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LANDSAT and Ground Data Analysis to Define Flood Risk

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Abstract. Flood is defined as an overflow of an expanse of water that submerges land. The spatial and temporal distribution of heavy rainfall over an earth surface is very important for flood modelling which is seen as an integral part of flood management. The average altitude of the city Istanbul in Turkey above mean sea level is around 107 m and the maximum altitude is 524 m. Farmlands cover 1304 km^2 and they decreased to 565 km^2 in the study period because of the high rate of urbanization in recent years. However, forest areas cover 42 percent of all the study area and there was no significant area change during the monitoring period. Wetlands also do not show an important decrease. Higher urbanization rate was observed both at the Asian and European sides of Istanbul through north to south and from east to west. In the lowest part of Istanbul, infiltration rate is also very low, and these areas are under the high flash flood risk. In this study, land surface characteristics were analysed using remote sensing methods for the city Istanbul by considering LANDSAT TM data between the years 1975 and 2010. Land use classification, slope classes, infiltration rate and run off analysis was based on digital height modelling. As a result of this study, satellite data and ground measurements were interpreted and the distribution of flood risk over Istanbul was described.

Keywords. Flood, remote sensing, satellite imagery, LANDSAT.

1. Introduction

Image classification techniques are most applied to spectral data of a single-date image or to the varying spectral data of a series of multidate images. Temporal and spatial variations of land use/land cover (LU/LC) classes can be determined by using classification of satellite data [1], [2], [3]. Remotely sensed satellite data have four important advantages, such as synoptic view, repetitive coverage, various wavelengths and low-cost compared to ground observations [2], [4], [5].

In this study, remote sensing techniques have been used to define LU/LC classes. For this purpose, LANDSAT MSS and ETM imageries have been analysed. These imageries have been commonly used for the definition of vegetation cover, farmlands, LU/LC classes. Another advantage of LANDSAT data is their wide archive, high spatial and spectral resolution [6], [7].

The main objective of this study is the determination of ‘potential (only based on ground measurements)’ and ‘actual (including LANDSAT data)’ flood risk maps in Istanbul (pilot meteorological stations in different districts: Bahçeköy, Florya, Göztepe, Kandilli, Kumköy, Kireçburnu, Şile, Kartal) based on different statistical approaches using remote sensing satellite data and ground measurements. Therefore, precipitation data (temporal and spatial variations), air temperature, radiosonde data, digital topographic data (1:25000), LANDSAT and METEOSAT data (process ongoing) were analysed. LANDSAT-MSS, ETM+ and ASTER data were used to obtain LU/LC classification and topographic (slope, aspect) information for the production of actual flood risk maps. The potential flood risk maps are used as a basis for the production of 'actual' flood risk maps. Potential flood risk maps were obtained using meteorological data, such as precipitation, air temperature and radiosonde data (meteorological data at different air pressure levels). DEMs were created from Terra/ASTER GDEM. For the production of potential flood risk maps, statistical approaches and instability indices (Sarı index, Kahraman index, Sweat index, K-index, Vertical Totals index, Humidity index, etc) were used. Processing and analysing of METEOSAT data to obtain cloud top temperatures and water humidity for linearly correlating these parameters with precipitation is still ongoing.

2. Study area

Istanbul, with a population of 14 million, is the largest city in Turkey, forming the country's economic, cultural, and historical heart. The city is located in northwestern Turkey within the Marmara Region on a total of 5443 km^2. The Bosphorus, which connects the Sea of Marmara to the Black Sea, divides the city into a European side and an Asian, Anatolian side. The city is further divided by the Holden Horn, a natural harbor bounding the Historic Peninsula. Due to its vast size, diverse topography, and maritime location Istanbul exhibits a multidate of distinct microclimates. In this paper, remote sensing data for the study area of Istanbul have been taken into account. Meteorological stations in this area are located in the districts Bahçeköy, Florya, Göztepe, Kandilli, Kartal, Kireçburnu (Sarıyer), Kumköy (Kilyos) and Şile in both sides of the city (Figure 1).

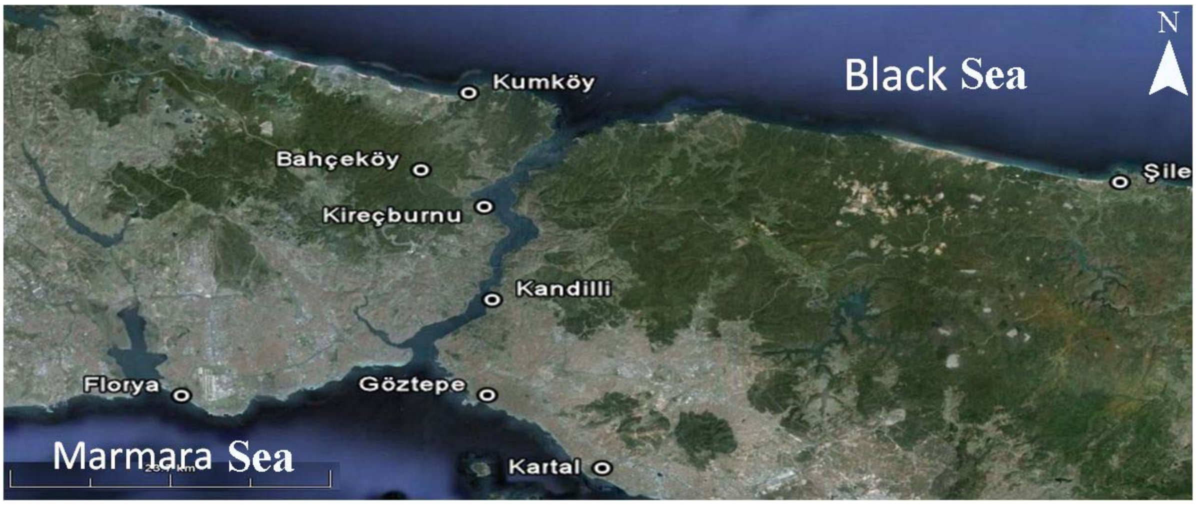


Figure 1: Study area.

3. Data and methodology

3.1. Data

Precipitation data for seven stations were taken from the archive of the Turkish State Meteorological Service (MGM). Data for the station Kandilli was recorded in Boğaziçi University, Kandilli Observatory and Earthquake Research Institute, Meteorological Laboratory (Table 1). Other data analysed in this study were:

- Precipitation data (daily, monthly, annual totals (mm))
- Air temperatures (daily, mean, max, min)
- Radiosonde data (at upper layer, 850 hPa, 700 hPa, 500 hPa air temperature, dew point temperature, wind speed and direction)
- Water flow rate (monthly, mean) (m^3/sec) (from the General Directorate of State Hydraulic Works)

Table 1. Meteorological stations and data periods.

Stations	Codes	Latitude (N)/ Longitude (E)	Altitude (m)	Precipitation records (years)
1 Bahçeköy	17619	41° 10'/28° 59'	130	1947 - 2006
2 Florya	17636	40° 59'/28° 45'	36	1937 - 2010
3 Göztepe	17062	40° 58'/29° 03'	33	1929 - 2007
4 Kandilli	B.Univ	41° 04'/29° 04'	114	1912 - 2010
5 Kartal	17638	40° 54'/29° 09'	18	1950 - 2010
6 Kireçburnu	17061	41° 08'/29° 03'	58	1949 - 2010
7 Kumköy (Kilyos)	17059	41° 15'/29° 02'	30	1951 - 2010
8 Şile	17610	40° 47'/30° 25'	83	1939 - 2010

To obtain LU/LC maps, LANDSAT data has been used (Table 2) obtained from US Geological Survey's (USGS) data archives. To obtain topographic information (slope, aspect) ASTER Global Digital Elevation Model (GDEM data was used.

Table 2. Satellite data used.

Dates	Sensors
May 31, 1975	LANDSAT MSS
October, 2009	TERRA ASTER
September 8, 2010	LANDSAT TM

3.2. Methodology

Precipitation data were collected from meteorological stations and analysed statistically with the statistical package for social sciences (SPSS), able to conduct a wide range of statistical analysis and procedures, the Excel and the MATLAB software.

Supervised classification technique was performed for LU/LC classification [8], [9] using ERDAS Imagine 9.1. Figure 2 gives the flow chart of LANDSAT data processing. Slope, aspect and urbanization rate were obtained from ASTER GDEM generated using stereo-pair images collected by the ASTER instrument onboard on Terra satellite. DEM accuracy is 7-14 m.

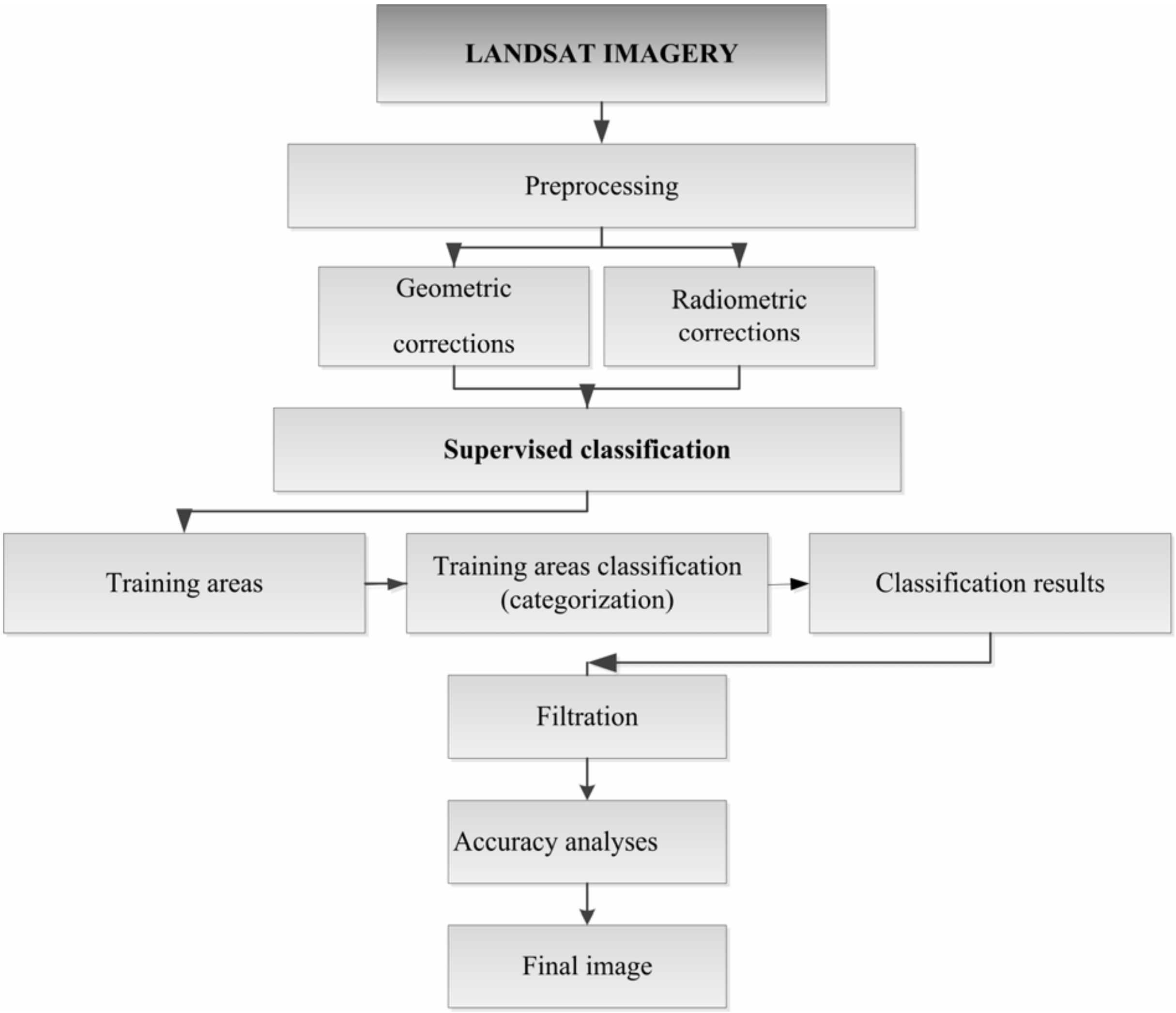


Figure 2: Satellite data and processing.

4. Analysis

4.1 Analysis for potential flood risk

Analysis of precipitation: Table 3 summarizes some statistics of annual precipitation data. The maximum, mean and annual total precipitation was recorded in Bahçeköy (1100 mm) and the minimum in Florya (646 mm). Extreme values (max and min) of maximum annual total precipitation were recorded in Şile (1697 mm) and Florya (969 mm), respectively.

Table 3. Descriptive statistics of precipitation data (annual total).

Stations	Precipitation (max, mm)	Precipitation (mean, mm)	Precipitation (min, mm)
1-Bahçeköy	1655	**1100 (max)**	694
2-Florya	**969 (min)**	**646 (min)**	420
3-Göztepe	1047	674	402

4-Kandilli	1289	841	449
5-Kartal	1076	653	424
6-Kireçburnu	1219	811	574
7-Kumköy	1231	795	471
8-Şile	**1697 (max)**	820	455

Three basic classes were selected to interpret precipitation descriptively. Precipitation classes: mean, mode, linear trend, number of observations deviated by σ from means. All classes were based on long term descriptive statistics of precipitation observation. Linear trend (slope value) was defined by using a linear model for temporal variations (Table 4).

Analysis of temperature: Similarly three basic classes were considered for temperature data. These were linear trend and number of observations deviated by σ from means (Table 4).

Table 4. Precipitation and temperature classes.

Precipitation					Temperature	
Classes	(mean, mm)	(mode, mm)	Linear trend	Number of observations (standard deviation, σ)	Linear trend	Number of observations (standard deviation, σ)
1	< 800	< 80	0-2	0-10	0.0-0.02	< 12
2	800-1000	80-120	2-4	10-20	0.02-0.04	12-16
3	>1000	>120	>4	> 20	> 0.04	> 16

Analysis of potential flood risk classes: Real data for precipitation and temperature are summarized in Table 5. Maximum mode (151 mm) value was observed in Göztepe. The highest linear trend (3.2) for total precipitation was computed in Kumköy. The highest linear trend for maximum temperature (0.051) was observed in Şile. The number of observations deviated as σ from means based on long term annual total precipitation and maximum temperature is 16 in Kandilli.

Table 5. Potential flood risk parameters.

Stations	Prec. (mean)	Prec. (mode, max.)	Total prec. (slope)	Max temp. (slope)	Control chart (max. temp.,σ)	Control chart (prec., σ)
Bahçeköy	1100	43	2.42	0.002	8	13
Florya	646	70	0.34	0.009	13	11
Göztepe	674	**151**	0.22	0.006	10	15
Kandilli	841	140	1.65	0.018	16	16
Kartal (Göksu)	653	78	0.42	0.042	8	8
Kireçburnu (Istranca)	811	87	3.13	-0.01	9	13
Kumköy (Istranca)	795	56	**3.20**	0.044	8	8
Şile (Göksu)	820	78	2.94	**0.051**	10	7
Şile (Kabaköz)	820	78	2.94	**0.051**	10	7

Weighted products of potential flood risk parameters and their classes have been categorized in five different risks. Classes 1 to 5 correspond from low to extremely severe potential flood risks (Table 6). Table 7 presents individual classes corresponding to actual precipitation and temperature data based on Table 4.

Table 6. Potential flood risk classes.

Classes	Weighted products	Flood risks
1	<10	Low
2	5-10	Moderate
3	10-15	Severe
4	15-20	Very severe
5	>20	Extremely severe

Weighted products of potential risk values in Kandilli and Kireçburnu are 24 and 16, respectively (Table 7). These values are accompanied by maximum potential risk classes (Table 4, 5).

Table 7. Potential flood risk parameters and classes based on ground observations.

Stations	Precipitation (mean/mode,max/ linear trend/σ) (A)	Max. temperature (linear trend/σ) (B)	Potential risk value (weighted products) (AxB)	Potential flood risk classes
Bahçeköy	3/1/2/1	1/2	12	3
Florya	1/1/1/2	1/2	4	1
Göztepe	1/3/1/2	1/1	6	2
Kandilli	2/3/1/2	1/2	**24**	5
Kartal (Göksu)	1/1/1/1	3/1	3	1
Kireçburnu (Istranca)	2/2/2/2	1/1	**16**	4
Kumköy (Istranca)	1/1/2/1	3/1	6	2
Şile (Göksu)	2/1/2/1	3/1	12	3
Şile (Kabaköz)	2/1/2/1	3/1	12	3

Based on Table 7 the potential flood risk map of Istanbul is presented in Figure 3. This map is mainly based on meteorological data (precipitation, temperature, radiosonde). Flood risk classes have been changed from low to extremely severe risk at the middle part of Istanbul. Low-severe risk values were evaluated at the Sea of Marmara and the Black Sea coasts.

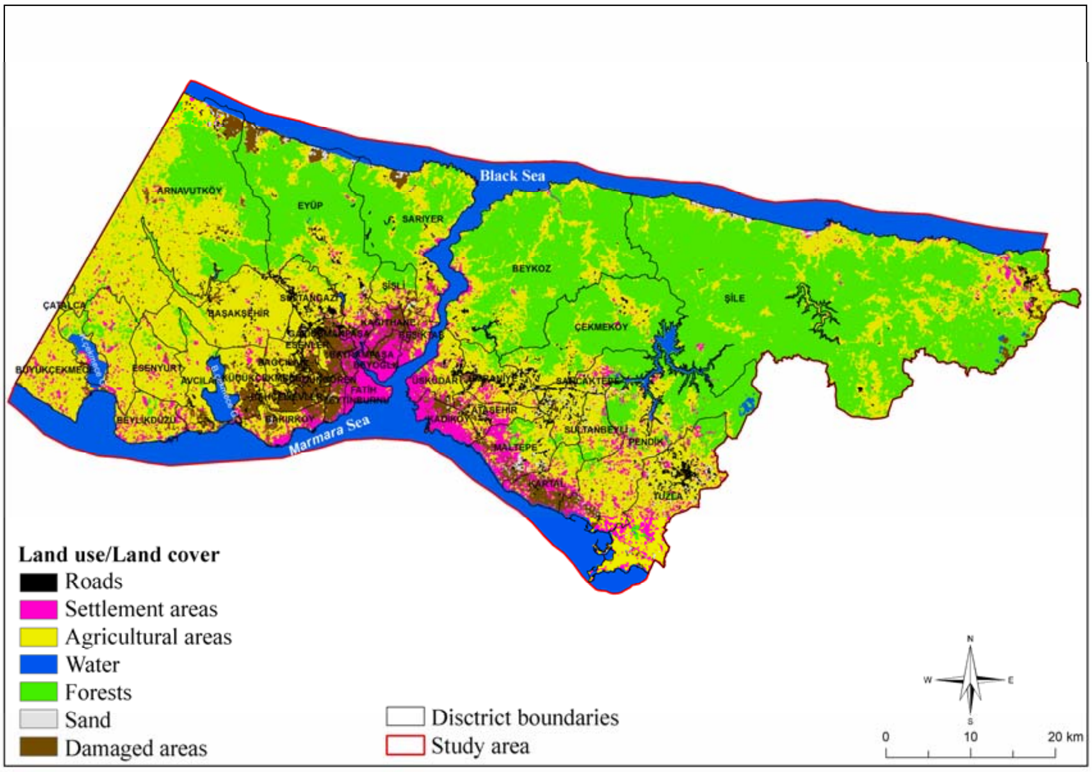
This map only considers ground measurements and it does not account for urbanization rate, aspect and slope analysis based on remote sensing techniques.

Figure 3: Potential flood risk map of Istanbul: low risk (*), moderate risk (**), severe risk (***), very severe risk (****), extremely severe risk (*****).

4.2. Analysis for actual flood risk

Analysis of classification: Comparison of multidate classified LANDSAT data shows intensive urbanization in the Historical Peninsula and in the vicinity of Bosphorus between 1975 and 2010 (Figure 4a, b, pink, Figure 5). For example two most urbanized areas are located in the vicinity of the districts Beşiktaş and Eminönü in the European side. Settlement areas cover ~155 km^2 (4,01% of the total study area). In the Asian side, most part of the study area is covered by forests. Total coverage of forests is more than that of the European part. Northern part of urbanized areas is generally covered by forests. Continuous extent of settlement areas has been observed since 1975 which caused dramatic decrease of agricultural areas. Total settlement areas have been increased up to 721 km² since 1975. In contrast, forests have been reduced to 1052 km² in that time period. In the Asian side, increasing urbanization has a damaging effect on agricultural areas, forest areas and dam basins (Figure 4). The decrease of forest and agricultural areas obstructs infiltration of surface water into the ground, which causes direct water flow on the surface. This results in flood and flash flood risk. The increase of settlement areas causes the increase of the flood and flash flood.

Accuracy assessment of the supervised classification of the LANDSAT data dated 1975 and 2010 gave more than 85% accuracy (Table 8).



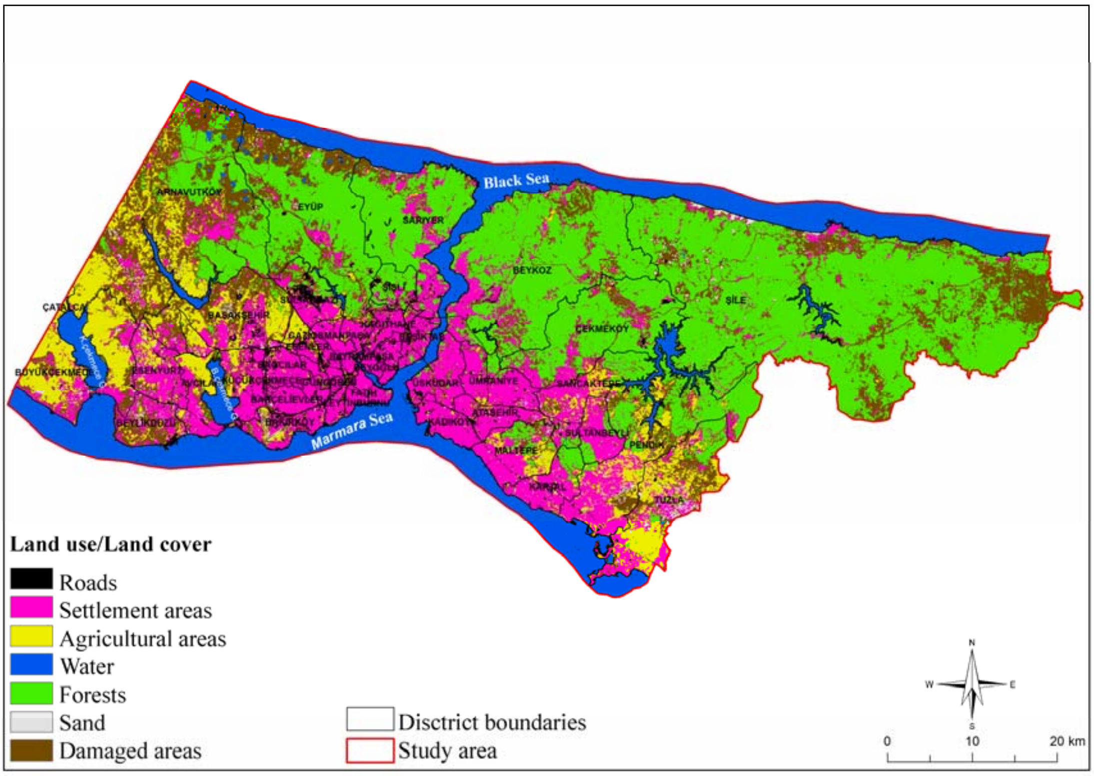


Figure 4: LULC (LANDSAT); a) May 31, 1975 (MSS); b) September 8, 2010 (TM).

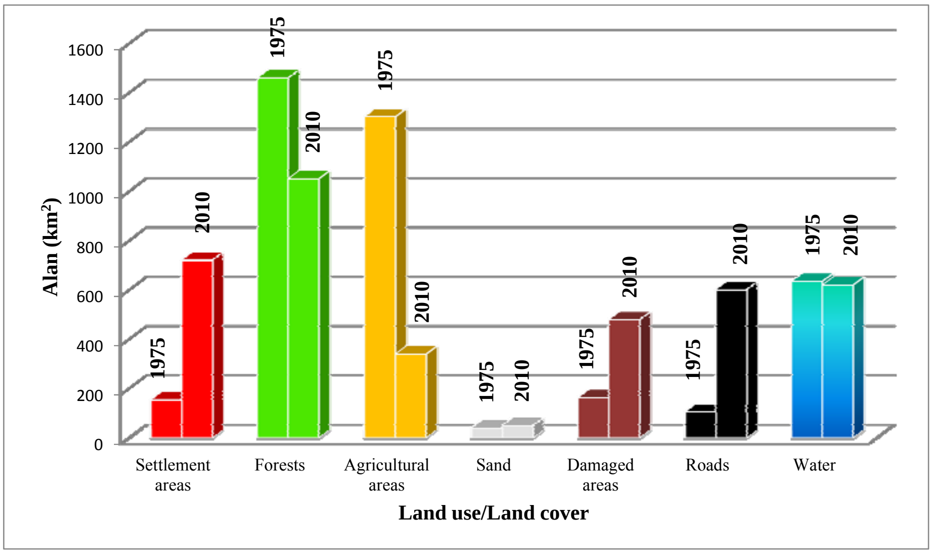


Figure 5: LULC changes (1975-2010).

Table 8. Accuracy analysis of supervised classification (May 31, 1975 – September 9, 2010).

Classes	Control points	Total classified	Correct classified	Correct (%)		Kappa
				Producer	User	
May 31, 1975						
Roads	16	15	12	73.11	75.76	0.7702
Water	15	15	15	100	100	1
Agricultural areas	16	15	13	81.25	86.67	0.8462
Sand	13	15	13	100	88.55	0.8705
Damaged areas	18	15	13	72.12	86.10	0.8431
Settlement areas	15	15	13	72.50	85.87	0.8582
Forest	15	15	15	75.00	100	1
Sum	108	105	94	88.99		0.8840
September 9, 2010						
Roads	15	15	14	76.3	84,12	0.704
Water	15	15	15	100	100	1
Agricultural areas	16	15	12	75.00	80	0.7731
Sand	14	15	14	100	93,33	0.9256
Damaged areas	15	15	13	86.67	86,67	0.85
Settlement areas	15	15	13	73.4	86,57	0.89
Forest	14	15	15	87.50	100	1
Sum	104	105	96	90.10		87.75

5. Results

The main goal of this study was to prepare two different flood risk maps, potential and actual, for the city of Istanbul. Potential flood risk map is based on meteorological ground measurements only and actual flood risk map is based on satellite data and remote sensing techniques.

The first part presents some statistical analysis of precipitation and air temperature values which play a critical role in flood risk assessment. Maximum annual total precipitation was recorded in the district Bahçeköy (1100 mm) and minimum in Florya (646 mm). Weighted products of potential flood risks were classified from low to extremely severe. Potentially higher flood risks are calculated for the districts Kandilli and Kireçburnu, whereas potentially lower risks for Florya and Kartal.

The second part is related to satellite data analysis by using remote sensing techniques. LU/LC classification showed spatial and temporal variations of roads, settlement areas, agricultural areas, water surfaces, forests, sand and damaged areas and their district boundaries in different provinces of Istanbul. Temporal variations showed high rate of urbanization in recent years, all over the study area. The increase of the settlement areas is higher in the southern part than that of the northern part.

Geological and morphological structures of study area trigger runoff along the tillage and flood risk. Individual hills, slope rate, aspects of land surface, valleys and stream basins also play a critical role in flood risk assessment. Slope values are lower in the European side than those of the Asian side. Rapid urbanization in wetlands through the western part increases flood risk.

The specific results of this paper cover the spatial variation of the ground measurements and potential flood risk classes in Istanbul. Some conclusions on urbanization rate and LU/LC are also discussed.

The third and ongoing part of the study is about the combined analysis of ground measurements by using statistical methods and satellite data based on remote sensing techniques to prepare the 'actual flood risk map of Istanbul'. It is expected that the highest risk area Kandilli would actually belong to another risk class, because of slope and topographic characteristics of this area. Similarly the Göztepe and Florya districts where lower risk values have been calculated would show another risk class. The results indicate the importance of the use of remote sensing analysis for flood risk classification.

Acknowledgements

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