyperspectral and multispectral imagery were made available.

2. Study site

Samara region is situated in the South-East of the Eastern European Plain in the middle flow of the greatest European river, the Volga, which separates the region in two parts of different size, Privolzhye and Zavolzhye. Study area (fig. 1) Samara known from 1935 to 1991 as Kuybyshev, is the sixth largest city in Russia and the administrative centre of Samara Oblast. Geographical coordinates are $53^{\circ}12'10''\text{N}$, $50^{\circ}08'27''\text{E}$ (fig. 1).



Figure 1. Study area image, Samara region, Russia (source: Google Earth).

3. Methods

3.1. Selection of satellite data, field work and ground trothing

In this research work we consider spatial, spectral and temporal resolution as well as cost and availability of data, when we reviewing most appropriate data. The Hyperion hyperspectral sensor (United States Geological Survey Earth Resources Observation Systems) and the multispectral OLI and ALI sensor [6] were then selected for this study. Few characteristics of all three sensors are showing in table 1.

Table 1. Characteristics of Hyperion, OLI and ALI sensors.

Sr. No.	Characteristics	Values		
		Hyperion	OLI	ALI
1	Sensor type	Push-broom	Push-broom	Push-broom
2	Wavelength range	400-2.500 nm	434-1.383 nm	433-2.350
3	Number of spectral bands	242	9	7
4	Spectral resolution	10 nm	15 – 200 nm	5 – 30 nm
5	Spatial resolution	30 m	30 m	30 m
6	Swath	7.5 km	185 km	37 km
7	Digitization	12 bits	12 bits	12 bits
8	Altitude	705 km	705 km	705 km
9	Repeat	16 day	16 day	16 day

Fieldwork to map individual land cover classes and obtained spectral measurements of the dominant species was conducted at 60 sites in Samara region, Russia. Ground-trothing surveys should be undertaken within two weeks of acquiring satellite remote sensing imagery [7]. The winter field campaigns took place on 10 to 25 January 2017 and summer was on 15 to 30 August 2017. A random sampling method was used across the Samara region, around 7-8 samples selected in each class. The FieldSpec 3 ASD handheld spectrometer was used to obtain quantitative measurements of radiant energy easily and efficiently. We find eightmeagre land cove classes and their sub-classes as shown in table 2.

Table 2. Land cover classes and their sub-classes in study area.

Sr.No.	Class level I	Class level II	Class level III
1.	Water	1.1 Inland water body	1.1.1 Deep water 1.1.2 Shallow water 1.1.3 Turbid water 1.1.4 Clean water
		1.2 Lake	
		1.3 River	
2.	Vegetation	2.1 Forest	2.1.1 Conifer forest 2.1.2 Deciduous/Broadleaved forest 2.1.3 Mixed forest
		2.2 Agriculture	2.2.1 Heterogeneous agricultural area 2.2.2 Permanent crops
		2.3 Mangroves	
		2.4 Grassland	
		2.5 Sparsely vegetated area	
3.	Settlements	3.1 residential	3.1.1 Old residential 3.1.2 New residential
		3.2 Industrial	
		3.3 Park	
4.	Wetland		
5.	Bare land	5.1 Scrubland	
		5.2 Transitional woodland	
6.	Transportation	6.1 Road	6.1.1 Highway 6.1.2 Inside road 6.1.3 Concrete road
		6.2 Rail	
7.	Bare rocks		
8.	Sand dunes		

3.2. Data preprocessing

Digital image processing was manipulated in ArcGIS software. The scenes were selected to be geometrically corrected, calibrated and removed from their dropouts. All images were projected in UTM 39N, datum WGS 84 projection. Other image enhancement techniques like histogram equalization were also performed on each image for improving the quality of the image [8]. Some additional supporting data were also used in this study such as topographic sheets and field data. Digital topographical maps, 1:50,000 scale, were used for image georeferencing for the land use/cover map and for improving accuracy of the overall assessment. Using ArcMap, we made a composite raster data of OLI and ALI using Arc toolbox data management tools (fig. 2). Both images were composed of 9 and 7 different bands respectively, each representing a different portion of the electromagnetic spectrum. By combining all these bands, composite raster data were obtained (fig. 2). Table 3 shows details of OLI and ALI data.

Table 3. Left: Wavelength ranges of the OLI image. Right: Wavelength ranges of the ALI image.

OLI Bands	Wavelength (micrometers)	Resolution (meters)	ALI Bands	Wavelength (micrometers)	Resolution (meters)
Band 1 - Ultra Blue	0.435 - 0.451	30	Pan	0.48 - 0.69	10
Band 2 - Blue	0.452 - 0.512	30	MS - 1'	0.433 - 0.453	30
Band 3 - Green	0.533 - 0.590	30	MS - 1	0.45 - 0.515	30
Band 4 - Red	0.636 - 0.673	30	MS - 2	0.525 - 0.605	30
Band 5 - Near Infrared (NIR)	0.851 - 0.879	30	MS - 3	0.63 - 0.69	30
Band 6 - Shortwave Infrared	1.566 - 1.651	30	MS - 4	0.775 - 0.805	30
Band 7 - Shortwave Infrared	2.107 - 2.294	30	MS - 4'	0.845 - 0.89	30
Band 8 - Panchromatic	0.503 - 0.676	15	MS - 5'	1.2 - 1.3	30
Band 9 - Cirrus	1.363 - 1.384	30	MS - 5	1.55 - 1.75	30
			MS - 7	2.08 - 2.35	30

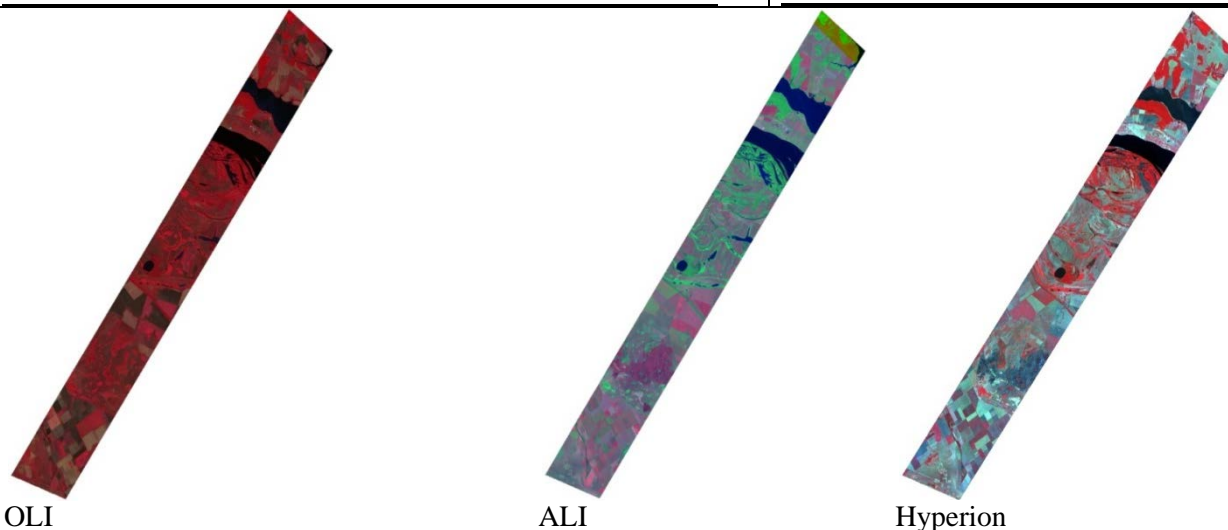


Figure 2. A sub-scene of the geometrically corrected OLI, ALI and Hyperion image over the study area in Samara region, Russia.

For pre-processing of Hyperion imagery, first georeferenced the image, subsequently were removed the non-calibrated bands of the Hyperion imagery. After this step, the resulting image was reduced to a subset of the studied region. These final 132 bands after this last pre-processing step were used in the present study (fig. 2).

3.3. Classification

In this research work we use USGS land use/cover classification system for all three images (fig. 3). For all three images, k -nearest neighbor algorithm(KNN)supervised classification and migrating means clustering unsupervised classification (MMC) approach was applied [9]. Training sites were

collected based on field data and also take help with topography maps. Initially, training sites were chosen for all 27 sub-classes derived from all three images, than all 27 sub-classes were aggregated into following 8meagre classes 1. Water; 2.Vegetation; 3.Settlements; 4.Wetland; 5.Bare land; 6.Transportation; 7.Bare rocks and 8.Sand dunes. For accuracy assessment 60 points were randomly collected in each image.

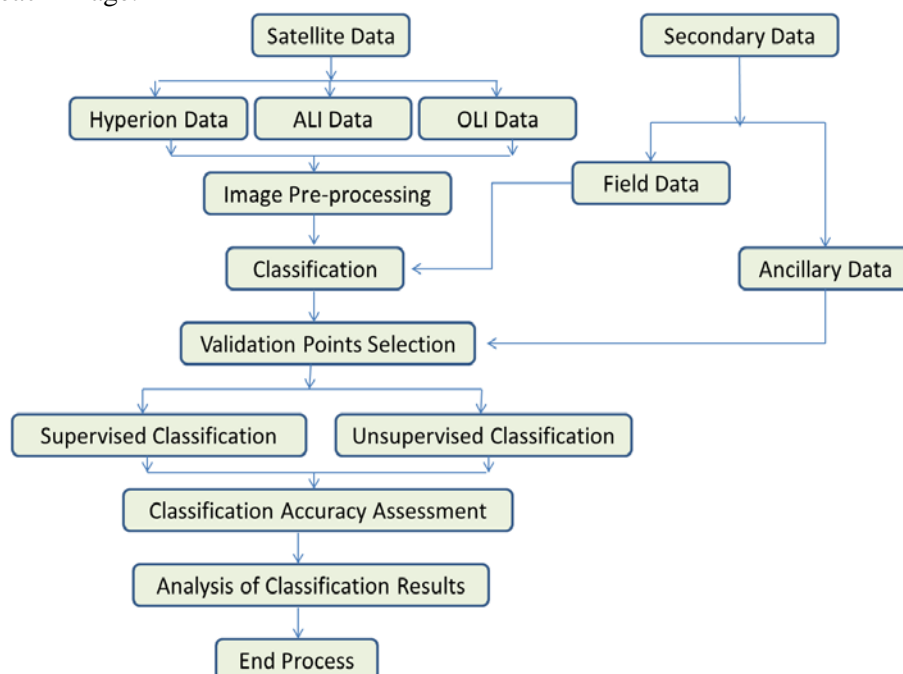


Figure 3. Flow diagram of methodological process.

3.3.1. Unsupervised classification

In unsupervised classification, image processing software classifies an image based on natural groupings of the spectral properties of the pixels, without the user specifying how to classify any portion of the image. Conceptually, unsupervised classification is similar to cluster analysis where observations (in this case, pixels) are assigned to the same class because they have similar values. The user must specify basic information such as which spectral bands to use and how many categories to use in the classification or the software may generate any number of classes based solely on natural groupings. Common clustering algorithms include K-means clustering, ISODATA clustering, and Narendra-Goldberg clustering.

Unsupervised classification yields an output image in which a number of classes are identified and each pixel is assigned to a class. These classes may or may not correspond well to land cover types of interest, and the user will need to assign meaningful labels to each class. Unsupervised classification often results in too many land cover classes, particularly for heterogeneous land cover types, and classes often need to be combined to create a meaningful map. In other cases, the classification may result in a map that combines multiple land cover classes of interest, and the class must be split into multiple classes in the final map. Unsupervised classification is useful when there is no preexisting field data or detailed aerial photographs for the image area and the user cannot accurately specify training areas of known cover type. Additionally, this method is often used as an initial step prior to supervised classification (called hybrid classification). Hybrid classification may be used to determine the spectral class composition of the image before conducting more detailed analyses and to determine how well the intended land cover classes can be defined from the image.

3.3.2. Supervised classification

In supervised classification the user or image analyst “supervises” the pixel classification process. The user specifies the various pixels values or spectral signatures that should be associated with each class. This is done by selecting representative sample sites of known cover type called Training Sites or

Areas. The computer algorithm then uses the spectral signatures from these training areas to classify the whole image. Ideally the classes should not overlap or should only minimally overlap with other classes.

In ArcGIS software there are many different classification algorithms and we can choose any from supervised classification procedure as:

- **Maximum Likelihood:** Assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. Each pixel is assigned to the class that has the highest probability (that is, the maximum likelihood). This is the default.
- **Minimum Distance:** Uses the mean vectors for each class and calculates the Euclidean distance from each unknown pixel to the mean vector for each class. The pixels are classified to the nearest class.
- **Mahalanobis Distance:** A direction-sensitive distance classifier that uses statistics for each class. It is similar to maximum likelihood classification, but it assumes all class covariance are equal, and therefore is a faster method. All pixels are classified to the closest training data.
- **Spectral Angle Mapper: (SAM)** is a physically-based spectral classification that uses an n -Dimension angle to match pixels to training data. This method determines the spectral similarity between two spectra by calculating the angle between the spectra and treating them as vectors in a space with dimensionality equal to the number of bands. This technique, when used on calibrated reflectance data, is relatively insensitive to illumination and albedo effects.
- **K-nearestneighbour algorithm (KNN):** K nearest neighbour is a simple algorithm that stores all available cases and classifies new cases based on a similarity measure (e.g., distance functions). KNN has been used in statistical estimation and pattern recognition already in the beginning of 1970's as a non-parametric technique. Pattern recognition is the scientific discipline whose goal is the classification of objects into a number of categories or classes. Depending on the application, these objects can be images or signal waveforms or any type of measurements that need to be classified. We will refer to these objects using the generic term patterns.

In supervised classification the majority of the effort is done prior to the actual classification. Once the classification is run the output is a map with classes that are labelled and correspond to information classes or land cover types. Supervised classification can be much more accurate than unsupervised classification, but depends heavily on the training sites, the skill of the individual processing the image, and the spectral distinctness of the classes. If two or more classes are very similar to each other in terms of their spectral reflectance (e.g., annual-dominated grasslands vs. perennial grasslands) misclassifications will tend to be high. Supervised classification requires close attention to development of training data. If the training data is poor or not representative the classification results will also be poor. Therefore supervised classification generally requires more time and money compared to unsupervised classification.

3.3.3. Classification accuracy assessment

Accuracy assessment of the thematic maps produced from the implementation of the supervised and unsupervised classification techniques on Hyperion, ALI and OLI imagery was also performed in ArcGIS based on the confusion matrix analysis [10]. As a result, the overall (OA), user's (UA) and producer's (PA) accuracies and the Kappa (Kc) statistic were computed. The OA provides a measure of the overall classification accuracy and is expressed as percentage (%). OA represents the probability that a randomly selected point is classified correctly on the map. Kc provides a measure of the difference between the actual agreement between reference data and the classifier used to perform the classification versus the chance of agreement between the reference data and a random classifier. PA indicates the probability that the classifier has correctly labelled an image pixel. UA expresses the probability that a pixel belongs to a given class and the classifier has labelled the pixel correctly into the same given class. In performing the accuracy assessment herein, a total of 60 sampling points for the different classes were selected (approximately 25 pixels per class) directly from the imagery following a random sampling strategy, and these points formed our validation dataset. Selection of

those validation points was performed following exactly the same criteria used for the selection of training points, described earlier (Section 3.3.2). For consistency, the same set of validation points were used in evaluating the accuracy of the land use/cover thematic maps produced.

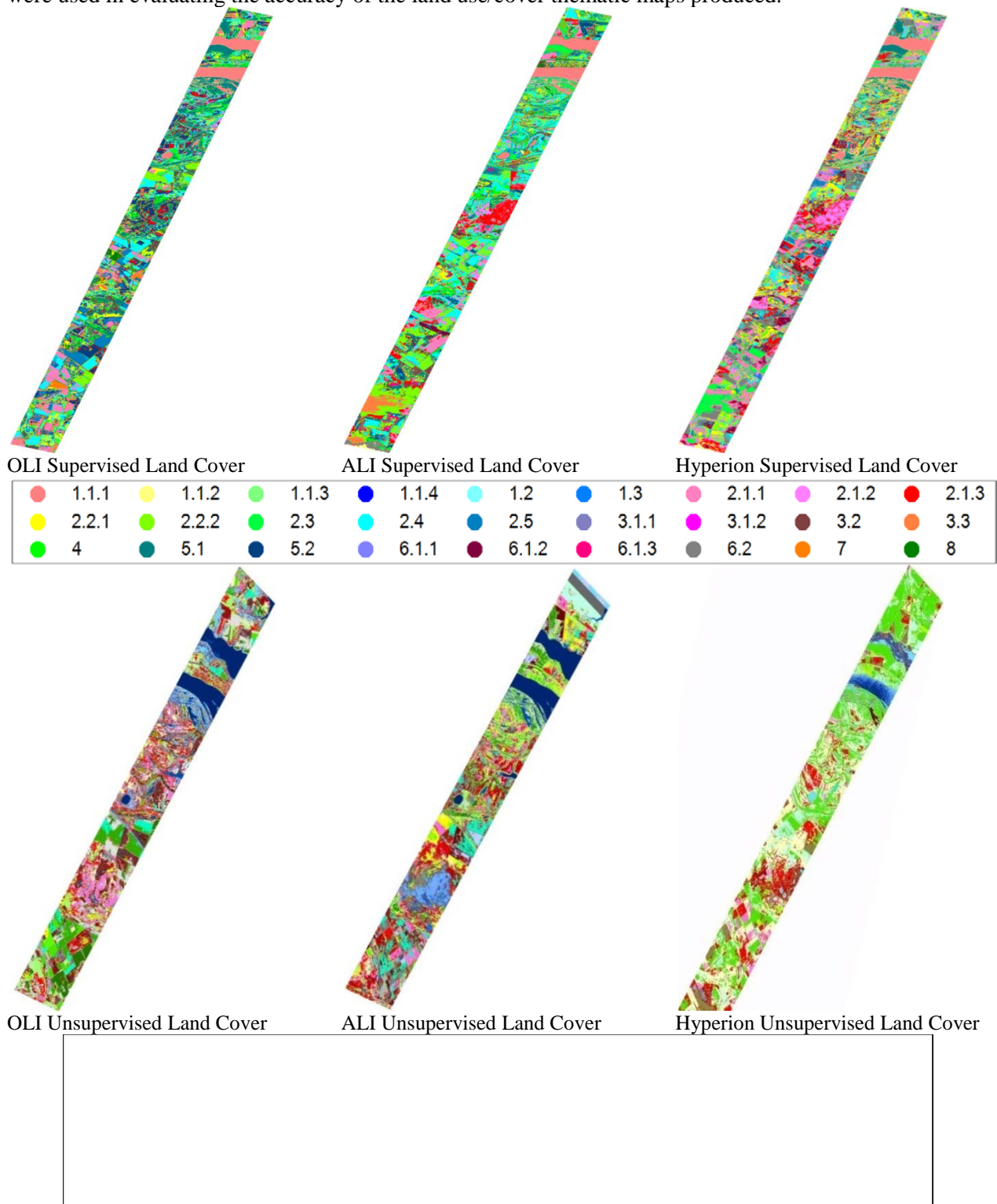


Figure 4. OLI, ALI and Hyperion images classified land cover maps by supervised and unsupervised classification methods.

4. Results and discussion

The LULC maps produced by supervised and unsupervised classification on Hyperion, ALI and OLI data acquired over the study region are demonstrated in figure 4. The statistical results of classification accuracy assessment are shown in table 4. On the basis of accuracy assessment results, it appears that supervised classification somehow better results than unsupervised classification in overall accuracy and individual classes accuracy. Results indicate that for KNN the overall accuracy was 95, 94, 88 and kappa coefficient .91, .89, .85 for Hyp, ALI, OLI respectively, whereas for unsupervised it was 93, 90, 84 overall accuracy and .89, .87, .81 kappa coefficient for Hyp, ALI, OLI respectively. Among the two classifiers, supervised classification was the best in describing the spatial distribution and the cover density of each land cover category, as was also indicated from the statistics of the individual classes' results produced (table 4).

In all classes similar patterns were easily identified in both classification. PA and UA for the supervised classification ranged between the classes from 86% to 99%, and from 79% to 94%, whereas for unsupervised classification varied from 82% to 95% and from 75% to 92% respectively. In both classification the highest accuracy were in turbid water, permanent crops, sparsely vegetated area and bare rocks classes, followed by deep water, industrial, mixed forest, grassland, highway and sand dunes classes. In individual classes the lowest PA and UA in both classifications were shallow water, clean water, turbid water, grassland and highway classes. For all three data the highest PA and UA present in Hyperion data and lowest value present in OLI data. This was perhaps due to the similar spectral characteristics between the two classes, which was affected by the mixed pixels, caused by the low density of these vegetation types and combined with the low spatial resolution of the sensors.

So overall we can say supervised classification is better than unsupervised classification. In unsupervised classification algorithms require the analyst to assign labels and combine classes after the fact into useful information classes (e.g. forest, agricultural, water, etc). In many cases, this after the fact assignment of spectral clusters is difficult or not possible because these clusters contain assemblages of mixed land cover types. Generally speaking, unsupervised classification is useful for quickly assigning labels to uncomplicated, broad land cover classes such as water, vegetation/non-vegetation, forested/non-forested, etc). Furthermore, unsupervised classification may reduce analyst bias. But supervised classification allows the analyst to fine tune the information classes--often too much finer subcategories, such as species level classes. Training data is collected in the field with high accuracy GPS devices or expertly selected on the computer. Consider for example if you wished to classify percent crop damage in corn fields. A supervised approach would be highly suited to this type of problem because you could directly measure the percent damage in the field and use these data to train the classification algorithm. Using training data on the result of an unsupervised classification would likely yield more error because the spectral classes would contain more mixed pixels than the supervised approach. Similarly, collecting in the field crop species training data is preferable to expertly selecting pixels on screen as it is often very difficult to determine which crops are growing visually. That's why supervised classification is outperformed the unsupervised classification. When we compare both classification in hyperspectral and multispectral data, results show that supervised classification have highest accuracy, which authors attributed to the supervised ability to locate an optimal separating hyperplane [11].

5. Conclusions

The accuracy assessment results show that supervised classification is better than unsupervised classification for all three (Hyperion, ALI and OLI) imagery. The higher classification accuracy reported by supervised classification is mainly attributed to the fact that this classifier has been designed as to be able to identify an optimal separating hyperplane for classes' separation, which the unsupervised may not be able to locate. This research found that, data analysis of hyperspectral imagery has the potential for improving classification accuracies of land cover and land use over multispectral imagery with the same resolution. If images were acquired the same day and time, then accuracies would be even more comparable. The latter, from an operational perspective, can be of particular importance particularly in the Mediterranean basin, since it can be associated to the mapping

and monitoring of land degradation and desertification phenomena which are frequently pronounced in such areas.

Table 4. Summary of the results from the classification accuracy assessment conducted.

Land cover classes	Supervised Classification						Unsupervised Classification					
	Producer's accuracy (%)			User's accuracy (%)			Producer's accuracy (%)			User's accuracy (%)		
	Hyp	ALI	OLI	Hyp	ALI	OLI	Hyp	ALI	OLI	Hyp	ALI	OLI
1.1.1 Deep water	98	91	88	90	83	84	95	86	85	88	80	81
1.1.2 Shallow water	94	93	86	87	86	78	92	90	82	85	81	75
1.1.3 Turbid water	99	93	87	91	86	79	94	90	84	90	82	76
1.1.4 Clean water	95	92	87	87	86	78	91	87	83	86	83	75
1.2 Lake	95	93	87	87	85	82	90	91	82	84	81	80
1.3 River	91	93	88	85	88	80	88	90	85	81	85	79
2.1.1 Conifer forest	94	93	88	89	86	82	89	89	86	84	82	80
2.1.2 Deciduous/ Broadleaf forest	92	99	92	83	92	86	90	96	90	80	90	81
2.1.3 Mixed forest	92	97	92	84	91	86	91	94	90	81	89	82
2.2.1 Heterogeneous agricultural area	94	92	90	87	86	81	90	87	89	83	82	80
2.2.2 Permanent crops	99	92	90	94	88	85	95	88	89	92	85	81
2.3 Mangroves	96	93	91	91	88	87	92	90	90	90	83	85
2.4 Grassland	95	97	88	89	91	79	91	94	85	86	90	76
2.5 Sparsely vegetated area	99	92	88	91	84	82	96	88	84	90	81	81
3.1.1 Old residential	95	94	86	90	88	81	91	90	82	89	83	80
3.1.2 New residential	94	94	87	85	85	80	90	90	84	82	80	77
3.2 Industrial	98	94	89	93	88	85	95	91	86	91	84	81
3.3 Park	93	93	87	88	85	81	90	90	85	86	81	78
4. Wetland	94	93	88	86	88	80	91	90	84	84	86	79
5.1 Scrubland	96	92	88	89	88	81	91	89	84	85	85	78
5.2 Transitional woodland	95	92	95	87	85	85	90	90	92	83	80	82
6.1.1 Highway	94	97	87	89	91	79	89	94	84	86	90	76
6.1.2 Inside road	92	99	87	86	94	81	88	95	83	82	91	80
6.1.3 Concrete road	93	92	86	85	86	81	87	89	82	81	82	77
6.2 Rail	96	96	87	86	86	81	90	91	82	81	81	79
7. Bare rocks	99	94	88	94	86	83	94	90	85	91	83	81
8. Sand dunes	95	97	88	89	88	84	91	92	86	86	86	82
Overall accuracy	95	94	88				93	90	84			
Kappa coefficient	.91	.89	.85				.89	.87	.81			

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