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Lineer Spektral Unmixing Yöntemi Kullanılarak Kentsel Değişimin Haritalanmasi

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Anahtar Kelimeler
Kentsel Büyüme,
LANDSAT,
Spektral Karışım Analizi,
Spektral Unmixing,

ÖZ

1950'li yıllardan itibaren dünyada artış gösteren kentleşme Türkiye'de ise 1980'lerden sonra ivme kazanmıştır. Bu artışta tarım ekonomisinin kısıtlı olması, iş ve eğitim olanaklarının yetersizliği nedeniyle kırsal kesimden kentlere göçler temel rol oynamıştır. Bu göçler sanayileşmenin ön planda olduğu İstanbul, Ankara ve İzmir gibi büyük şehirlere olmuştur. Kentleşmedeki bu artış kentlerin kontrolsüz büyümesi, plansız altyapı ve doğal kaynakların yanlış kullanılması gibi sorunlara yol açmaktadır. Kentsel çevredeki bu değişimlerin izlenmesinde klasik dijital görüntü işleme yöntemleri ile elde edilen "maksimum olabilirlik" ve "isodata" sınıflandırma tekniklerinin kullanıldığı arazi örtüsü ve arazi kullanımı haritaları kullanılmaktadır. Ancak elde edilen bu tematik haritalarda özellikle mekânsal çözünürlüğü düşük uydu verilerinin kullanıldığı heterojen arazilerde hatalı sınıflandırma sonuçları ortaya çıkabilmektedir. Bunun nedeni, her pikselin yalnızca bir sınıf değeri ile temsil edilmesidir. Bu kısıtlamayı ortadan kaldırmak için bu çalışmada spektral karışım analizi kullanılmıştır. Spektral karışım analizi ile her bir piksel kendisini oluşturan uç üye (endmember) fraksiyonları ile temsil edilir. Lineer karma modele dayalı bu analizle birlikte yeryüzü substrat (S), yeşil bitki örtüsü (V) ve karanlık yüzeyler (D) olarak spektral uç üye projeksiyonlarında daha hassas bir şekilde temsil edilir. Bu çalışmada, İstanbul'a ait farklı tarihlerde elde edilmiş LANDSAT görüntülerine spektral karışım analizi uygulanarak kentte meydana gelen arazi örtüsü ve arazi kullanımı değişimleri belirlenmiş; kentsel büyüme izlenmiş ve analiz edilmiştir.

Mapping Urban Change by Using Linear Spectral Unmixing Method

Keywords
Urban Growth,
LANDSAT,
Spectral Mixture Analysis,
Spectral Unmixing

ABSTRACT

Urbanization, which has increased in the world since the 1950s, gained momentum in Turkey after the 1980s. Migration from rural areas to cities played a key role in this increase due to the limited agricultural economy and the inadequacy of employment and education opportunities. These migrations have been to big cities such as Istanbul, Ankara and Izmir, where industrialization is at the forefront. This increase in urbanization causes problems such as uncontrolled growth of cities, unplanned infrastructure and misuse of natural resources. To monitor these changes in the urban environment, land cover and land use (LCLU) maps, which are obtained by classical digital image processing methods and using "maximum likelihood" and "isodata" classification techniques, are used. However, in these thematic maps obtained, incorrect classification results may occur, especially in heterogeneous terrains where satellite data with low spatial resolution are used. This is because each pixel is represented by only one class value. In order to eliminate this limitation, spectral mixture analysis was used in this study. With spectral mixture analysis, each pixel is represented by its constituent endmember fractions. With this analysis based on a linear mixed model, the earth is represented more precisely in the spectral endmember projections as substrate(S), green vegetation (V), and dark surfaces (D). In the study, LCLU changes in the city were determined by applying the spectral mixture analysis to the LANDSAT images of Istanbul obtained on different dates; urban growth has been monitored and analyzed.

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1. INTRODUCTION

In Turkey, the percentage of population living in cities was 25% in 1950 increasing to 43% in 1980 and to 93% in 2021 (TurkStat, 2021). There have been large cities like Istanbul, Ankara, Izmir, Adana, Bursa and Antalya which draw migrations and where urban change is being experienced (Maktav & Erbek 2005; Maktav et al. 2005). In 1980, 10% of Turkey's population was living in Istanbul (4,741,890) and then this increased to 19% by 2021 (15,840,900) (TurkStat 2021). Compared to the other cities in Turkey, Istanbul provides better economic opportunities as it has more industrial and trade areas. Therefore, migrations to the city continues from the other regions of the country (Geymen & Baz 2008).

However, Istanbul is located very close to the NAF which is one of the most energetic and hazardous earthquake zones in the world. This strike-slip fault system extends along northern Turkey for more than 1500 km from 41^{o}E to 29^{o}E and accommodates about 25 mm/year right-lateral slip between Anatolia and Eurasian plate (McHugh et al. 2014; Straub et al. 1997). The NAF has been unusually active seismically since the 20th century and it has been rupturing in a sequence of large earthquakes from east to west, starting in 1939 (Barka 1996; Cormier et al. 2006; Fichtner et al. 2013). Therefore, it is important to monitor the urban changes in the city.

It is known that rapid increase in urbanization generally causes problems such as unplanned infrastructure and unregulated development of hazard-prone areas. This unplanned and unregulated urbanization may also lead to the misuse of and damage to green areas, cultivated areas and natural resources like water sources (Al-Rawashdeh & Saleh 2006). Urban growth and development have conventionally been mapped using discrete thematic classification methods such as isodata and maximum likelihood algorithms. However, each pixel is only represented by one class value in such techniques. This generally lead to low classification accuracy for the mixed pixels that represent most urban land cover (Shanmugam et al. 2006).

The problem of spectral heterogeneity and inaccurate discrete classification can be resolved by using continuous field depictions of land cover like those provided by linear spectral mixture models (Adams et al. 1993; Gillespie et al. 1990). The spectral mixture analysis (SMA) has been widely used to divide mixed pixels into its components. The consistency of the spectral mixing space for a variety of environments suggests that a simple three-component linear mixture model may provide a consistent, general characterization of Landsat land surface reflectance. The three-component linear mixture model based on SVD endmembers. Once the dimensionality of the mixing space is determined and endmembers chosen, it is straightforward to invert the linear mixture model for endmember fraction estimates. Inversion of the linear mixing model for each image pixel yields fraction estimates for each endmember (Small 2004). In linear mixture model, the substrate endmember (S) represents a variety of soil, rock and impervious surfaces, the vegetation endmember (V) represents green vegetation and the dark surface endmember (D) represents water, shadow and nonreflective surfaces.

2. METHOD

2.1. Study Area & Data

Being within the borders of Marmara Region to the northwest of Turkey, Istanbul has approximately 5343 km^2 of surface area. The Bosporus Strait, connecting the Sea of Marmara to the Black Sea splits the city in two pieces which are Asia (on the east) and Europe (on the west) (Fig. 1).

Figure 1. Study area

In this study, Landsat images, which have 30m spatial resolution, from 12/06/1984 (TM), 02/07/2000 (ETM+) and 23/06/2011 (TM) were used. These data were processed as Level 1 terrain-corrected (L1T) data and they were available in GeoTIFF format in the UTM map projection with WGS84 datum. L1T processing includes radiometric correction, systematic geometric correction, precision correction using ground control points, and the use of a digital elevation model to correct parallax error due to local topographic relief. ENVI 4.8 software was used for exoatmospheric calibration and spectral unmixing.

2.2. Method

Firstly, potential Landsat images were selected and downloaded from USGS-Glovis in this study. Images from 1984, 2000 and 2011 were chosen among the Landsat data to monitor and analyze the urban change areas within the study area. Special attention was paid for cloudlessness or cloudy ratio to be less than 10% while choosing these data. Images collected under similar solar elevation conditions were used to minimize differences in illumination and shadow extent. Exoatmospheric calibration process was applied before applying the SMA method to selected images. Under normal conditions, spectral radiance sensed by Landsat sensors is stored as 8-byte DN. But these values should be converted to radiance and then to top of atmosphere reflectance (ToA) values to minimize the changes arising from the sun - earth distance, solar geometry and spectral band gain differences. This process is important for Landsat data which are used for long time periods or wide areas.

A linear spectral mixture model was used to unmix the calibrated images. This mixing space topology may be represented accurately through the standardized spectral endmembers (Small 2004). The endmembers used in this study consist of global SVD endmembers acquired by the assessment of images which may be applied for the worldwide study area and which are selected from different 100 geographical regions (Small & Milesi, 2013). The globally representative mixing space has used a collection of 100 Landsat TM and ETM subscenes. Principal component analysis of the global composite indicates that 98% of the spectral variance can be represented within a 3D spectral mixing space.

The mean SVD endmembers have defined a standard global mixture model for Landsat spectra (Small 2004). The standardized mixture models have provided consistency, rapid applicability and simplicity.

These SVD endmembers which are being used on global scale and mixed pixels are represented in percentages and a linear spectral mixture model was obtained. δSVD maps were also prepared by taking the differences of SVD layers obtained for different dates.

These difference maps obtained are important in terms of determining the changes occurring on LCLU in long time periods. Also, analyses were conducted using the S layers from the three different years selected especially for the assessment of changes in urbanization.

3. RESULTS

Analyses and results especially in Istanbul have been carried out detailed due to rapid urbanization and complexity of the city. LCLU changes in both sides of Istanbul were mapped and analysed and generating SVD and tri-temporal substrate map were explained detailed for the city. Moreover, color composites of fraction maps were generated for Istanbul.

Figures 2, 3 and 4 have shown Landsat false color images using 7-4-2 band combination. Substrate, vegetation and dark surface fraction images was generated using SMA for 1984, 2000 and 2011. Figures 5, 6 and 7 have shown substrate fraction since 1984. Fraction values range from 0 to 1 and 0 value corresponds to 0% substrate cover, while 1 value corresponds to 100% substrate cover.

According to these substrate fraction maps, substrate fraction has increased dramatically from 1984 to 2000. Especially new urban area needs have resulted in to increase of substrate in the city.

Also, there has been slightly increase in substrate fraction from 2000 to 2011 and this increase has been detected towads out of the city.

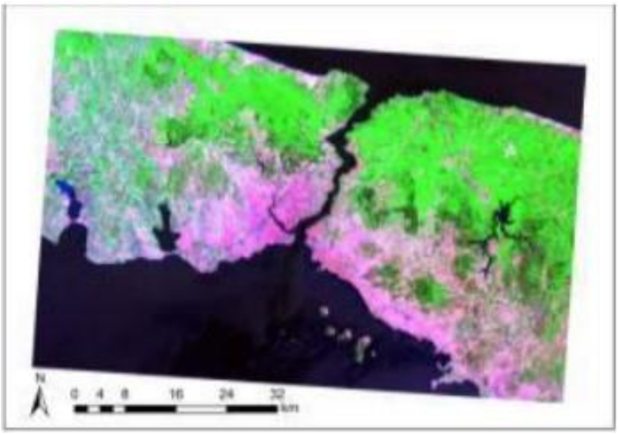

Figure 2. Calibrated Landsat TM (1984)

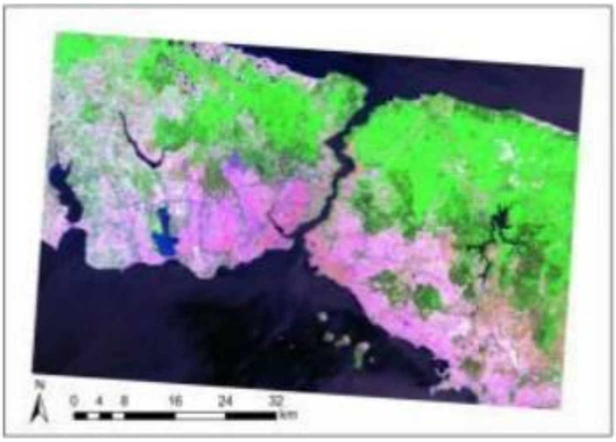

Figure 3. Calibrated Landsat ETM (2000)

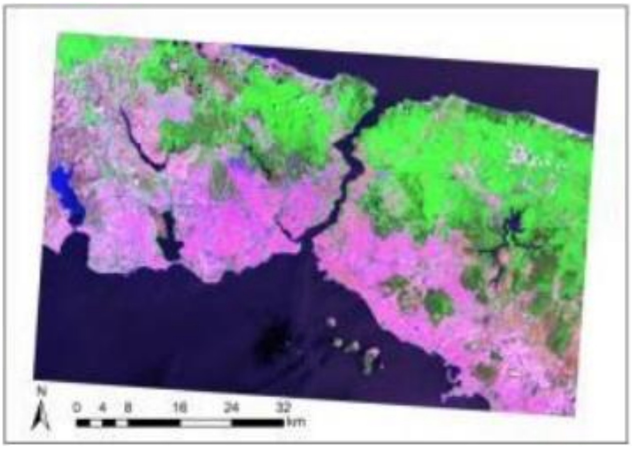

Figure 4. Calibrated Landsat ETM (2011)

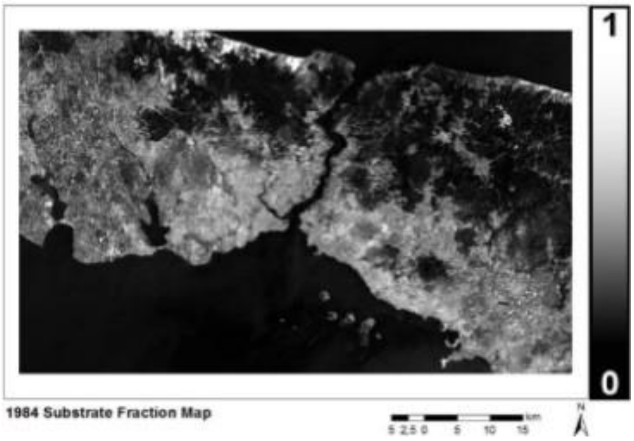

Figure 5. Substrate fraction map of Istanbul (1984)

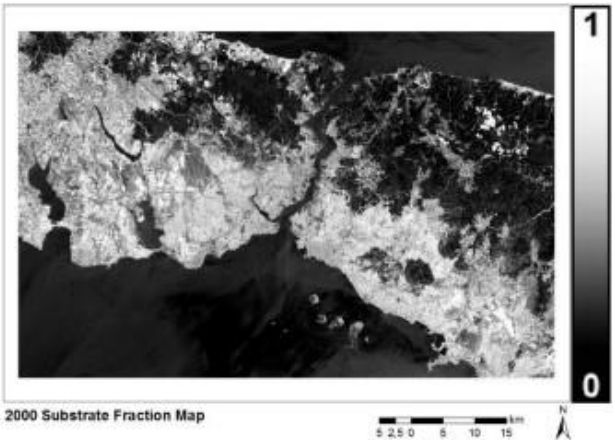

Figure 6. Substrate fraction map of Istanbul (2000)

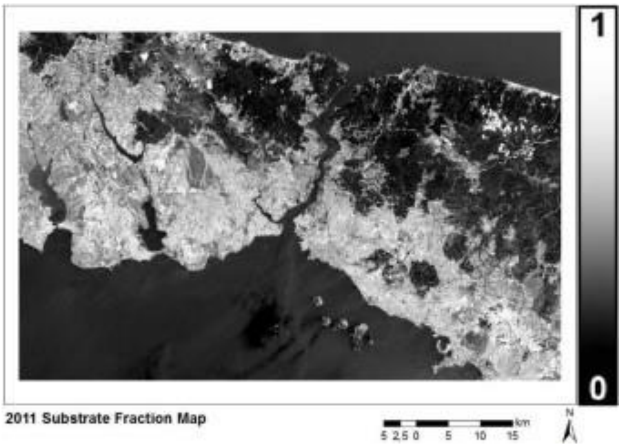

Figure 7. Substrate fraction map of Istanbul (2011)

Correspondingly, vegetation and dark surface fractions were generated respectively. In the next step, color composites of the fraction maps have been generated (Figures 8, 9 and 10). These maps have shown changes in substrate, vegetation and dark surface fraction for the selected years. Similarly, these maps have verified that urban expansion have increased in the city since 1984.

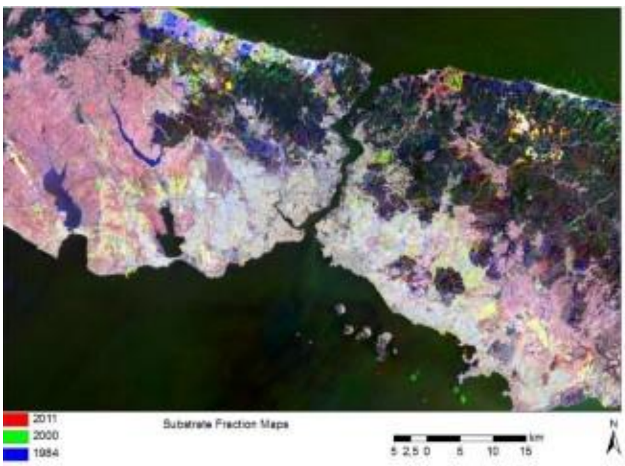

Figure 8. Color composite of substrate fractions

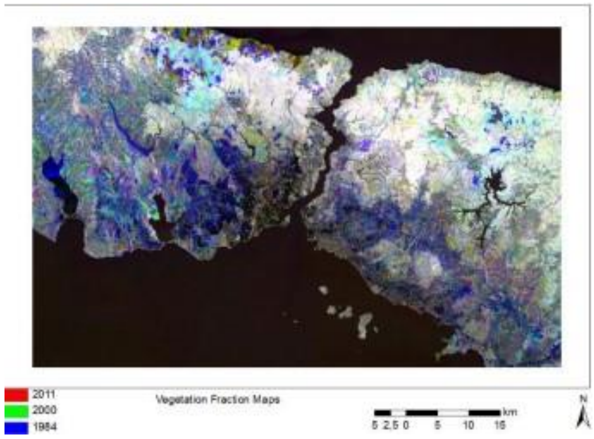

Figure 9. Color composite of vegetation fractions

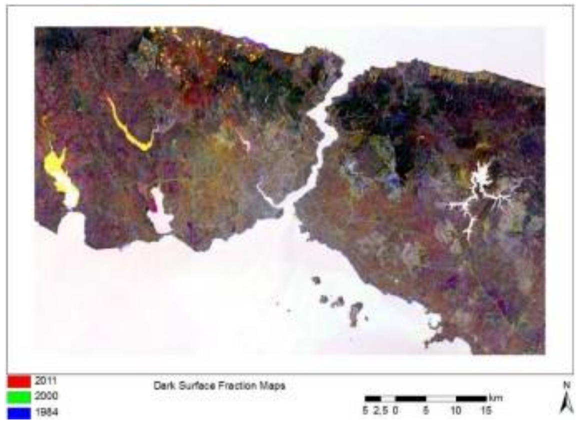

Figure 10. Color composite of dark surface fractions

SVD linear mixture model was applied and SVD maps were generated using the global endmembers (Figures 11, 12 and 13). DSVD fraction maps were obtained by taking the differences of SVD values from selected different years. These maps have shown the changes in -S-, -V- and -D- values (Figures 14, 15 and 16).

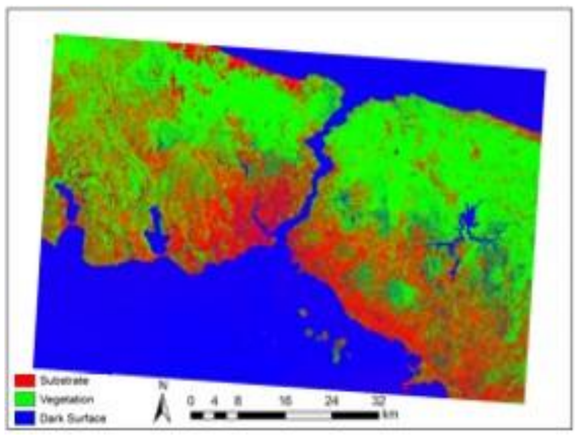

Figure 11. SVD map (1984)

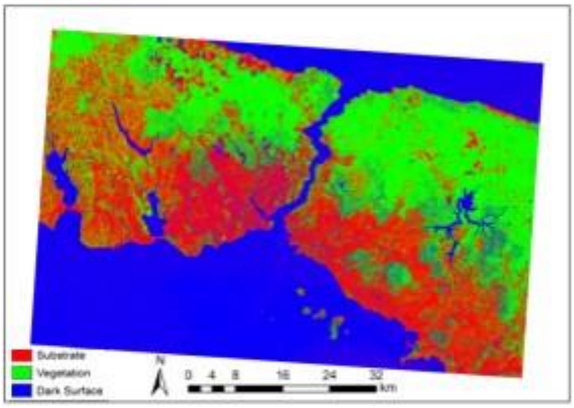

Figure 12. SVD map (2000)

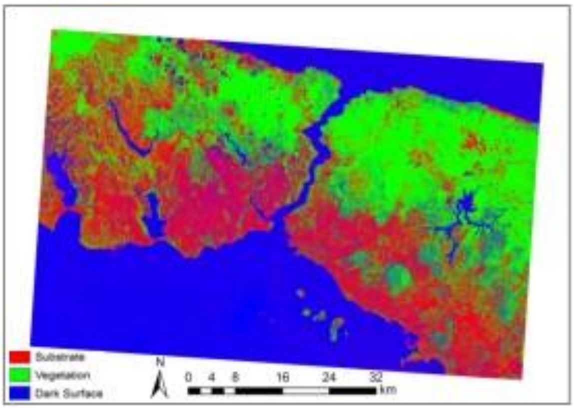

Figure 13. SVD map (2011)

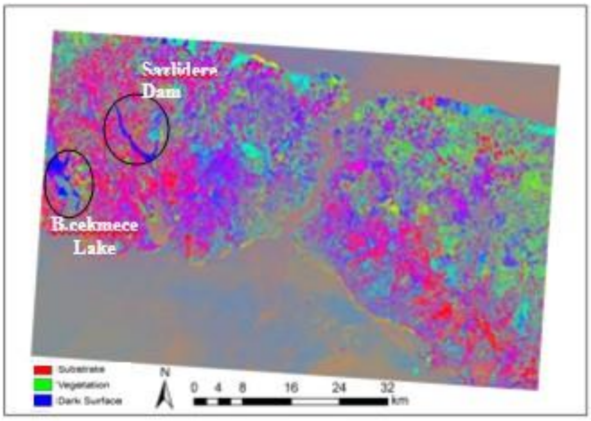

Figure 14. dSVD map (1984-2000)

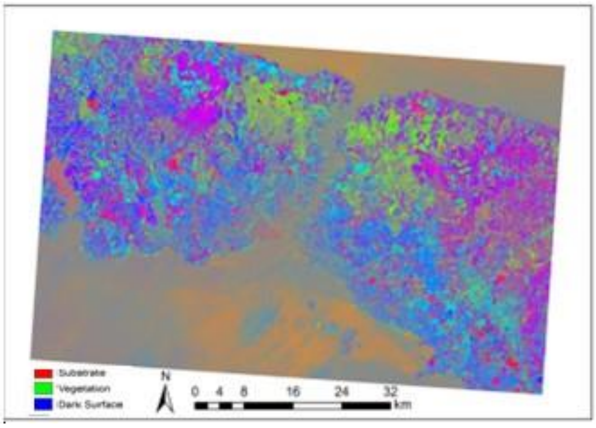

Figure 15. dSVD map (200-2011)

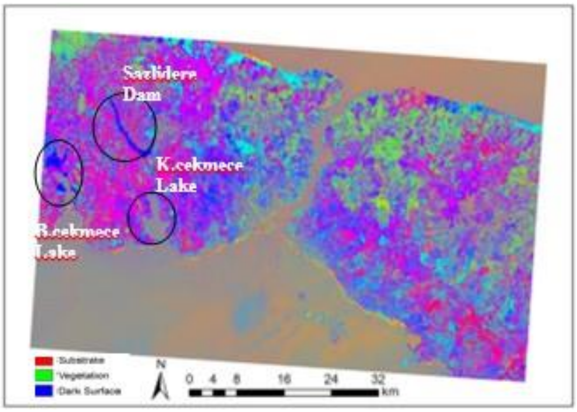

Figure 16. dSVD map (1984-2011)

According to Figures 11, 12 and 13, it can be stated that S areas have increased from 1984 to 2011. This expansion has shown that the urban areas in the city spread along the north coasts of the Sea of Marmara and suburban regions towards outside of the city. Moreover, it is detected that the urban growth was more on the European side. Figures 14 and 16 show the LCLU changes between 1984-2000 and 1984-2011, respectively. Particularly the increase in S values which refers to the recently built urban regions towards the west of the city is clearly seen. Figure 15 has shown that the rapid increase in S values from 1984 to 2000 has slowed down during the period between 2000 and 2011. The main cause of this is the reduce in the immigration rate from rural areas during that period. Again in Figures 11 and 12, S-D mixture is dominant especially in inner parts of the city and it has been observed that the D values increased much more between 2000 and 2011. In this situation, S values a little decreased and D values increased in the builtup areas of the city, it is consistent with an increase of shadow fraction from increasing urban growth. D values have increased due to shadow effect of the changeable height of buildings. High buildings have increased after 2000 especially in built-up areas and suburban regions of the city.

Apart from the SVD maps, tri-temporal (color composite of substrate fractions) substrate maps that shows substrate changes using only the S layers were also generated (Figure 17). According to this map, regions in which urbanization increased after 1984 have spread towards west and east of the city across the coasts of Marmara Sea. This zone is also known as risky seismic activity zone and it has been potential risk for densely populated areas (Fichtner et al., 2013).

The tri-temporal substrate map has shown that the increase in S values are observed in the region between Kucukcekmece and Buyukcekmece Lakes. It is determined that the new urban areas in Kucukcekmece, Buyukcekmece, Beylikduzu, Esenyurt, Basaksehir and Avcilar districts located in this region have expanded (Figure 17). The region between two lakes and Ikitelli Industrial zone in Basaksehir district to the northeast of Kucukcekmece Lake and areas around which were opened to settlement played a major role in the increase of S values (Maktav et al., 2000). On the European side, new urban growth areas about 192 km^2.

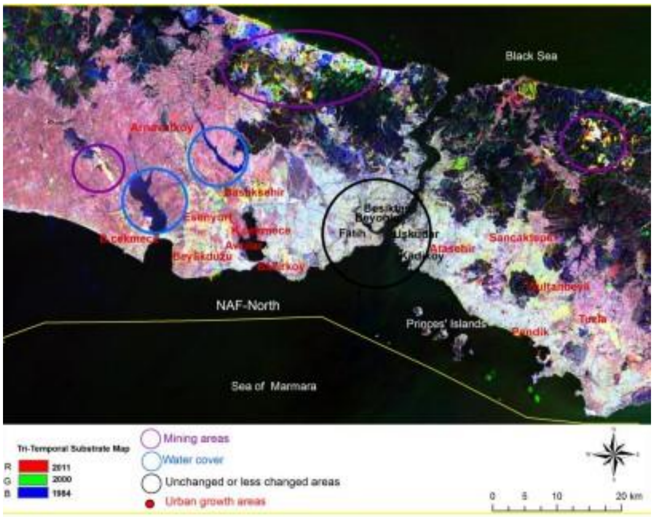

Figure 17. Tri-temporal substrate map (Regions changed and remained unchanged according to the substrate values in 1984, 2000 and 2011).

On the tri-temporal substrate map, Sabiha Gokcen Airport and the region developed near it can be seen. The airport which was opened in 2001, industry zones and settlement areas are the regions in which the S increase is the most on the Asian side. There have been more than 110 km^2 urban growth areas on the Asian side in Sancaktepe, Sultanbeyli, Atasehir, Pendik and Tuzla districts (Figure 17).

Moreover, core areas in which were not subjected to any significant changes were detected. On the tri-temporal substrate map which shows the changes in the substrate values on 1984, 2000 and 2011, the change in S values and SVD values on LCLU determined in previous figures on the European side (Historical Peninsula) is very small. However, there have been various historical buildings in this area which remain unchanged and in 1995, the area was declared as a first degree archaeological and urban-historical protected area (Dincer et al., 2011). Existence of dense settlement and refusing new settlements for the protection of the historic fabric prevented the product of new urban areas here. Also, many areas which do not show a significant change in years in S value are within the borders of core districts of Beyoglu, Fatih and Besiktas on the European side and Kadikoy and Uskudar on the Asian side (Figure 17). In addition, population densities in these districts did not change significantly and the did reduce even in some historical districts, such as Fatih and Beyoglu.

Also, water covered surfaces have been analysed from 1984 to 2000 in the study. Observing the changes in dark surface projection, changes on Buyukcekmece Lake and Sazlidere Dam, which have provided drinking and utility water to the city, were detected. Sazlidere Dam, which is not visible in the 1984 SVD and Landsat images, was constructed in 1996. Therefore, while being represented mainly by S and V values on the SVD map of 1984, this area is represented mainly by D value on the maps from 2000 and 2011. In 1984-2000 and 1984-2011 DSVD maps, this dam area with 10 km^2 surface area can be clearly seen as the change area (Figures 14 and 16). As a result of a dam constructed on the Buyukcekmece Lake in 1988, the lake area was enlarged and caused an increase in the D value in this area.

On the tri-temporal substrate map, another LCLU change is observed. On the Asian side, the increase in S values in the mining area located between the Omerli Dam and the Black Sea started in 1984 continues after 2000. Likewise, the change in mining areas lying along the coast of Black Sea on the European side is seen on SVD maps.

Figure 17 also shows quarries opened to the northwest of Buyukcekmece as substrate area. This substrate area is not related to urban area because interannual changes in agricultural and mining phenology resulted in increase in substrate values.

All the results above derived from the tri-temporal substrate maps are not satisfactory enough. They mostly show substrate areas very well between 1984 and 2000. If there has been any constructions on these substrate areas after 2000, it would be difficult to determine them using usual methods and even tri-temporal substrate maps particular in small spaces of the city. Therefore, in this study DSVD maps were used to map vertical urban growth in the inner side of the city. In these small inner parts of the city, the areas were mostly involving S values in 2000, then the areas had mixture of S and mostly D values in 2011 so these increasing urban growth areas were determined using DSVD maps. According to DSVD maps, new urban growth areas after 2000 Basaksehir, Avcilar, Esenyurt, Beylikduzu and Arnavutkoy were determined on the European side of the city. Districts of Pendik, Umraniye, Cekmekoy, Atasehir, Sancaktepe and Tuzla were determined as urban growth areas on the Asian side of the city.

4. DISCUSSION

The linear spectral unmixing method is not only limited to the horizontal urban growth different from other standard classification methods, but it may also provide useful information regarding the vertical urban growth. In this study, in inner parts in densely populated districts of cities especially in Istanbul, it is observed that S value decreases and D value increases when SVD maps from 1984 to 2011 are examined. This shows that the city reached a built-up position and that there are more complex pixels on the image. Also, dark surface fraction maps have supported that Istanbul has reached a built-up position and the city has grown vertically since 2000. For cities in such situation, it is only possible to talk about vertical growth in the form of inner city. The data approximately belonging to the same period of time and where the atmospheric impact is minimum, should be used to be able to mention such a vertical urban growth. However, such analyses are generally expected to produce most trustable results only in well planned cities.

5. CONCLUSION

Using the spectral mixture analysis, it is possible to determine the spatial and temporal changes in land covers of different types and land use changes. In this study, urban growth was determined by monitoring and analyzing the different LCLU changes that occur in European and Asian sides of Istanbul by applying SMA method to Landat images from 1984, 2000 and 2011. In the results obtained, it is seen that the city entered into a rapid urban growth process from 1984 to 2000, and after 2000, although the process slowed down it continued in west - east direction. Besides, unchanged LCLU changes and areas with limited urban growth were detected. Apart from urban growth, changes in areas covered with water and in mining areas were also observed. Thanks to the rapid applicability provided by this method, this was determined to be a suitable method to determine the changes in land use in other cities using the global endmember values.

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Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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