MULTI-TEMPORAL ANALYSIS OF URBAN AREA CHANGES USING BUILT-UP INDEX

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ABSTRACT: The population of Istanbul has increased rapidly in the last three decades similar to other metropoles of the world. While the population in 1980 was around 4.7 million, it exceeded to 15 million in 2015. The city has been affected from population growth and rapid urbanization, and the land cover/use characteristics of Istanbul changed very fast. In consequence of unplanned urbanization, rapid land use/cover changes caused heterogeneity in urban texture. Increasing urbanization and spatial expansion of the urbanized areas caused land changes from natural landscapes to impervious surfaces. This paper aims to determine the multi-temporal change of urban texture in Istanbul metropolitan area using Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-up Index (NDBI) focusing on district level. The study was conducted using Landsat TM images of Istanbul respectively acquired in 1984, 2002 and 2011. An automated water extraction index (AWEI) is used to extract water bodies from study area. To obtain district level index images, all derived index images are clipped using the district administrative borders. The results indicate that significant increase in impervious surfaces is identified along with a considerably decrease in vegetation in some districts of Istanbul between 1984 and 2011.

1. INTRODUCTION

One of the main problems of the world is increasing population. Especially over three decades, the growth rate of population reached dramatical levels. Researches show that, by 2050 the population of world is expected to rise from 3 billion to 6.4 billion. (United Nations, 2007). By 2009, %60.1 of population has been living in urban areas and by 2050 it is estimated that this amount will reach to %68.7 (Zhaoqi et al., 2015).

A rapid urbanization process that leads reduction in green spaces and increase in urban impervious surfaces occurs in response to growth of population in urban areas. This urban development also affects urban land cover, ecosystems, and regional climates (Ma et al., 2010). Therefore, monitoring and management of these environmental changes in urban areas became obligatory to protect urban ecosystem and improve quality of life over time.

Census data is one of the main data sources which is primarily relied for studies in urban ecosystem analyses in traditional way. However, the acquisition frequency of census data is coarse and often cannot capture rapid changes On the other hand, remotely sensed image data provides ability to monitor urban environment in better temporal frequency (Kaya and Curran, 2006; Wu and Murray, 2003).

Remote sensing data is often used to derive some important information about vegetation and impervious surfaces. As some land cover types have unique spectral responses in different portions of electromagnetic spectrum, many approaches are developed to retrieve information by using this property. Normalized difference vegetation index (NDVI) and Normalized difference built-up index (NDBI) are the two commonly used indicators for vegetation and impervious surface monitoring. NDVI is one of the most used vegetation index that provides information about vegetation cover and vegetation density. On the other hand, NDBI provides information about imperviousness which is generally used as an indicator for urbanization level by using unique responses of built-up areas.

In this study, NDVI and NDBI maps of Istanbul is derived using multi-temporal Landsat 5 TM images acquired respectively in 1984, 2002 and 2011. To evaluate the urbanization along with vegetation cover changes in district level, an administrative border data is used to clip index maps. To identify the land cover changes, mean NDVI and NDBI values are calculated for years 1984, 2002 and 2011 for each district.

2. MATERIALS, METHODS AND RESULTS

2.1 Study Area

The study area is Istanbul, which is one of the World's biggest metropolitan areas with population, approximately 15 million as of 2015. The city is divided by Bosphorus that connects Black Sea with Sea of Marmara as an important waterway and covers a total area of 5.343 km² (Figure 1). Each individual part of the city is located in different continents, the part located in Asia continent is called Anatolian side and the part located in European continent is called European side which includes a natural harbor called Golden Horn.

The city is located within the Marmara region, which is the most important industrial region in Turkey. In virtue of being located in a highly industrial region in modern day, and also being on a strategic location as one of the important points on ancient silk road trade route, Istanbul always become a migration-receiving city through ages.

Especially in last three decades, with rapid industrialization and economic growth, the population of Istanbul increase more than 3 times of its population in 1980. Thus with a rapid increase in population, urban areas increased dramatically.

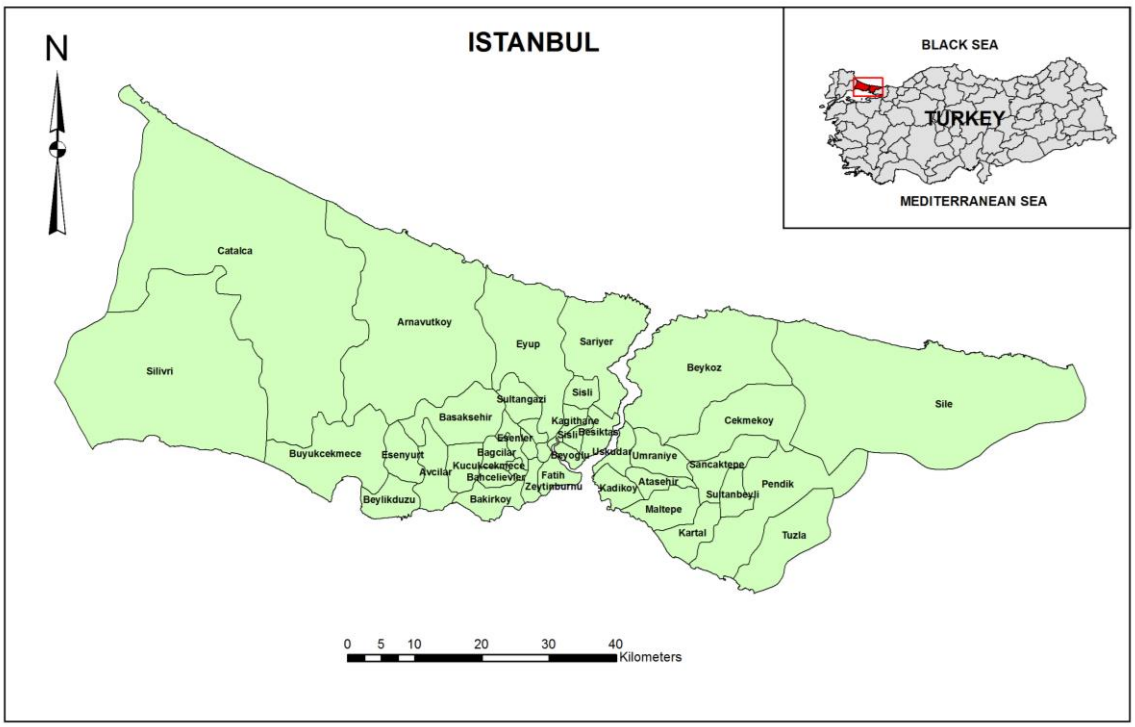

Figure 1. Study Area.

2.2 Data Processing and Methodology

The dataset used in the study consists of 3 Landsat TM images with 7 bands respectively acquired in 12 June 1984, 14 June 2002 and 23 June 2011 with a cloud coverage less than %9. All Landsat TM images were obtained in L1T processing level, provided by USGS Level 1 Product Generation System (LPGS) and downloaded from USGS Earthexplorer data distribution platform.

In atmospheric correction process of TM bands, 6S radiative transfer code (Vermote et al., 1997) was used to obtain surface reflectance. Even all 3 images have minute amount of cloud cover, also an automated cloud cover assessment ACCA (Irish, 2000) algorithm was implemented to mask the cloud covered regions that may cause errors in index values. To focus on land cover and mask water bodies, an Automated Water Extraction Index (AWEI) algorithm proposed by (Feyisa et al., 2014) was implemented.

For the district level assessment of urban land cover, an administrative border vector file, including the district borders is obtained from Istanbul Metropolitan Municipality. Administrative border data was acquired in ED50

datum with Gauss-Kruger projection which is derived from topographic and cadastral maps of Istanbul. The vector file was then transformed to WGS84 datum with UTM coordinates in order to have a common coordinate system with Landsat Imagery.

NDVI is the most common vegetation index used because of its properties that provide some important advantages. It is very sensitive to chlorophyll content in vegetation and also reduces some noise effects such as shadows generated by topography, atmospheric effects and illumination variations caused by varying sun angles by using normalization. NDVI was calculated using following equation;

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}} \quad (1)$$

Where NIR represents the spectral reflectance values in Near-Infrared spectrum, and Red represents the spectral reflectance values in red spectrum. NDBI index is originally proposed by (Zha et al., 2003) and designed for Landsat TM bands to map urban areas automatically. It is based on higher reflection of built-up areas in Mid-infrared region of electromagnetic spectrum than Near-Infrared region (Xu, 2007).
NDBI was calculated using following equation;

$$NDBI = \frac{\rho_{MIR} - \rho_{NIR}}{\rho_{MIR} + \rho_{NIR}} \quad (2)$$

where MIR and NIR represent the spectral reflectance values in Mid-Infrared and Near-Infrared wavelength range respectively. NDBI and NDVI images of Istanbul for 1984, 2002 and 2011 are shown in Figure 2 and Figure 3.

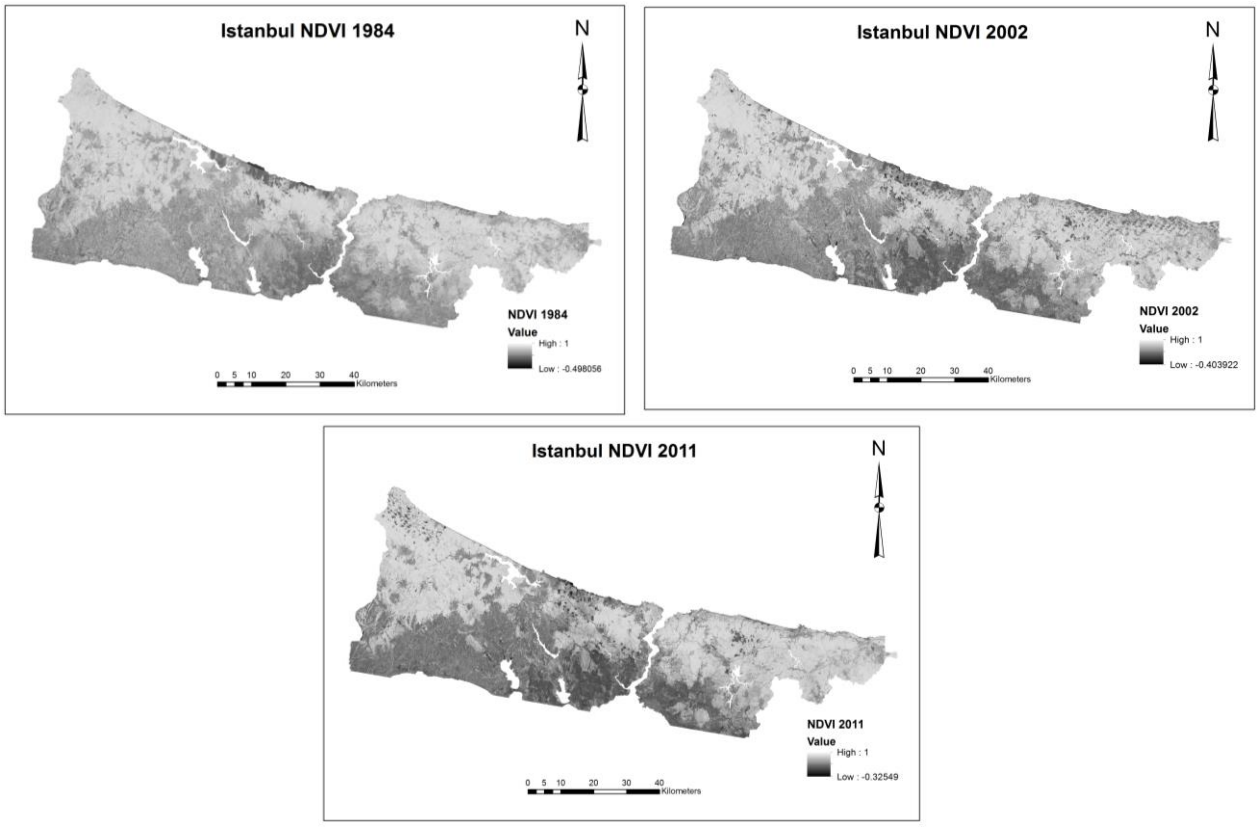

Figure 2. NDVI Images of Istanbul in 1984, 2002 and 2011.

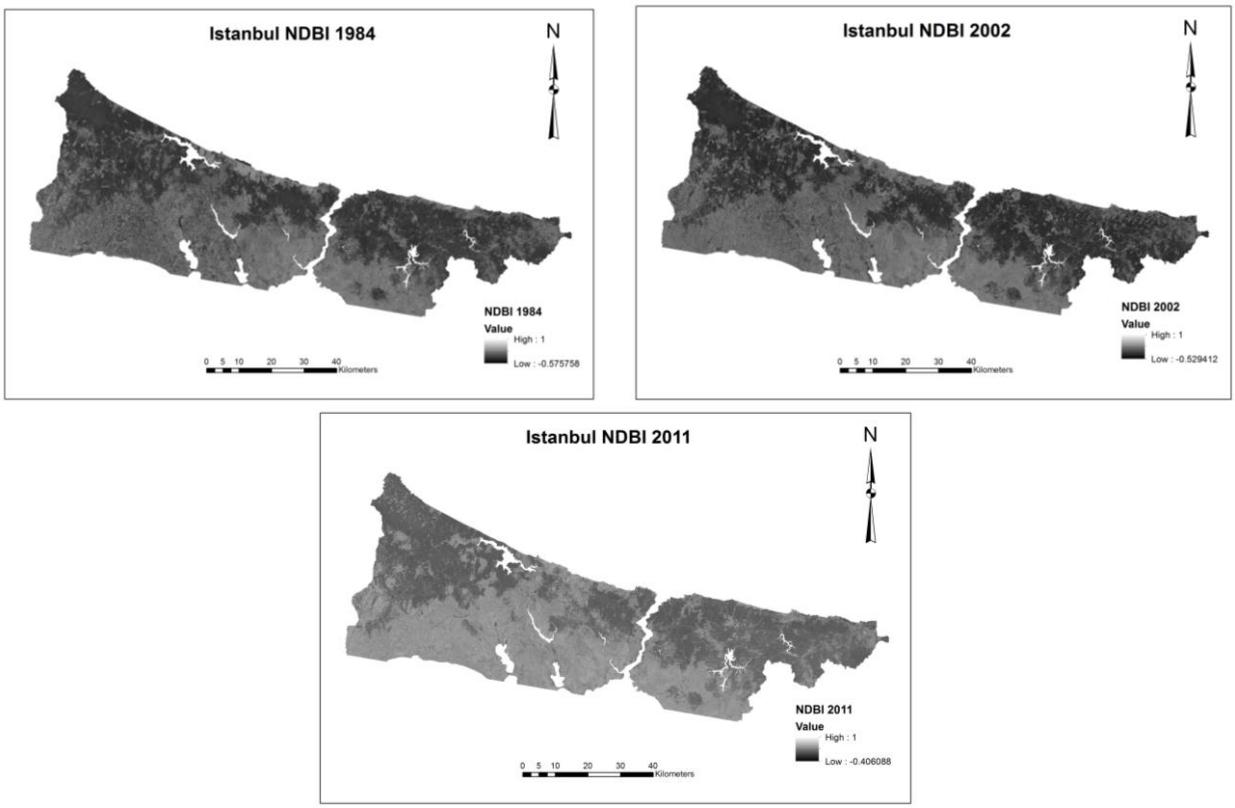

Figure 3. NDBI Images of Istanbul in 1984, 2002 and 2011.

NDVI and NDBI image were clipped using administrative border file of Istanbul in order to obtain index images of each individual district. For each district, mean value of NDVI and NDBI and the differences were calculated between years 1984, 2002 and 2011 (Table 1).

Table 1. NDVI and NDBI Mean Values and Differences.

	1984		2002		2011		1984 – 2002	1984 – 2002	1984 – 2011	1984 – 2011
	NDVI	NDBI	NDVI	NDBI	NDVI	NDBI	NDVI	NDBI	NDVI	NDBI
Arnavutkoy	0.2846	-0.0088	0.2705	-0.0007	0.2528	0.0281	-0.0140	0.0081	-0.0318	0.0369
Atasehir	0.1479	0.0699	0.0867	0.0867	0.0867	0.0830	-0.0612	0.0168	-0.0612	0.0131
Avcilar	0.1519	0.0176	0.1135	0.0304	0.1020	0.0549	-0.0384	0.0128	-0.0499	0.0373
Bagcilar	0.1895	0.0940	0.0887	0.1164	0.0817	0.1263	-0.1009	0.0224	-0.1078	0.0323
Bahcelievler	0.2092	0.1273	0.1118	0.1516	0.1031	0.1632	-0.0974	0.0243	-0.1061	0.0360
Bakirkoy	0.1573	0.0658	0.1095	0.0749	0.1172	0.0876	-0.0479	0.0090	-0.0401	0.0218
Basaksehir	0.2668	0.0350	0.1975	0.0669	0.1815	0.0740	-0.0693	0.0319	-0.0853	0.0390
Bayrampasa	0.1574	0.0991	0.0904	0.1141	0.0858	0.1194	-0.0670	0.0149	-0.0717	0.0203
Besiktas	0.1578	0.0684	0.1546	0.0564	0.1615	0.0514	-0.0032	-0.0120	0.0037	-0.0170
Beykoz	0.3770	-0.0724	0.3600	-0.0747	0.3767	-0.0765	-0.0170	-0.0023	-0.0003	-0.0042
Beylikduzu	0.1120	0.0165	0.0495	0.0277	0.0678	0.0477	-0.0625	0.0112	-0.0442	0.0312
Beyoglu	0.0990	0.1105	0.0889	0.1050	0.0911	0.1041	-0.0100	-0.0055	-0.0078	-0.0064
Buyukcekmece	0.1889	0.0199	0.1547	0.0390	0.1358	0.0710	-0.0342	0.0191	-0.0531	0.0511
Catalca	0.2693	-0.0404	0.2675	-0.0417	0.2652	-0.0333	-0.0018	-0.0013	-0.0042	0.0071
Cekmekoy	0.3560	-0.0728	0.3421	-0.0701	0.3438	-0.0565	-0.0139	0.0027	-0.0122	0.0163
Esenler	0.1278	0.0464	0.0902	0.0567	0.0869	0.0603	-0.0377	0.0103	-0.0409	0.0139
Esenyurt	0.2808	0.0331	0.1893	0.0642	0.1357	0.1028	-0.0914	0.0311	-0.1451	0.0697
Eyup	0.2699	-0.0270	0.2515	-0.0256	0.2580	-0.0170	-0.0184	0.0014	-0.0119	0.0100
Fatih	0.1030	0.0988	0.1076	0.0902	0.1098	0.0903	0.0046	-0.0086	0.0068	-0.0085
Gaziosmanpasa	0.1188	0.0911	0.0730	0.0937	0.0741	0.0976	-0.0458	0.0026	-0.0447	0.0066
Gungoren	0.1455	0.0867	0.0734	0.1184	0.0677	0.1254	-0.0721	0.0317	-0.0778	0.0387
Kadikoy	0.1373	0.0925	0.1194	0.0999	0.1276	0.0939	-0.0179	0.0074	-0.0097	0.0014
Kagithane	0.0995	0.0562	0.0800	0.0546	0.0836	0.0491	-0.0196	-0.0016	-0.0159	-0.0072
Kartal	0.1329	0.0582	0.1093	0.0510	0.1177	0.0616	-0.0236	-0.0072	-0.0153	0.0035
Kucukcekmece	0.2654	0.0802	0.1747	0.1093	0.1584	0.1193	-0.0907	0.0290	-0.1071	0.0390
Maltepe	0.2143	0.0762	0.1672	0.0888	0.1720	0.0850	-0.0472	0.0127	-0.0424	0.0089
Pendik	0.1396	0.0063	0.1293	0.0010	0.1360	0.0094	-0.0103	-0.0052	-0.0036	0.0031
Sancaktepe	0.1837	0.0148	0.1566	0.0218	0.1547	0.0259	-0.0271	0.0070	-0.0290	0.0111
Sariyer	0.3162	-0.0389	0.3019	-0.0454	0.3192	-0.0510	-0.0143	-0.0066	0.0030	-0.0121
Sile	0.3961	-0.0714	0.3716	-0.0788	0.4031	-0.0738	-0.0246	-0.0074	0.0070	-0.0024
Silivri	0.3232	-0.0067	0.3023	0.0209	0.2763	0.0586	-0.0209	0.0276	-0.0470	0.0652
Sisli	0.2006	0.0337	0.1896	0.0192	0.1909	0.0190	-0.0110	-0.0146	-0.0097	-0.0147
Sultanbeyli	0.2564	0.0883	0.1784	0.1042	0.1808	0.1010	-0.0780	0.0160	-0.0756	0.0127
Sultangazi	0.2493	0.0470	0.1754	0.0473	0.1693	0.0490	-0.0740	0.0003	-0.0801	0.0019
Tuzla	0.1456	0.0381	0.1297	0.0329	0.1389	0.0418	-0.0158	-0.0052	-0.0067	0.0038
Umraniye	0.2410	0.0394	0.1785	0.0622	0.1894	0.0563	-0.0625	0.0229	-0.0516	0.0170
Uskudar	0.1494	0.0406	0.1301	0.0448	0.1391	0.0400	-0.0194	0.0042	-0.0104	-0.0005
Zeytinburnu	0.1173	0.1001	0.0892	0.1060	0.0916	0.1079	-0.0282	0.0059	-0.0258	0.0077

According to the results, 11 districts have a decrease in NDVI values with more than %25 between 1984 and 2011. NDVI differences between 2002 and 2011 are relatively smaller than the change between 1984 and 2011.The highest decrease in NDVI between 1984 and 2002 occurs in four districts with more than %50. Esenyurt, Bagcilar, Kucukcekmece and Bahcelievler that are known to have a rapid urbanization rate and yet the highest rate in population increase. In addition, Basaksehir, Sultangazi, Gungoren and Sultanbeyli also have a high changes in NDVI. These districts are also affected by urbanization and population growth.

Besiktas, Sisli and Fatih have the minimum change in NDVI and NDBI values. (Figure 4). These districts are located in the center of Istanbul which already reached the maximum rate of urbanization. Sariyer is also one of the districts have minimum change in NDVI and located in northern side of Istanbul surrounded by forests.

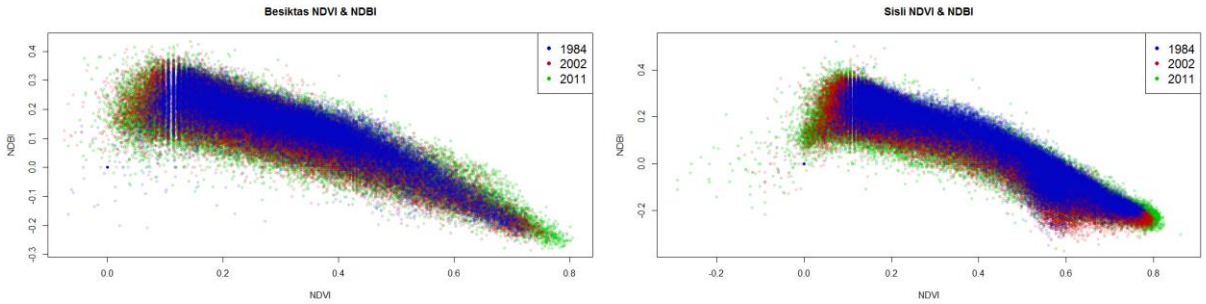

Figure 4. NDVI & NDVI Scatter Plots of Besiktas and Sisli Districts.

In addition to NDVI, the differences of NDBI values were also evaluated. A maximum amount of change in NDBI occurred in six districts which are Avcilar, Silivri, Buyukcekmece, Esenyurt, Arnavutkoy and Basaksehir. In comparison with NDVI changes, although there is a significant amount of change in built-up indices, some districts like Arnavutkoy, Sariyer, Cekmekoy and Silivri have a very small amount of change in NDVI values. This is due to the surrounding forests in northern region of Istanbul, non-cultivated agricultural areas and temporary mine dumps which affects NDBI values as built-up areas.

Therefore, with further combined evaluation of NDVI and NDBI in each district, Bagcilar, Bahcelievler Esenyurt and Kucukcekmece districts showed a change from vegetation to built-up areas. The scatter plot of NDVI and NDBI values for each district is shown in Figure 5.

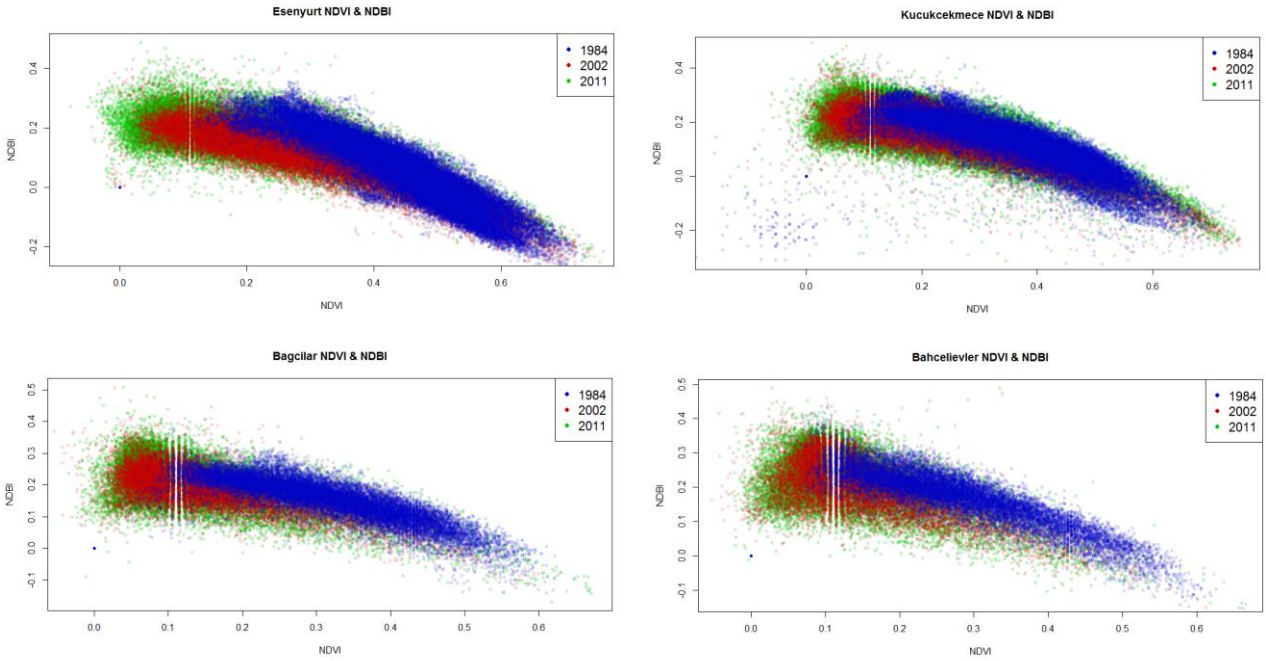

Figure 5. NDVI & NDVI Scatter Plots of Esenyurt, Kucukcekmece, Bagcilar and Bahcelievler.

In Figure 5, the horizontal axis indicates the NDVI values and vertical axis indicates the NDBI values. All index values for 3 different years are plotted for each pixel. Blue, red and green plots respectively show the index values corresponding to years 1984, 2002 and 2011. As seen in the figure, distributions of pixels are accumulated to upper-left side of the plot for each epoch. This result indicates that from 1984 to 2011 districts faced increase in built-up areas along with decrease in vegetation.

3. CONCLUSIONS

Due to the rapid population growth and migration to big cities, new lands has been opened to settlements. This situation resulted with expansion of urban areas that affects ecosystems and climate on regional scale which have dramatic effects on human health and life quality. In this study, one of the world's most migration-receiving megacity Istanbul is evaluated in terms of vegetation and built-up areas using NDVI and NDBI in district level between years 1984 and 2011.

The study is conducted by using Landsat TM 5 satellite imagery. The results highlight that in some districts of Istanbul with high urbanization rate, vegetation density decreases in contrast with increasing built-up areas. Further studies on the effects of the urbanization and vegetation density change to urban ecosystem of Istanbul should be carried out using remote sensing images to maintain sustainability. The results of this study will provide insights in further investigations.

References

Feyisa, G. L., Meilby, H., Fensholt, R., Proud, S.R., 2014. Automated Water Extraction Index: A new technique for surface water mapping using Landsat imagery, Remote Sensing of Environment, Volume 140, January 2014, pp. 23-35.

Irish, R., 2000. Landsat 7 Automatic Cloud Cover Assessment. Algorithms for Multispectral, Hyperspectral, and Ultraspectral Imagery. SPIE Vol. 4049, pp. 348-355.

Kaya, S. and Curran, P.J., 2006. Monitoring urban growth on the European side of the Istanbul metropolitan area: A case study, International Journal of Applied Earth Observation and Geoinformation, Volume 8, Issue 1, January 2006, pp. 18-25, ISSN 0303-2434, http://dx.doi.org/10.1016/j.jag.2005.05.002.

Ma, Y., Kuang, Y., Huang, N., 2010. Coupling urbanization analyses for studying urban thermal environment and its interplay with biophysical parameters based on TM/ETM+ imagery, International Journal of Applied Earth Observation and Geoinformation, Volume 12, Issue 2, April 2010, pp. 110-118, ISSN 0303-2434).

United Nations, 2007. World Urbanization Prospects:The 2007 Revision. ST/ESA/SER.A/276, Sales No. E.08.XIII.13.

Vermote, E.F., Tanré, D., Deuzé, J.L., Herman M., Morcrette, J.J.,1997. Second Simulation of the Satellite Signal in the Solar Spectrum, 6S: An Overview, IEEE Transactions on Geoscience and Remote Sensing, Vol. 35, No. 3, pp. 675-686.

Wang, Z., Gang, C., Li, X., Chen, Y., Li, J., 2015. Application of a normalized difference impervious index (NDII) to extract urban impervious surface features based on Landsat TM images, International Journal of Remote Sensing, 36:4, pp. 1055-1069, DOI: 10.1080/01431161.2015.100725.

Wu, C. and Murray A.T., 2003. Estimating impervious surface distribution by spectral mixture analysis, Remote Sensing of Environment, Volume 84, Issue 4, 10 April 2003, pp. 493-505, ISSN 0034-4257, http://dx.doi.org/10.1016/S0034-4257(02)00136-0.

Xu, H., 2007. Extraction of urban built-up land features from Landsat imagery using a thematic oriented index combination technique. Photogrammetric Engineering & Remote Sensing, 73(12), pp.1381-1391.

Zha, Y., Gao, J., Ni, S., 2003. Use of normalized difference built-up index in automatically mapping urban areas from TM imagery, International Journal of Remote Sensing, 24(3): pp. 583–59.