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Performance evaluation of spectral indices and classification algorithms for built-up area extraction using PRISMA hyperspectral images

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Abstract

This article aims to evaluate and compare NDBI, NBI, PB1BI and HIBI spectral indices and SVM, ANN and MLC classification algorithms in order to identify and extract urban constructions using Prisma hyperspectral images. took The findings of this research indicate that the classification algorithms in both Tehran and Urmia have higher accuracy than the spectral indices; So, in Tehran city, PB1BI and HIBI indices have higher accuracy than NDBI and NBI indices with overall accuracy of 85% and 86% and kappa coefficient of 70% and 72% respectively from left to right. On the other hand, in Urmia city, NBI indices with 88% overall accuracy and 77% kappa coefficient and NDBI with 87% overall accuracy and 75% kappa coefficient showed better performance than PB1BI and HIBI indices. Also, in Urmia city, the overall accuracy and Kappa coefficient of SVM and ANN classification algorithms were more accurate than MLC with over 90%. Also, in the city of Tehran, SVM and ANN algorithms with overall accuracy and high Kappa coefficient of 90% and 83% performed better than the MLC algorithm. In general, according to the effectiveness of various factors including the scope of the study, the spectral range used, the type of roof of the buildings, the types of uses, etc., the combined and comparative use of indices and spectral algorithms improves the results.

1. Introduction

Urban areas usually cover a small portion of land around the world. However, the high population density and intensity of resource use compared to the surrounding environment make these areas very important areas of the earth (Firouzjaei et al. 2023). Population growth in urban areas leads to the expansion of built-up areas (Shahfahad et al, 2020).

Urbanization is increasing rapidly and it is predicted to increase to seven hundred to one million square kilometers by 2030 (Angel et al., 2005). In Iran, major changes in urban areas, especially big cities, have become more important due to the occurrence of fundamental changes (Eisizadeh et al. 2022).

Remote sensing technologies provide a reliable source of urban land cover/land use data collection. NASA's Landsat satellite data series (e.g., MSS, TM, and ETM+) have been widely used to map urban extent and monitor urban growth (Zhang et al., 2014).

Satellite data have also been used to calculate built-up extent, and these images are useful due to their historical availability and large-scale spatial coverage (Guindon et al. 2004).

In this study, data from the new Prisma hyperspectral satellite was used. In fact, using this new satellite, urban areas have been extracted to a limited extent. The purpose of the current study is to evaluate and compare new indicators of urban construction with classification algorithms in the extraction of urban construction.

2. Method

In this study, Prisma hyperspectral satellite images and a set of spectral indices and classification algorithms are used to extract and identify urban areas in the two cities of Tehran and Urmia in Iran.

2.1 Case Study

Tehran, as the capital of Iran, is located at 51° 6' to 51° 38' east longitude and 35° 34' to 35° 51' north latitude, and its height from the open water level is between 1800

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meters in the north to 1200 m in the center and 1050 m in the south is variable (Figure 2).

The city of Urmia is one of the metropolises of Iran, the capital of West Azarbaijan province and the city of Urmia in the northwest of Iran, which is located in the Azarbaijan region. This city is located on an orbit of 37 degrees and 32 minutes in the northern hemisphere from the equator. Also, this city is located on the meridian of 45 degrees and 2 minutes east of the Greenwich meridian, and the height of Urmia is 1,332 meters above sea level (Figure 1).

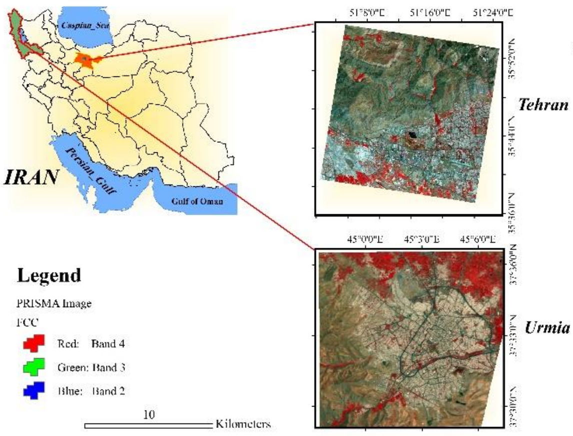

Figure 1. Geographical location of the study area

2.2 Datasets

PRISMA satellite or in other words (PRecursore IperSpettrale della Missione Applicativa) is a medium resolution hyperspectral satellite. This satellite was placed into Earth orbit in 2019 by the Italian Space Agency (ASI). The bands of this satellite include 250 bands that cover wavelengths from 400 to 2500 nm. Table (1) shows the complete specifications of the PRISMA satellite (Galeazzi et al, 2008 and Candela et al, 2016).

Table 1. Complete specifications of the PRISMA satellite

City	Spectral range (nm)	Spatial resolution (m)	Date of Acquisition
Tehran Urmia	VNIR:400-2505 PAN: 400-700	30 5	2020-8-2 2022-7-12

2.3. Data Processing

To extract and identify residential areas, Normalized Difference Built-up Index (NDBI), New Built-up index (NBI), powered B1 built-up index (PB1BI) and Hyperspectral Imagery-based Built-up Index (HIBI) (Jieli et al, 2010; Zha et al, 2010; Mukherjee et al, 2020; Gaur et al, 2023) and statistical classification algorithms, neural network and machine learning are used.

$$NBI = \frac{Red \times Swir2}{Nir}$$

$$NDBI = (SWIR - NIR) \,/\, (SWIR + NIR)$$

$$PB1BI = \frac{(Blue)^{a}}{(Red)^{\beta} \times (Nir)^{y}}; a, \beta, y > 0. \qquad a = 10.5,\ \beta = 5,\ y = 3.5$$

$$HIBI = \frac{BLUE(\lambda = 492.69nm) - NIR(\lambda = 959.52nm) - SWIR1(\lambda = 1626.78nm)}{BLUE(\lambda = 492.69nm) + NIR(\lambda = 959.52nm) + SWIR1(\lambda = 1626.78nm)}$$

In this regard, after applying the indices on the images of Tehran and Urmia cities, the threshold limit is used to separate the pixels related to Built-up areas from other pixels. The final output of indicators was classified into two classes: Built-up and No-Built up. On the other hand, to extract and identify residential areas using classification algorithms, 200 training data were taken on each of the images for Built-up and No-Built-up classes.

In the following, a number of ground control samples were taken from Google Earth's high spatial resolution photos to be used to evaluate the accuracy of the results of classification algorithms and indices using the Confusion matrix.

3 Results

Table (2) shows the thresholds extracted from spectral indices related to Built_up and NoBuilt_up classes for the cities of Tehran and Urmia.

Table 2. Spectral indices

Index	Tehran	Urmia
NBI	Built_up: 0.22 - 0.64 NoBuilt up: 0.00 - 0.85	Built up: 0.31 - 0.68 NoBuilt up: 0.00 - 0.84
HIBI	Built_up: -2.25 - 0.45 NoBuilt up: -60.31 - 0.87	Built_up: -2.61 - 0.48 NoBuiltup: -49.07 -0.48
PB1BI	Built_up: 0.00 - 12.02 NoBuilt up : 0.00 - 12.02	Built_up: 0.00 - 0.11 UnBuilt_up: 0.00 - 0.0048
NDBI	Built_up: -0.29 - 0.85 NoBuilt up: -2.36 - 0.94	Built_up: -0.01 - 0.91 UnBuilt_up: -3.31 - 0.91

The results of evaluating the accuracy of the results of spectral indices and classification algorithms in order to extract residential areas are given in Tables (3 and 4).

Table 3. Evaluation of accuracy of Tehran city results

Index/ Algorithm	Overall Accuracy (%)	Kappa (%)
NBI	69.87	38.49
HIBI	85.35	70.30
PB1BI	86.61	72.51
NDBI	65.69	37.36
SVM	92.46	84.52
ANN	91.63	83.63
MLC	89.95	79.41

The findings of this research indicate that in Tehran, PB1BI and HIBI indexes have higher accuracy compared to NDBI and NBI indexes, both visually and in terms of accuracy evaluation criteria. On the other hand, in Urmia, NBI, NDBI and PB1BI indices have the highest accuracy and HIBI index has lower accuracy than other indices. In this regard, as shown in Tables (3 and 4), in both Tehran and Urmia cities, SVM and ANN classification algorithms have the highest accuracy compared to MLC algorithm. In general, as can be cited from the results, the classification algorithms in both Tehran and Urmia have higher accuracy than the spectral indices, and the percentage of correct pixels assigned to the Built-up class and No-Built up is more in them. Figure (2 and 3) shows the results of spectral indices and classification algorithms for identifying and extracting urban areas.

Table 4. Evaluation of accuracy of Urmia city results

Index/ Algorithm	Overall Accuracy (%)	Kappa (%)
NBI	88.59	77.16
HIBI	84.21	65.90
PB1BI	85.96	70.70
NDBI	87.71	75.67
SVM	96.49	92.60
ANN	94.73	90.07
MLC	92.98	84.97

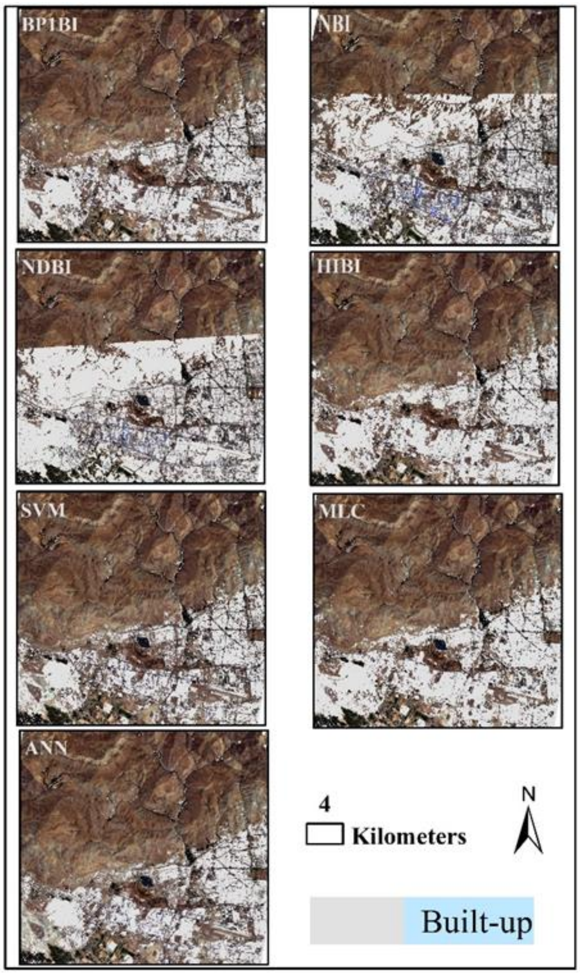

Figure 2. Map of built-up areas extracted from spectral indices and classification algorithms (Tehran)

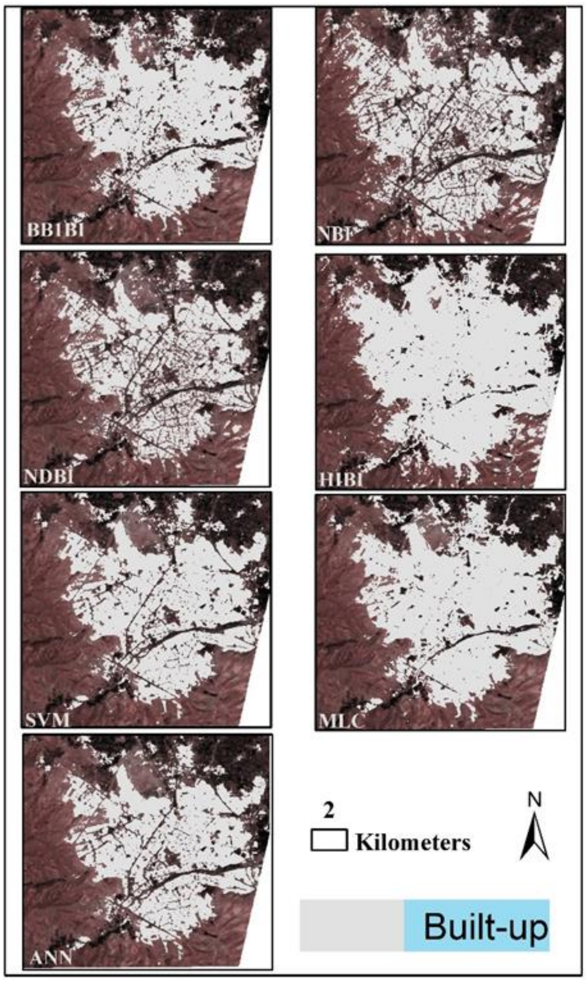

Figure 3. Map of built-up areas extracted from spectral indices and classification algorithms (Urmia)

4 Discussion

Due to continuous urbanization, land cover in urban areas is continuously developing in a short period of time compared to other areas. Therefore, the use of remote sensing, especially hyperspectral images, due to the multiplicity of its production bands, can be fruitful in order to identify and discover built-up areas. This article is done with the aim and comparative comparison of NDBI, NBI, PB1BI and HIBI production indices and SVM, ANN and MLC classification algorithms in order to identify and discover urban constructions using Prisma hyperspectral images.

As shown in Figure (2 nd 3), even though the Prisma images have a spatial resolution of 30 meters, in both Tehran and Urmia, the NDBI and NBI indices have been able to distinguish the built from the roads with high accuracy. In the meantime, although SVM and ANN classification algorithms are not very accurate in separating buildings from roads compared to other indicators and MLC classification algorithm, they perform well in separating buildings in places where the roads are wider. On the other hand, as seen in the center of the image in Tehran, there are gabled buildings with blue roofs, which the PB1BI and HIBI spectral indices were able to fully consider as built-up areas, while the NDBI and NBI indices performed poorly. In this regard, PB1BI and HIBI have not been able to separate the water area of the artificial lake from the built areas in the north of Tehran, which can be due to the presence of water area in the calculation of these indicators. In fact, areas with high reflectivity in the blue band range are considered as built-up areas. In this regard, one of the challenges faced by most indices, especially the NDBI and NBI indices, is the separation of bare soil and built-up areas; Since bare soil ranges are very similar to built up areas. Therefore, this has caused spectral integration between these two classes more than other complications. As seen in Figure (3), most of this spectral integration can be seen in the city of Tehran, and the reason for this is the presence of bare soil in the north and west of Tehran. In fact, these areas have a reflection similar to built-up areas. And the presence of high spectral integration has caused the results of Tehran city to be less accurate than the results of Urmia city. Meanwhile, the poor performance of NDBI and NBI indices compared to other indices is due to the greater influence of the SWIR band, where bare soil also has a high reflectance. In general, what is important from the findings of the research is that classification algorithms have performed better than spectral indices in identifying and extracting residential areas, and one of the important reasons is the direct participation of the user in the selection of training samples.

5 Conclusion

In this research, by using Prisma hyperspectral images and construction spectral indices as well as machine learning, statistical classification algorithms and artificial intelligence, urban built areas in Tehran and Urmia cities were separated from other complications. The findings of this research show that classification algorithms have performed better than spectral indices in identifying and extracting urban built-up area. In this regard, the findings indicate that each spectral index has strengths and weaknesses; So that each of these spectral indices will perform differently according to various factors such as the studied area, the spectral range used, the type of roof of the buildings, the types of uses, etc. Therefore, the combined use and comparison of spectral indices and classification algorithms together can greatly improve the results.

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