Integration of RS and GIS as Modern Technological Tools in Environmental Management Studies: Case Studies from Istanbul

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ABSTRACT: GIS and RS in watershed and environmental studies enable to conduct studies in a shorter period of time for low cost. Land-use detection and planning are the essential steps to be considered in keeping the environmental balance. Such detections are done through the classification of satellite images by means of RS technology whereas data storage, manipulation and querying are done through GIS technology. As such, maps of different thematic layers are produced to illustrate the findings especially to the decision makers and to conduct various administrative and/or watershed-scaled modeling and management studies. Five studies conducted on one of the most crowded and oldest megacities of the world, Istanbul, by the joint efforts of experts in Istanbul Technical University (ITU)-Turkey during years 2010-2015, will be briefly mentioned in this study. The first three studies deal with the most important problem of the megacity which is rapid and quite uncontrolled urbanization. The effects of urbanization on forests and on the significant drinking water reservoirs are examples representing the outcomes of urban sprawl. The direction and intensity of urbanization is also calculated via a components model. The last two case studies are on the Istanbul Strait which is one of most important waterways of the world, known with its natural beauty and marine traffic. The main aim of this paper is to give information on the different types of integrated and interdisciplinary studies as examples from a developing country and a megacity utilizing GIS and RS technologies.

1. INTRODUCTION

1.1 Interdisciplinary and Integrated Studies in Environmental Management of Remarkable Areas

Rapid population increase, urbanization, increase in water demand, water pollution, natural disasters like flooding and drought, desertification, deforestation, pollutants, degradation of ecosystems, and last but not the least climate change effects on the vulnerable sites like watersheds and remarkable areas like megacities can be addressed as the significant environmental concerns of today's world. These numerous problems can be solved through sustainable use of natural resources, water and land. Rehabilitation and prevention of further deterioration of water and water related ecosystems can best be realized via integrated watershed management that is so far a universally accepted approach for the sustainable management of natural resources (ESCAP, 1997; EPA, 1998; Randhir, 2007; Heathcote, 2009; Beheim et al., 2010). Such a holistic understanding necessitates integration of various disciplines like environmental, geomatics, hydraulic and agricultural engineers/scientists and utilization of management tools like decision-support systems, databases, models, GIS and RS. Therefore, management efforts enhance users to work together and to evaluate potential threats on the environment.

The use of tools like GIS and RS in watershed and environmental studies enables to conduct the studies in a shorter period of time for low cost. Land-use detection and planning are the essential steps to be considered in keeping the environmental balance. Such detections are done through the classification of satellite images by means of RS technology whereas data storage, manipulation and querying are done through GIS technology. As such, maps of different thematic layers are produced to illustrate the findings especially to the decision makers and to conduct various administrative and/or watershed-scaled modeling and management studies.

In this study, five of the recent studies listed below conducted on one of the most crowded and oldest megacity of the world, Istanbul, by the joint efforts of experts in Istanbul Technical University (ITU)-Turkey, will be briefly mentioned to give information on the different types of integrated and interdisciplinary studies as examples from a developing country and a megacity utilizing GIS and RS technologies.

- Temporal Impact of Urbanization on Forests in the Megacity Istanbul (Seker et al., 2010)
- Analysis of Urbanized Areas Using VIS Components Model (Kaya et al., 2012)
- Temporal Impact of Urbanization on the Protection Zones of Two Drinking Water Reservoirs in Istanbul

(Kaya et al., 2014)

- Mapping the Distribution of Oil Sensitive Fish and Bird Species in the Istanbul Strait (Dikerler et al., 2014)
- Use of Remote Sensing and Geographical Information Systems in the Determination of High- Risk Areas Regarding Marine Traffic in the Istanbul Strait (Musaoglu et al., 2015)

The first three studies deal with the most important problem of the megacity which is rapid and quite uncontrolled urbanization. The effects of urbanization on forests and on the significant drinking water reservoirs are examples representing the outcomes of urban sprawl. The direction and intensity of urbanization is also calculated via a components model. The last two case studies are on the Istanbul Strait which is one of most important waterways of the world, known with its natural beauty and marine traffic.

1.2 Study Area

Istanbul is ranked as the 7th crowded city of the world with a population of 14,160,467 and population density of 2593 capita/ km^2 according to October 2015 figures (URL-1). Its population in 1985 was almost 6 million, and then it jumped to 9 million in 2000 and to 13 million in 2010. By 2030, it is expected to reach 20 million. As such, at all terms, the city has been experiencing various environmental problems arising mostly due to unregulated and unplanned urbanization. Fulfilling infrastructure needs have usually lacked and stayed far beyond the expectations. Within the last decade, the Greater Metropolitan Municipality has shown tremendous efforts in realizing better infrastructure networks.

Figure 1 shows the geographical location of this megacity in Turkey together with a recent satellite view. From this view, it can easily be seen that this unique city forms a bridge between Europe and Asia continents via the Istanbul Strait, known as the Bosphorous. The north of the city towards the Black Sea is mostly covered by protected forest patches, and the expansion of the city in that direction is mostly confined to along the Bosphorus. The most densely populated parts of the city lie in the southern parts along the Sea of Marmara.

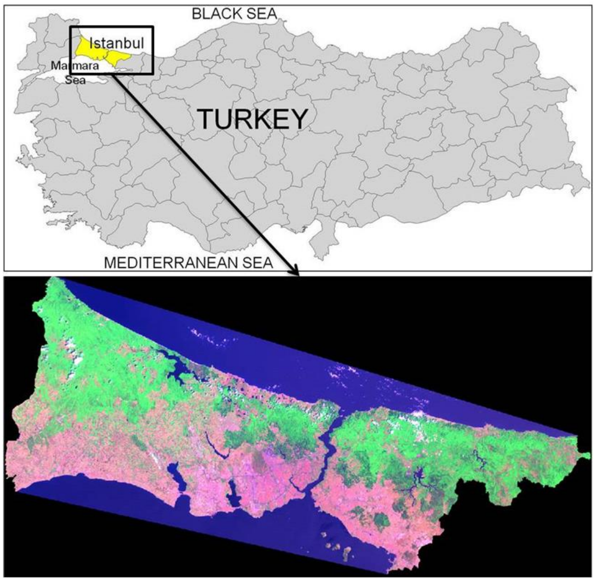


Figure 1. Geographical location of megacity, Istanbul

2. CASE STUDIES CONDUCTED ON ISTANBUL UTILIZING RS AND GIS TECHNOLOGIES

Numerous studies and researches have been realized on this ancient city at different times dating back to 1960's. In parallel to developments in computer science and to advances in technology, related studies accelerated within the past decade. In this paper, only the most recent ones conducted during 2010-2015 will be referred; however, the same expert team has been working on this city where they live prior to 2010. Musaoglu et al. (2006), Goksel et al. (2006) and Kaya (2007) are a few of these early studies.

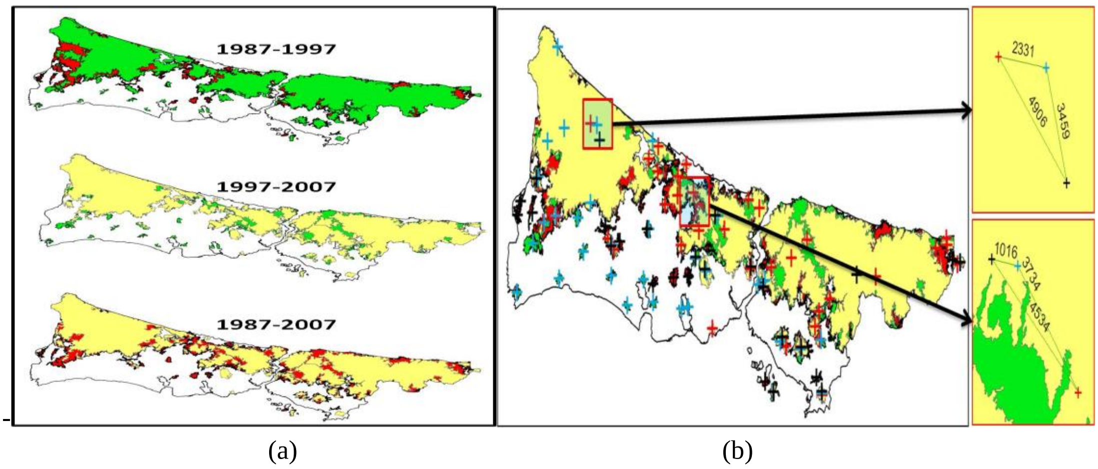
2.1 Temporal Impact of Urbanization on Forests in the Megacity Istanbul (2010)

The aim of this study was to examine the temporal impact of rapid urban growth on forest cover in the megacity during the two decades of 1987-2007 via Landsat images belonging to years 1987, 1997 and 2007. Due to urbanization increase and industrialization in addition to immigration from the other regions of Turkey for benefitting from better employment opportunities within years, the main forestry area located especially at the northern part of the city, has been severely damaged during this period. Spatial distribution of forests and their temporal changes were analyzed and via RS and GIS. In order to identify and visualize the environmental changes in an urban area, VIS method is a convenient conceptual model to apply and achieve good results (Setiewan et al., 2006). It was proposed by Ridd (1995) to simplify urban environments as combination of three basic ground components: vegetation (forest, green areas, parks, etc.)- V-, impervious surface (settlements and transportation) - I-, and soil -S-. To present the land cover trend and spatial changes on the forestry area, center of gravity of the forest polygons were calculated for the inspected years, and changes of the center of gravity were presented. The center of gravities and VIS method for determining the land-use distribution were analyzed for each of the examined year. Landsat 5TM images with spatial resolution of around 30 meters were geometrically corrected using more than 30 ground control points derived from 1: 25.000 scaled map. Images were transformed to Universal Transverse Mercator (UTM) coordinates using a first-order polynomial transformation and nearest neighbor re-sampling. 3 images that belong to different years were classified using the ISODATA classifier without atmospheric correction. At the beginning, 100 ISODATA spectral classes were combined to form the 3 classes of VIS.

Table 1 indicates the areal values and the corresponding changes within years after classification. Even though the changes in reality are quite high; they are observed as small changes in the figures due to largeness of the study area. In case of decreasing the study area, the changes appear as significant variations. In order to better illustrate the negative impact of urbanization on forests the values obtained from the results of classification are transferred to linear format so as to investigate the findings in GIS environment (Figure 2a). For this purpose, center of gravity of forest cover related to each of the 3 years under inspection are calculated by excluding those forest areas with areas less than 2 km^2. As such, it becomes easier to indicate the striking change in forests. A macro program was used to realize this process. Figure 2b indicates these differences. Black plus sign represents center of gravity of year 1987, magenta 1997, and red sign indicate year 2007. It is seen that at some points of the center of gravity indicate differences approaching 5 km.

Table 1. Areal values attained after classification and the changes in land cover within years

Class	Area (km^2) 1987	Area (km^2) 1997	Area (km^2) 2007	Changes in 1987-1997	Changes in 1997-2007	Changes in 1987-2007
Vegetation	2867	2832	2714	-34.81	-117.79	-152.60
Impervious	402	513	714.17	+110.94	+200.49	+311.43
Soil	2090	2017	1895	-72.57	-122.02	-194.59



(a) (b)

Figure 2. a) Differences in forest areas within investigated years by the aid of GIS, b) Differences observed at the center of gravity values calculated for the forests

When the findings of the study were analyzed, it was observed that rapid urbanization within a period of 20 years has a negative impact on forests, and within this period loss of forests have become significant on the contrary to urbanization. If this trend continues in future and if no precautions are to be taken, severe threat will be expected to occur on the forests of Istanbul.

2.2 Analysis of Urbanized Areas Using VIS Components Model (2012)

In this study, the spatial distribution of land-use /cover, and its corresponding temporal changes that have occurred in the megacity of Istanbul were analyzed by utilizing Landsat 5 TM images belonging to years 1987 and 2007. The land-use/cover distribution was realized through the application of VIS model. Besides, the urbanized area boundary obtained for 2007 was overlaid on the classified image of 1987 to recalculate VIS components, and to represent the changes that have occurred during the years. The past and present land-use status of the sub-urban residential area, Sultanbeyli, representing one of the areas under severe threat of illegal and rapid population increase since 1987, and the highly urbanized district of Kadikoy representing a district with high population density, was thoroughly investigated by utilizing the VIS model.

The areal distribution of the 3 components is given in Table 2 for the overall megacity. According to data processed, it was found that the surface area of Istanbul is approximately 5360 km^2 out of which 2867 km^2 in 1987 was covered by vegetation, 402 km^2 by impervious land, and 2090 km^2 by soil; on the other hand, the corresponding distribution was 2714 km^2 vegetation, 714 km^2 impervious land, and 1895 km^2 of soil in 2007. During 1987- 2007, impervious land increased by 311 km^2, while the vegetation and soil land comparatively decreased.

Table 2. Areal distribution of the VIS components in megacity Istanbul

Land Classes	**Areal distribution in 1987 (km^2)**	**Areal distribution in 2007 (km^2)**	**Variation between 1987-2007 (km^2)**
Vegetation	2867.04; 53.5 %	2714.44; 51.0 %	-152.60
Impervious	402.74; 7.5 %	714.17; 13.4 %	+311.43
Soil	2090.02; 39,0 %	1895.43; 35.6 %	-194.59

Further analyses were performed on more specific sites focusing on only the urbanized areas of the megacity, sub-urban district of Sultanbeyli, and on urban district of Kadikoy. Corresponding presentation of the VIS components for the referred areas are shown in Figure 3 (a, b, c, d).

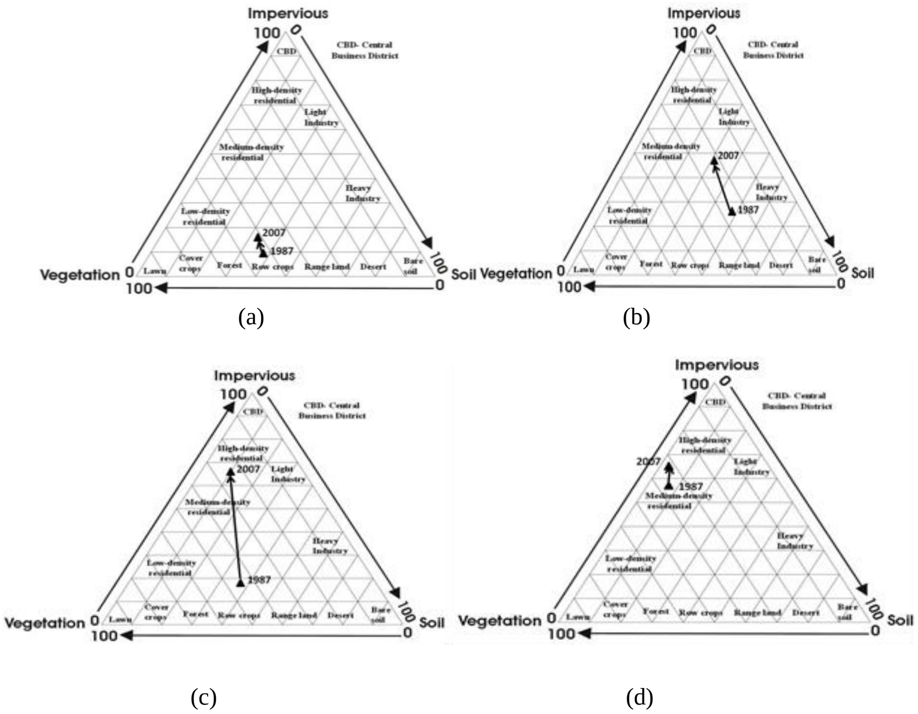


Figure 3. Presentation of the VIS components for a) the overall Istanbul Metropolitan area, b) urbanized regions of Istanbul, c) sub-urban district of Sultanbeyli, d) urban district of Kadikoy

In this study, VIS components defined the development direction of change and were shown by drawing vectors within the boundaries of the megacity, urbanized regions, and on the two districts representing suburban and urbanized regions. Particularly in urban areas, impervious land increased while the vegetation and soil components decreased. Intensively populated district of Sultanbeyli which is under the threat of illegal and rapid population has been determined to put forth the drastic changes in the land-use distribution. This remarkable variation is clearly indicated by the model as well. In general, the model applications on various lands in the megacity of Istanbul have exerted a common finding that the upward movement of the direction vector is towards the impervious land region.

The findings point out the drastic land-use changes in the suburban district, and a highly stable situation in the old residential urban district of the megacity. It is expected that such results are achieved in quite shorter periods of time by application of simple models with fewer components providing valuable information to decision and policy makers who are responsible for the sustainable management of administrative areas.

2.3 Temporal Impact of Urbanization on the Protection Zones of Two Drinking Water Reservoirs in Istanbul (2014)

The aim of this study was to examine the temporal impact of rapid population growth within the protection zones (absolute, short-range, medium range and long-range protection zones) of the two selected drinking water reservoirs of the megacity of Istanbul between the years of 1987-2011 that is under the effect of significant urbanization trend. Spatial distribution of land-use/cover and corresponding changes that have occurred throughout the various protection zones were analysed via Landsat 5 TM images belonging to the inspected years. Drinking water reservoirs selected for this study are Omerli located on the Asian side, and Buyukcekmece situated on the European side of the city. The land-use/cover distributions were extracted from satellite sensor images based on the 3 classes of the VIS model. The areal analyses were conducted using VIS component analysis for the two different examined years.

The two drinking water reservoirs selected for this study shown in Figure 4 are Omerli with a drainage area of 1612 km^2 located on the Asian side of the city that supplies almost 27% of the water demand of the mega city; whereas the other is Buyukcekmece that situated on the European side of the city supplying 17% of the overall water demand with a drainage area of 632 km^2. Figure 5 (a) and (b) illustrates the results of VIS model application to Buyukcekmece and Omerli Reservoir watersheds for the two examined years based on the various protection zones referred above.

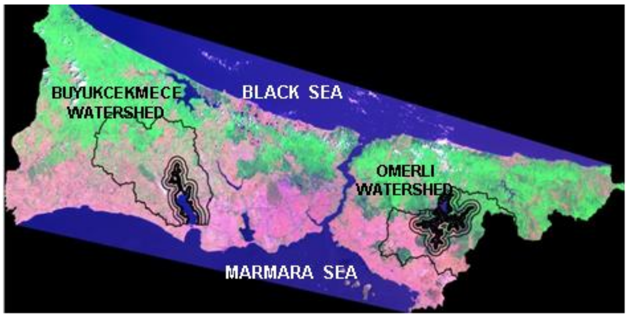
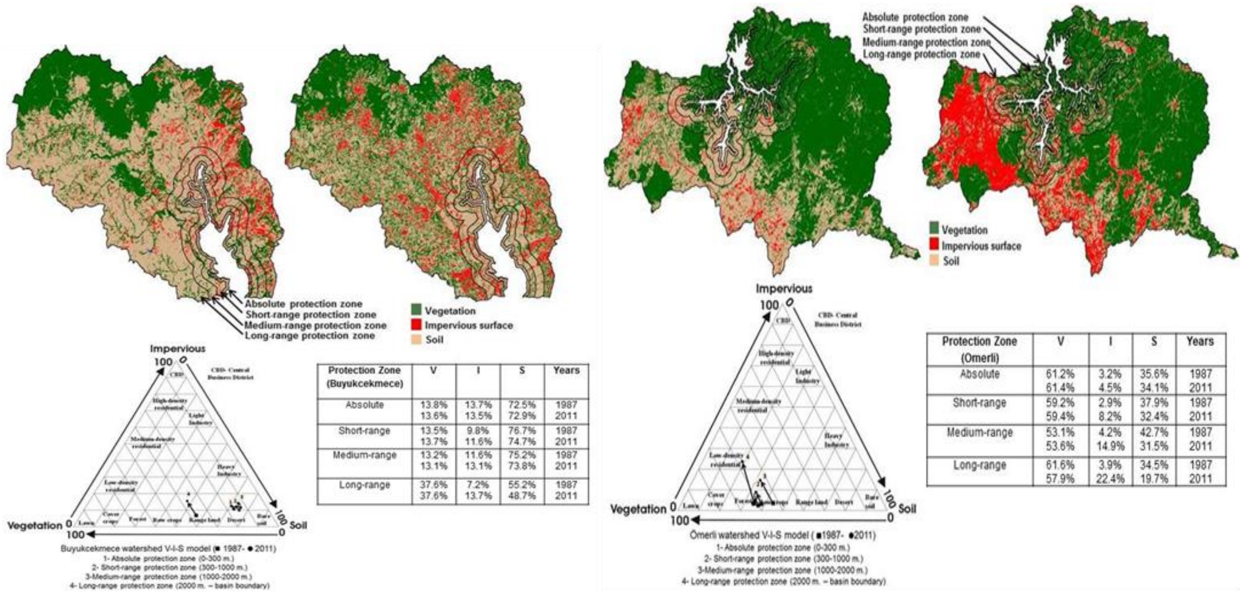


Figure 4. Location of the two drinking water reservoirs of Istanbul

The corresponding classification on Buyukcekmece Reservoir determined that no changes have occurred between 24 years in the absolute protection zone of the reservoir. This situation is also confirmed by the outputs of the VIS model that puts forth the changes in the form of percent land-use changes. A negligible change in the vegetation cover is observed in the short-range and medium-range protection zones of within the inspected years. However, in these protection zones some of the villages that have been established years ago have shown a slight increase that resulted in a decrease in the soil- S- class. While the vegetation-V- class exerted no change in the long-range protection zone of the reservoir, residential areas have increased from 7.2% to 13.7% within the examined years. This situation affected the soil-S-class that had decreased from 55.2% to 48.7%. VIS model at the same time determined the development trend of the watershed based on the 3 classes by making use of the land-use changes.

Regarding the Omerli Reservoir, almost no changes are recorded in the vegetation-V-class in the absolute-protection zone of this watershed. However, a slight increase is detected in the impervious-I- class indicating an increase in the villages that have been established in the old times. As expected, this increase caused a decrease in the soil component-S-. A similar variation is detected in both of the short-range and medium-range protection zones. While almost no change in the vegetation -V- cover is observed, an increase in the residential areas denoted by impervious land -I- is seen and this increase in parallel caused a decrease in the soil class -S-. These smooth changes are unfortunately were not valid for the long-range protection zone of this watershed. A significant increase in the impervious land -I- is observed within years indicating a huge urbanization effort in the region. The share of the residential areas in this protection zone is seen to increase from 3.9% to 22.4%. This tremendous change resulted in a significant decrease in the soil-S- class. The reduction in the vegetation-V-cover is comparatively small. VIS model results indicate the development trend of the watershed towards urbanization.



Protection Zone (Buyukcekmece)	V	I	S	Years
Absolute	13.8% 13.6%	13.7% 13.5%	72.5% 72.9%	1987 2011
Short-range	13.5% 13.7%	9.8% 11.6%	76.7% 74.7%	1987 2011
Medium-range	13.2% 13.1%	11.6% 13.1%	75.2% 73.8%	1987 2011
Long-range	37.6% 37.6%	7.2% 13.7%	55.2% 48.7%	1987 2011

Protection Zone (Omerli)	V	I	S	Years
Absolute	61.2% 61.4%	3.2% 4.5%	35.6% 34.1%	1987 2011
Short-range	59.2% 59.4%	2.9% 8.2%	37.9% 32.4%	1987 2011
Medium-range	53.1% 53.6%	4.2% 14.9%	42.7% 31.5%	1987 2011
Long-range	61.6% 57.9%	3.9% 22.4%	34.5% 19.7%	1987 2011

(a) (b)

Figure 5. Classification and VIS model results of a) Buyukcekmece and b) Omerli watersheds within years

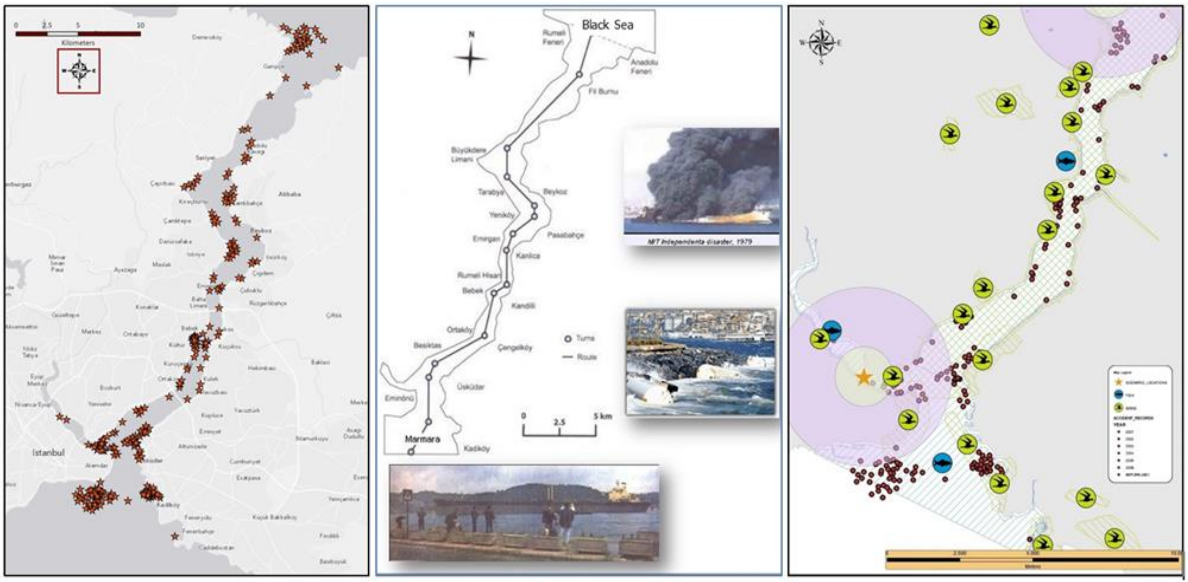
The findings were of course known by the authorities; however, VIS indicates the realities in numerical values and clearly points out the pressure on the impervious land cover in the watersheds of concern. VIS model results indicate the development trend of the watershed towards urbanization. Striking information is obtained regarding the urbanization effects on the various protection zones by the use of the VIS model

2.4 Mapping the Distribution of Oil Sensitive Fish and Bird Species in the Istanbul Strait (2014)

As evidenced by the previous accidents, a considerable increase in the marine vessels over the past decade is an indication of the high oil spill risk potential for the Istanbul Strait (Bosphorus) that bears a natural beauty and various human-use resources. This situation poses a considerable threat on the Bosphorus ecosystem which is one of the most important migration routes of the Mediterranean and Black Sea fish and of many continental bird species. Therefore, this study aimed to map the ecosystem resources regarding possible oil spill threats.

With the help of Environmental Sensitivity Index (ESI) classification which is developed by US-NOAA, fish and bird species encountered around Bosphorus for a year-round were collected through a literature and field survey. Ecosystem dataset contains name of the species, their abundance, time and location of presence. It was further compiled into a geodatabase where data on marine accidents were analyzed and risk posing areas regarding to marine accidents and possible oil spill locations are determined. With the analysis of the most probable accident locations through the Bosphorus, information is produced on a monthly basis on the potential risk that might affect the fish and bird species by exposure to oil spills.

Figure 6 (a) shows the location of the accident sites, whereas Figure 6 (b) transportation route along the Strait and finally Figure 6(c) is a map indicating the biological resources (bird and fish species) along the Bosphorus.



(a) (b) (c)

Figure 6. (a) Locations of the accident sites, (b) transportation route, sharp turns, and (c) mapping of biological resources (bird and fish species) along the Bosphorus

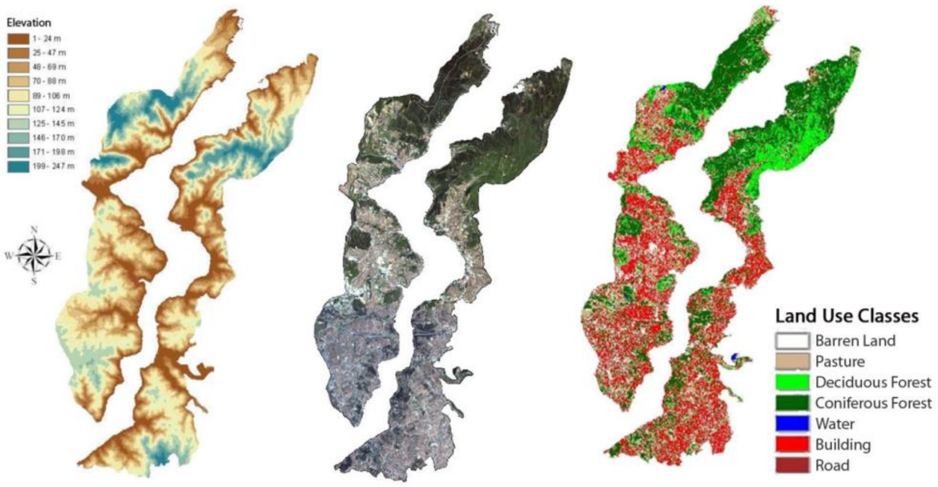
This study shows the importance of an ecosystem geodatabase and its utility regarding oil spill risk. By the integration of such an inventory into GIS, species to be considered during an emergency can be analyzed, specific protection measures based on the species can be defined beforehand, and this information can be utilized by the marine food auditors in order to inspect seafood sales or to mobilize NGOs working for the protection of oil-slicked organisms. As an example, distribution of queried bird species is shown in Figure 7.

(a) (b) (c)

Figure 7. Distribution of queried bird species, (a) Mew gull, (b) Eurasian coot, (c) LabrusBergylta along the Bosphorous and the Golden Horn

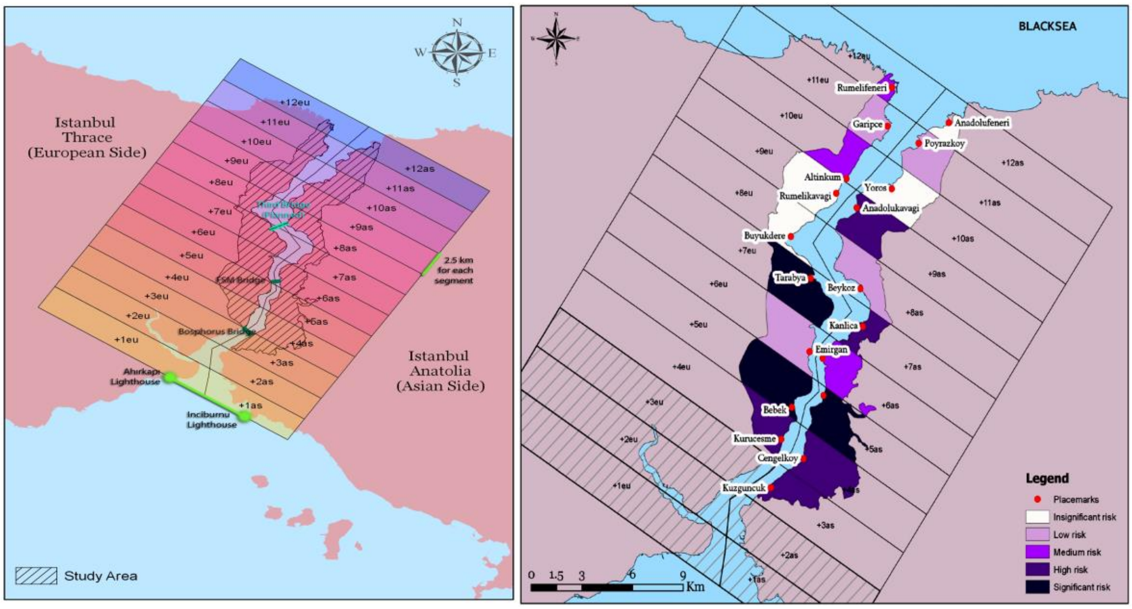
2.5 Use of Remote Sensing and Geographical Information Systems in the Determination of High- Risk Areas Regarding Marine Traffic in the Istanbul Strait (2015)

A considerable increase in the number of vessels over the past decade has indicated the high potential for oil spillage and fire hazards in the Bosphorous. This study aimed to determine the coastal areas that are under an oil spill/fire/explosion risk in the Istanbul Strait by using geoinformatics. RS technology was used for classifying the shoreline and land-use activities in the fore-scene and back-scene zones as shown in Figure 8 followed by assigning risk scores to various GIS data layers and suitability evaluation based on the weight of each score. The risk components were prioritized and layers were allocated according to their risk scores. Major components that classify risk-posing areas are accident likelihood, number of historical assets, human-use resources, population, and lack of critical facilities. Segment-wise risk levels that resulted in comparatively higher scores indicated the vulnerable areas along the Strait to draw the attention of the society and the decision-makers who are responsible for the policy implications. Figure 9 (a) shows the risk segments of the study area, and Figure 9 (b) is the final risk map of the Bosphorus in terms of oil spill vulnerability and preparedness.



(a) (b) (c)

Figure 8. Fore-scene and back-scene zones of Bosphorus: (a) DEM, (b) IKONOS image and (c) classification result



(a) (b)

Figure 9. (a) Risk segments, (b) final risk map of the Bosphorus in terms of oil spill vulnerability and preparedness

This study can be regarded as a preliminary risk assessment analysis regarding oil spill risk in the Bosphorous. The methodology developed is furnished by GIS and RS technologies that allow an expression of risk level grading as a calculation grid. Each grid throughout the Strait has an equal width of 2.5 km which may vary in other studies. The number of GIS layers may be increased in future studies by adding ecological coastal and recreational components for a more detailed assessment. One of the concluding remarks of the study is that the application of the methodology developed tends to have a positive impact on the coastal management system of the Bosphorus by mapping and visualizing the areas at risk. In case of an emergency situation, prepared maps will act as valuable guides to cope with the effects of probable disasters, and in the general sense it will help the decision-makers to develop their coastal management strategies and to imply corresponding human policies. Such studies have become even more pronounced in parallel to an increase in navigation. Similar other waterways that are main routes of oil transfer should be subject to risk assessment studies.

3. DISCUSSIONS AND CONCLUSIONS

In the first three case studies on Istanbul, it is seen that such practices of utilizing RS and GIS technologies enable to qualitatively and quantitatively calculate the spatial and temporal changes in selected areas. It is expected that obtained results provide valuable information to especially decision and policy makers which is important for the sustainable management of the megacity as well as the development of the vulnerable and sensitive watersheds of the city that used to supply its water demand from the surface water bodies. Urbanization and its sprawl is really a drastic problem in the highly crowded metropolitan areas of especially developing countries. Therefore, utility of the modern technological tools of RS and GIS is uncountable in the sense of monitoring and mapping of both the spatial and temporal changes in the areas of interest.

VIS components model is capable of defining the development direction of change that are indicated by drawing vectors within the boundaries of the megacity. Particularly in urban areas, impervious land increased while the vegetation and soil components decreased. In general, the model applications on various lands in the megacity of Istanbul have exerted a common finding that the upward movement of the direction vector is towards the impervious land region. Thus, such practices give rise to valuable information on the urban morphology with fewer components in a short period of time. It can be emphasized that such simple models can be applied with ease, and the findings can be submitted and presented to the decision makers who are responsible for the well-being of the urbanized areas.

Maps and geodatabase developed and updated over heavily used shipping routes in the Istanbul Strait with high emergency and oil spill risk is vital for the sake of the vulnerable coastline. Seasonal maps for sensitive areas need to be mapped in order to get prepared against probable oil spills. Those geodatabases could be used for tracking ecosystem development/damage or for preparing ecosystem protection maps. An updated spatial ecosystem inventory integrated with GIS allows many spatial and ecological analyses resulting in immediate response on emergencies.

As such, the last case study can be regarded as a preliminary risk assessment analysis regarding oil spill risk in the Bosphorous. Such studies have become even more pronounced in parallel to an increase in navigation. Similar other waterways that are main routes of oil transfer should be subject to risk assessment studies. Thus, the methodology developed may act as a road map for determining and mapping areas at risk in a waterway and helps conducting similar risk assessment studies. The functional entity and risk grading scores are subject to change based on the characteristics and precision of the input data used and on the expected outcomes of the study.

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