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Abstract: Remote-sensing and geographic-information-systems (GIS) techniques were jointly used in this study to establish a GIS database system for the Yeşilırmak watershed provinces, which include Amasya, Tokat, Çorum, Yozgat and Samsun. Composite multicolour images (down to 6 m resolution) from the LANDSAT TM and Indian IRS C/D satellites, land-use/land-cover maps derived from these images, road networks, soil information, digital terrain model, slope and aspect information derived from digital elevation data and meteorological data at province level are the major constituents of this database. A '*project office*' has been established with trained personnel at each province centre to effectively use the resultant GIS in planning, monitoring and applications, as well as to update it regularly. Some sample applications of the resultant Yeşilırmak Watershed Provinces Geographic Information System (YPG) to various provincial and watershed-level problems are presented.

Key Words: Satellite Remote Sensing, Geographic Information Systems, Watershed Management, Image Processing

Uydu Görüntüleri ve Diğer Veriler Kullanımı ile Yeşilırmak Havzası İlleri İçin Coğrafi Bilgi Sistemi Altyapısının Kurulması

Özet: Bu çalışmada, uydularla uzaktan algılama ve diğer ilgili veriler birlikte kullanılarak Yeşilırmak havzası için Amasya, Çorum, Yozgat, Tokat ve Samsun illerini temel bir Coğrafi Bilgi Sistemi veri tabanı altyapısı kurulmuştur. LANDSAT-TM ve IRS-C/D uyduları görüntülerinden oluşturulan 6 m çözümlemeli renkli kompozit görüntüler, uydu görüntülerinden türetilen arazi kullanımı/arazi örtüsü haritaları, iller düzeyinde yol ağı şebekeleri, illerdeki tüm yerleşim birimleri, illere ait toprak bilgileri, tüm il alanlarını kaplayan 3 boyutlu sayısal arazi modeli ile eğim ve bakı gibi bundan türetilen bilgiler ve meteoroloji verilerinden oluşturulan ana katmanlar, bu veri tabanının temel bileşenlerini oluşturmaktadır. Ayrıca, her ilde bu veri tabanını etkin şekilde kullanabilecek, planlama, uygulama, takip ve güncelleme çalışmalarını yürütebilecek, eğitimli personele sahip bir '*Proje Ofisi*' kurulması hedeflenmiş, bu veri tabanı kullanılarak, iller ve havza bazında gerçekleştirilebilecek uygulamalara örnekler verilmiştir.

Anahtar Sözcükler: Uydularla Uzaktan Algılama, Coğrafi Bilgi Sistemleri, Havza Yönetimi, Görüntü İşleme

Introduction

Joint use of satellite-remote sensing (RS) and GIS technologies (Sabins 1987; Drury 1990; Aranoff 1991; Sharma *et al.* 2001) to create an accurate and up-to-date information system for large regions such as provinces or watersheds is a common economic solution for handling the planning, monitoring and implementation of activities for sustainable development (Yıldırım *et al.* 1995, 1999; Özel *et al.* 1997). To establish the infrastructure for a Yeşilırmak Watershed Provinces Geographic Information System (YPG), a joint program with Marmara Research Centre was initiated by the Yeşilırmak Provinces Joint Public Services Union (Yeşilırmak Havzası İlleri Özel İdareler Hizmet Birliği, YİB) which is a public office established by the governors of five provinces (Amasya, Tokat, Çorum, Yozgat, Samsun) in the region. One of its initial aims was to establish a basic natural inventory and database in the management level of these provinces to be shared by various local offices and institutions (Özel *et al.* 1999a). This goal was also considered to be a basis for physical development plans for this watershed area and the provinces concerned. For the formation of the YPG, currently available high-resolution, multicolour images

from several types of satellite images as well as other existing data (maps, reports, plans and attribute data) from different government ministries and sources [such as the Ministry of Agriculture and Village Affairs (Unpublished Soil Data Reports by TOKB-KHGM 1972, 1984, 1991, 1994, 1997), the State Meterological Office (DMİGM 1989), the General Command of Mapping (Harita Genel Komutanlığı 1996), the State Water Works (Devlet Su İşleri 1995) and the State Statistical Office (Devlet İstatistik Enstitüsü 2000)] were evaluated and used.

The physical boundaries of the Yeşilırmak watershed as described by the State Water Works, include the Amasya and Tokat provinces in their entirety and parts of Samsun, Çorum and Yozgat provinces, and are shown in Figure 1. The watershed occupies an area of about 36,000 km^2, while the total area of the five provinces is approximately 51,000 km^2. The total area of the provinces is actually the basis of present GIS, and corresponds to approximately 7% of the total area of Turkey. The total population of the watershed provinces is almost 4 million, or about 6% of the total population of Turkey (DIE 2000). Small areas of the Giresun, Ordu, Gümüşhane, Erzincan and Sivas provinces – a total of about 8.000 km^2 – are also within the physical geographical boundaries of the watershed, but outside the five provinces considered here. However, these areas are not considered in any detail in the YPG layers.

Owner of GIS the Database and Its Use

The analysis and work foreseen in this project was completed for total coverage of the five provinces named above, irrespective of being part of the natural watershed coverage (in fact, the provincial areas outside the physical watershed boundaries comprise a large part – 36 % – of the physical watershed coverage). The local governance of Yeşilırmak Provinces' Union (YİB), created by the

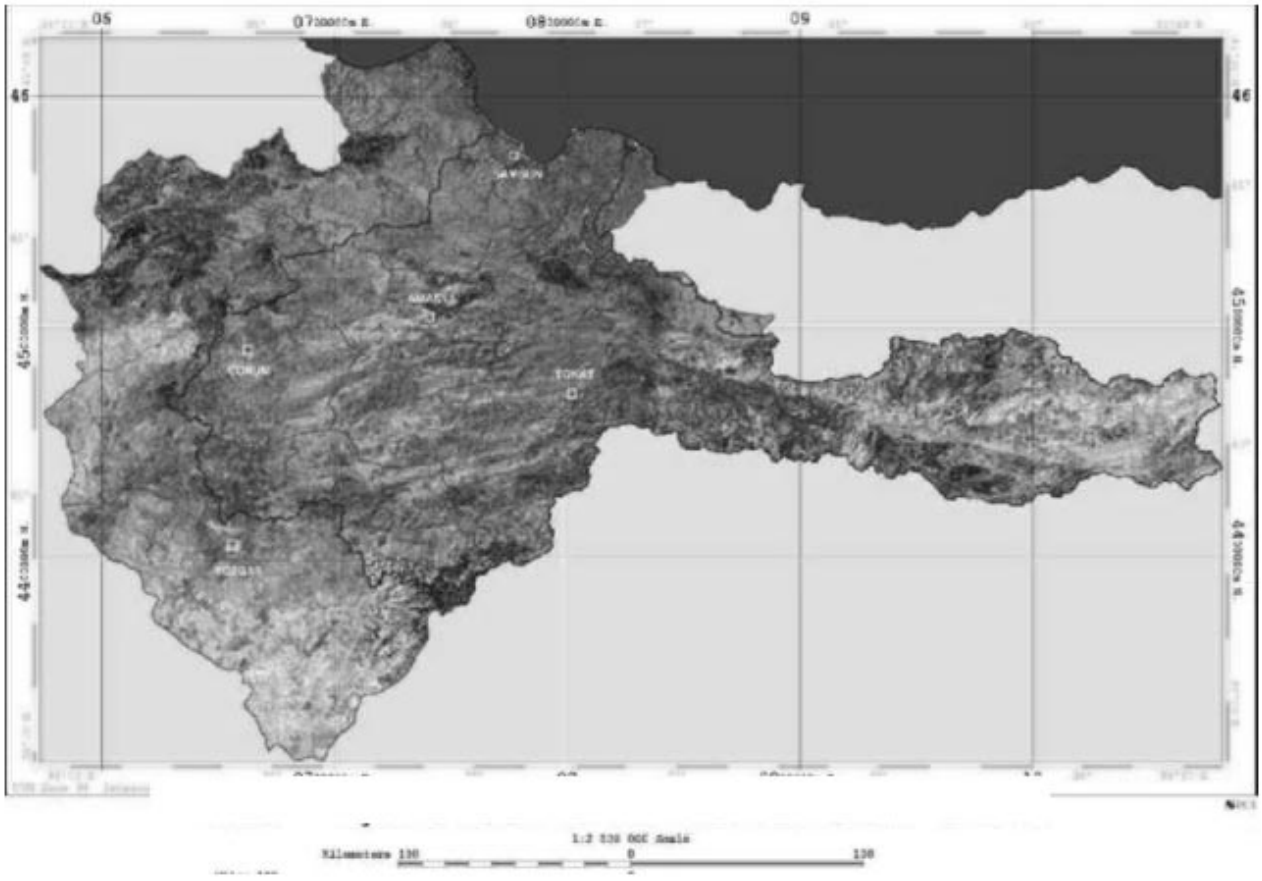

Figure 1. Boundaries of Yeşilırmak Watershed (blue) and the studied 5 provinces (red) on Landsat TM satellite image.

province governors, financed the preparation of the Yeşilırmak Watershed GIS (YPG), which was completed in June 2000 together with the establishment of a *project office*, in each provincial centre. Complete YPG data, in one workstation (WS), and one personal-computer (PC)-based computer system were delivered to the main project office (MPO) established in Amasya, while local branch project offices (BPO) in Samsun, Tokat, Çorum and Yozgat have facilities that host provincial level data. BPO's can get connected through their computer links via the *Internet* to the MPO, in order to do more detailed image processing, larger scale printing and GIS updating operations. Coordinating database management is to be carried out by the YİB MPO in Amasya.

The owner of the database system, as well as the main and branch project offices, is the YİB, established in 1997 (The YİB is approved by the Ministry of Internal Affairs as the official body for planning activities in the watershed and nearby provinces). The YİB is also planning a feasibility study for the Yeşilırmak Watershed Physical Development Project (YPDP). Planning is such that present YPG data layers are to be for utilised in YPDP preparation. It is also foreseen that this large pool of regional-level data will be open to the use of local government bodies, institutes, private and public organisations and individuals in the provinces, with different levels of access, manipulation and information-exchange possibilities.

Method: RS and GIS Used to Create the Watershed Geographic Information System

Satellite Remote-Sensing (SRS) technology, with its high-resolution, multicolour images of large areas, is an important source of contemporary data and knowledge for the YPG database. Through use of such images, various information layers can be prepared and updated easily. In the present case, LANDSAT-TM images (with 30 m resolution), providing full coverage of Yeşilırmak provincial areas, are used for visual inspection and also for the natural-looking basic layer. These images are also processed for various thematic purposes, including a land-cover/land-use map of the watershed provinces through image classification and a vegetation-index analysis (Pratt 1978; Chalappa 1995). On the other hand, Indian IRS-1C's panchromatic images (with 6 m resolution) are utilised to enhance LANDSAT-TM's coarser resolution (but which is richer in colour information) through well known *'image-fusion'* techniques (Yıldırım *et al.* 1996, 1997, 1998). This way, we can obtain fused images rich in color and high (6 m) in resolution that can be used for various purposes. A number of other layers for YPG were created by using data and maps from various local- and national-level public sources.

Data Sources and Layers for the GIS

Satellite Data

Five LANDSAT-TM frames are needed to cover all the provinces included in the project. These images are from the years 1997 and 1998, on cloudless days in spring and summer months. After geo-coding these images with a root-mean-square (RMS) positional error of < 1 pixel size (30 x 30 m^2), a joint mosaic of all five provinces and the physical watershed area were created (Figure 1). A separate mosaic of area covered by five provinces was also prepared with enhanced geometric resolution by fusing 6 m IRS-1C panchromatic and 30 m LANDSAT TM images. Examples from this mosaic are given in Figure 2. Besides these, images of the study area dating back to the time intervals 1974-1976 and 1984-1986 (from the archives of Space Technologies Group) were also available for sample studies to reveal and detect long-range changes in the project area.

Digital Elevation Data

For the preparation of a digital elevation model of the provinces, the area is fully covered by standard topographic map sheets (122 in number) prepared by the Turkish Army-General Commander of Mapping (Harita Genel Komutanlığı) at a 1:50,000 scale. After the creation of a GIS layer of elevation contour lines (separated by 20 m, vertical) from the raw elevation data, a digital elevation model (DEM) for each sheet was produced. This data is prepared as a mosaic of map sheets for each province. Draping satellite images of proper colour bands over the DEM results in three-dimensional, realistic-looking virtual images from every part of the project area. One can choose the points of view and elevations of observation, with natural or artificial colours. Examples of such images are given in Figure 3. The terrain slope, its slope length and aspect angle at any location, as well as drainage network layer

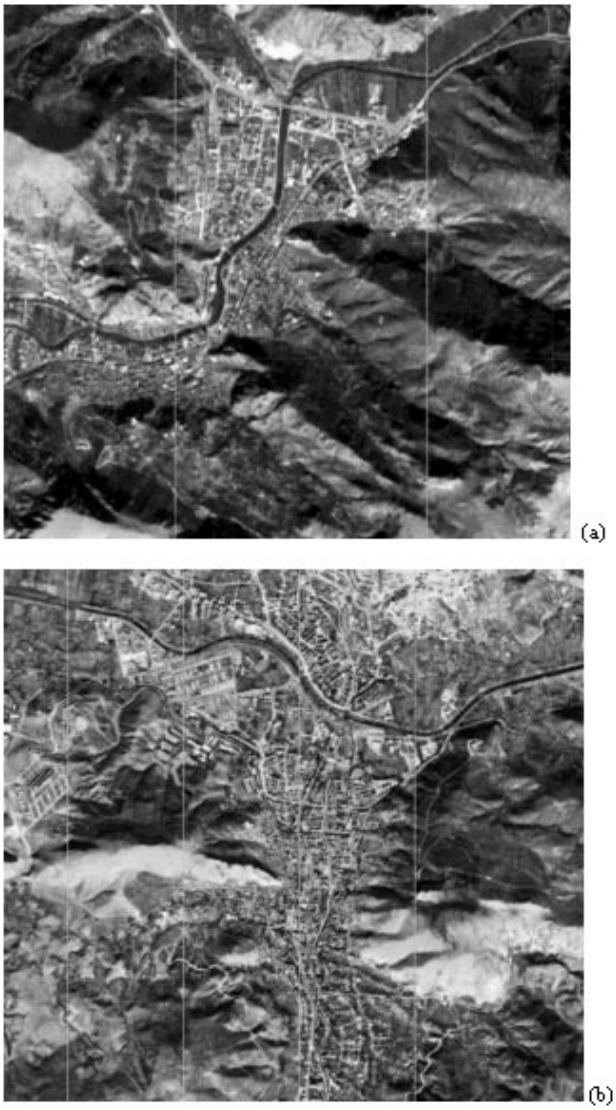

Figure 2. Landsat TM and IRS grey colour composite satellite images of Yeşilırmak Valley over Amasya **(a)** and Tokat **(b)** city centers.

for a selected area within the project provinces and a hill-shade image for 3D-appearances for visual evaluation are derivable from the DEM for further analysis, if the need arises.

Road Network and Official Settlement Centres-Layer

The road network of the subject provinces was produced from composite (fused) satellite images (at 6 m resolution) and was compared with "*official sketch-maps*" from the General Directorate of Rural Affairs (Köy Hizmetleri Genel Müdürlüğü, KHGM). All of the locations

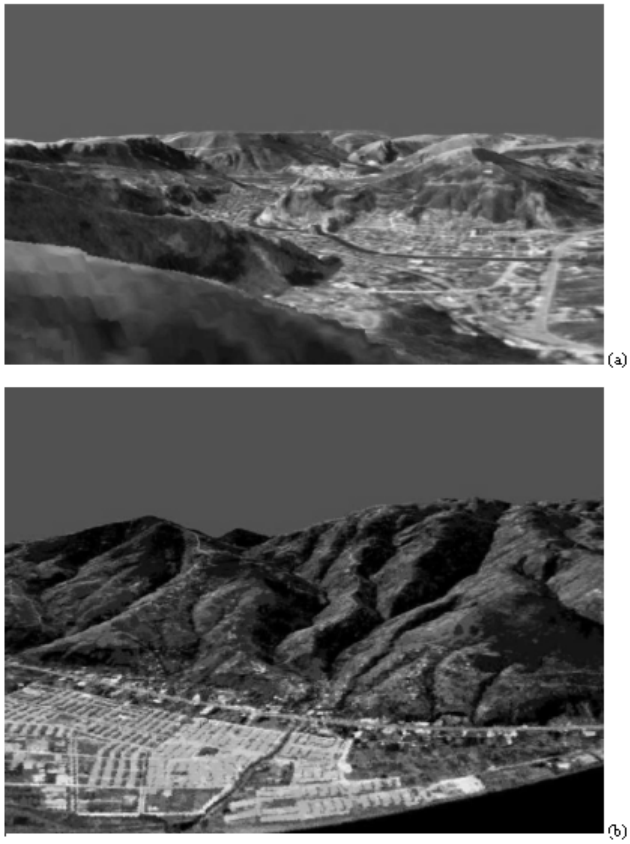

Figure 3. 3D virtual scenes over Amasya **(a)** and Samsun **(b)** obtained through draping of grey colour composite images created, over digital elevation model.

of official settlements, including province centres, counties and villages, were also created as a separate layer connected to the road network. Consequently, conventional hardcopy drawings and sketch-maps of the KHGM were correctly re-created, and can now be easily updated, scaled, and geo-coded. Thus, the acquired road network of the provinces offers more detailed and truer shapes, positions and structures. The present scale of the road network has been 1:25,000, because of the best-look resolution of fused satellite image. In practice, each province had created its own "road maps" and "road legends" for their 'sketches'. Now these also may be standardised for all watershed provinces through the MPO and BPO's.

Soil Information Layer

Soil data was acquired from soil maps (unpublished Soil Data Reports by TOKB- KHGM) prepared by the former

Office of Land and Water Works (TOPRAK-SU Genel Müdürlüğü). The soil maps for three provinces are quite recent (post 1990), while for the Yozgat and Samsun provinces, soil maps date from 1972 and 1984, respectively. All soil maps were at a 1:100,000 scale. These maps were also quite sketchy and had no proper co-ordinate system. By using standard geo-coding procedures, these plan-maps were given co-ordinates and were then digitised by the TÜBİTAK-MRC-Space Technologies Group. Later, separate map sheets were combined to create the mosaic for each province.

The soil information layer consists of nine different attributes, including soil depths, technical soil groups, agricultural usability level, salinity level, soil-erosion level etc. for each soil polygon, defining various properties of the soils at hand. All attributes could be used separately or jointly, to form several new and independent GIS layers.

Meteorological Information Layers

Meteorological data layers included in the YPG were created by the MRC-STG from point data and/or hard copy maps by the State Meteorological Office (DMIGM). They consist of the following separate layers: (1) types of climatic regions, (2) rainfall statistics (monthly and annual means), (3) temperature statistics (monthly and annual means), (4) date of first frost in the autumn and date of latest frost in spring, and (5) vegetation growth period length. All these layers (except temperature) were digitised by the MRC project group, from a publication by the State Meteorological Office (DMIGM 1989). However, temperature data needed a further correction for elevation. Relevant data were smoothed and modelled through the DEM for different climatic zones in the region, with parameters provided by the DMIGM. Typical linear resolution of the temperature layer was about 100 m, while other meteorological layers have the coarser resolution of about 500 m.

Administrative Information Layer

This layer includes the boundary information for the provinces and their counties, is in simple vector form, and is important for administrative purposes. Provincial boundaries also offer an important means for percentage-area analysis, temporal change statistics and comparison. Another layer to define was that comprising the official 1:50,000-scaled map sheet frames of the HGK. This layer makes it easier to describe the co-ordinates in order to locate and identify villages, places and points of interests, using the standard HGK map sheet numbers and names.

Organisation of YPG Layers

Since the YPG is a system consisting of numerous database layers, some common rules given below have been accepted in creating and organising the layers.

(a) All the layers were prepared using Universal Transverse Mercator (UTM) co-ordinates. In the UTM system, Turkey falls between internationally accepted Zones 35 through 38. However, the transition stripe from UTM Zone 36 to Zone 37 passes through the project area dividing the Amasya and Samsun provinces into two halves. Since the raster-based data layers occupy a lot of disk space on the system, it was impossible to keep data from both UTM zones. Consequently, it was decided to keep all the data of Çorum and Yozgat in Zone 36 while keeping the other provinces in Zone 37. However, this decision was valid only for the raster data. The vector-based data was prepared in both UTM zones respecting the relationships between the data layers.

(b) A maximum of 90 individual data layers is possible for each province, totalling 450 layers for the whole project area. However, not all the layers possible are presently fully occupied. At present, a total of 22 layers exist, and they are grouped under six main divisions: (1) satellite images; (2) DEM; (3) road network; (4) soil information; (5) meteorological information; and (6) administrative information. To make all the data files reachable in the YPG, some standards – such as naming the layers, installing them under specific themes and handling the attributes – were accepted.

(c) Formats of the data layers had to be carefully defined due to the high volumes of physical disk space required for the files (as vector or raster data). The *master project office* (MPO) at Amasya acquired a full copy of all the layers and data (with more extensive image processing, GIS and presentation software) while *branch project offices* (BPO)'s were to keep track only of their province's data. The software at BPO's was also limited to serve the project clients and to facilitate simpler demonstrations. Format organisation for use and

exchange of data with the MPO and with each other is one of the main current tasks of each project office.

(d) the YPG database was designed to be actively used by several technical groups of various professions at different provincial offices. So, it was critically important for the project team to build a user-friendly GIS structure and interface. The interface should be understandable, and easy to utilise and update. Therefore, the project team has prepared a simple and user-friendly form of GIS interface for the PC environment. During the project development and implementation some training was also given to technical groups from each province in order to inform and educate them about the formation, use and beneficial details of the YPG data layers.

Results

A number of sample application exercises were devised and the use of the YPG was shown to project office staff at MRC and at local project offices during training sessions and post-delivery stages.

Application Examples using the YPG in Problem Definition and Solutions

Among the project topics and related activities we note the followings:

(i) The YPG is to form a basis for planning, implementation and monitoring of economical decisions and constraints in the development programs of the provinces as well as in the watershed region. The YPG aims to contribute to the solution of observed ecological, agricultural and other problems of the area. A sample sub-project for the Samsun province named "*Agro-Ecological Zoning*", has been jointly realised with the project office team for this province, located at the Black Sea Agricultural Research Institute (Karadeniz Tarımsal Araştırma Enstitüsü, KTAE) in Samsun. For this work, more than 20 levels of data (most of which re-created and derived from existing layers for Samsun) were prepared to achieve this goal. The aim was to define agriculturally uniform crop-growth regions defined by several topographic, climatic and ecological constraints. Its preliminary results were published as a project technical report (Özel *et al.* 1998), and will be prepared for another publication. This work was completed in a relatively short time period (several months) using the already existing YPG database. Besides the creation of crop-yield suitability maps for the province, introducing a local expert group to the detailed structure and use of the YPG was another important purpose of this joint exercise. This experience was also an example to show that, by active participation from local project offices and other institutes (or universities) in the provinces, high-quality work and application projects can easily be planned and carried out to meet local needs, if enough incentive and initiative are given.

The agro-ecological zoning exercise is a good example of the use of the YPG at the technical-management level for a high-priority purpose, due to the significant potential economic value of its results for the province. For example, by using this type of YPG-based models, areas of incorrect or inefficient land use in these provinces can easily be assessed, and recommendations can be made to administrators at different levels to take necessary measures to re-plan and re-manage the land. One such case has been the need for re-evaluation and follow-up re-management planning for the excessive hazelnut tree cover on the Çarşamba plain. The land here is known to have much higher agricultural value for fresh vegetables and other fruits than for hazelnut.

(ii) Still another case of interest on the Bafra Plain was discovered by temporal investigation of satellite images of the delta region. It was recognized that the coastline of the Bafra Plain was widely destroyed over the last 10 years. The main reason for this excessive coastal change was the construction of new dams (the Fuat Uğurlu and Suat Uğurlu dams) on the Yeşilırmak River, together with incorrect water regulation and related pumping system down these dams. The accumulated effects over the years have caused losses and flooding of valuable fertile land near the sea (Figure 4).

(iii) As is clear from the explanations, the scale of the YPG layers vary between 1:10,000 and 1:100,000 due to the variety of data sources. Pixel sizes of satellite images also vary: on one hand, LANDSAT-TM images with 30 m linear resolution correspond roughly to the 1:100,000 resolution at their visual optimum; on the other hand colour composite satellite images created using data fusion of LANDSAT-TM images with IRS-1C images having a linear solution of 6 m enable us to produce more detailed GIS layers, down to scales of 1:10,000, when hard-copied, if the need arises. Delineation of the boundaries threatening rapid

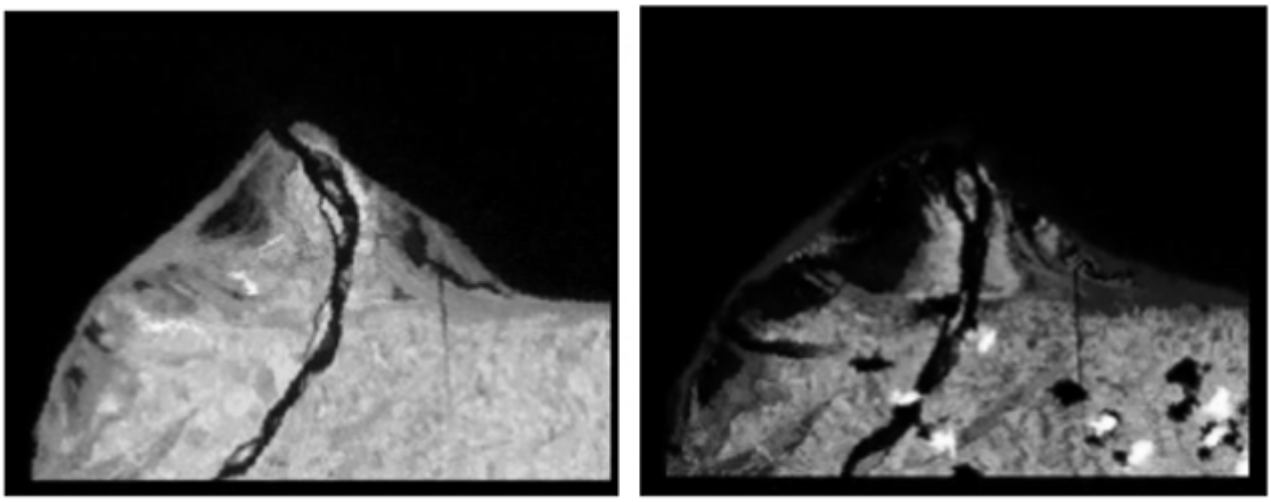

Figure 4. Changes in coastal line of Bafra Plain as observed from LANDSAT TM images taken at 1984 and 1997.

industrialisation areas around main cities, as well as primary streets and some structures in medium-level towns, can be easily observed at these scales via satellite images. Such an exercise was carried out in Tokat, in cooperation with staff from Gazi Osman Paşa University and the Tokat Municipality (Susam 2000).

(iv) It is also important to utilise the most recent possible data in the work. The satellite images used in the YPG project were purchased at the project start, in 1997 and 1998. Accordingly, the main GIS data layers produced from these are quite up-to-date. Using 6 m resolution satellite images, a contemporary and detailed road network of Amasya province was created in cooperation with staff from the local Village Affairs Office in Amasya (Figure 5). This effort is an example of the use of GIS and satellite images to update the existing road network plan, and bring it to map status with all details correct and up-to-date. However, some of the layers in the YPG (for example, soil and erosion information) are much older and may need minor or extensive upgrading with the participation of proper technical personnel. Sometimes the only available information about the

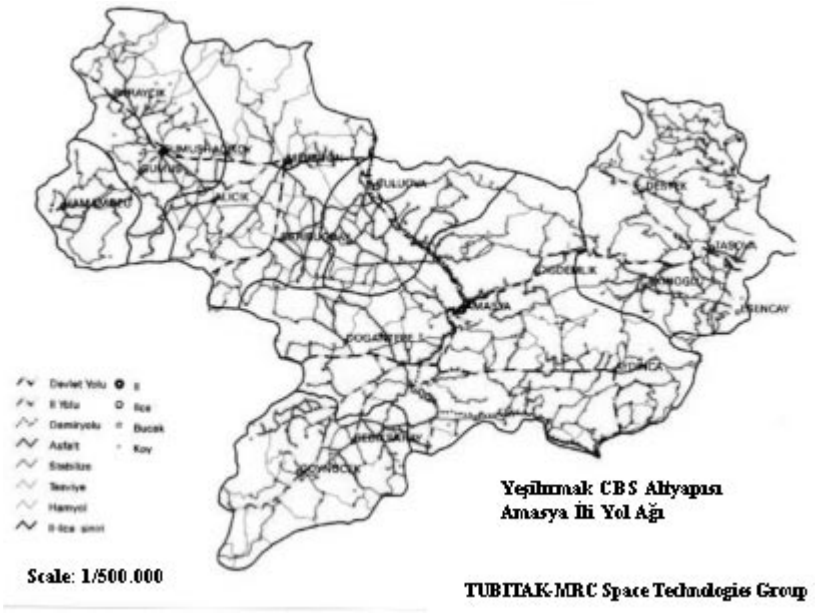

Figure 5. Up-to-date Amasya Province Road Network as extracted from 6 m resolution IRS Pan satellite image.

subject matter may be quite dated. Such information and thematic maps must be used with due care and warning. Comparison of such data with contemporary satellite images does help to estimate the present status of the data.

Conclusions

Modern technologies, including satellite remote sensing, advanced computer hardware and software technologies (such as GIS, which has very capable data-handling and querying capabilities) need to be utilised at all levels of administration, planning and monitoring. Since all data used are in digital form, they have all the flexibility of easy manipulation, augmenting, updating and re-application practicalities much needed by present problem handlers and solvers.

Watershed and/or province-level GIS's need to be the basic administrative, planning, monitoring and assessment tools throughout Turkey. Recognition of the need for the use of such tools has been especially acute since the 1999 Marmara earthquake (Özel *et al.* 1999b; Yıldırım *et al.* 2001). During the build-up of the YPG, we have seen that many of the essential layers necessary for agricultural, environmental and administrative applications have already been created, in various forms and scales, by various public offices and institutions of Turkey. Among the most notable of are:

1. Soil data for all provinces at a 1:100,000 scale by TOPRAK-SU (presently owned by the Village Affairs General Directorate-Ankara), created between the 1970's and the 1990's;

2. Meteorological data for all provinces at various scales by the State Meteorological Office in Ankara, based on extensive data collected since 1923;

3. Geological data for all provinces at 1:25,000 and/or 1:100,000 scales by the General Directorate of Mineral Research and Exploration (Maden Tetkik Arama Enstitüsü, MTA) in Ankara, based on many surveys done since 1935;

4. (Digital) elevation data for all provinces at 1:25,000 and other scales by the General Command of Mapping in Ankara, in digital and analog forms, at NATO standarts, available for special purpose public use requests; and

5. Satellite data with full coverage for Turkey: one coverage by LANDSAT-TM images for the years 1984-1986, and two coverages by LANDSAT-MSS images for the years 1972-1975 and 1984-1987, are at the disposal of the TÜBİTAK-MRC Space Technologies Group's Satellite Images Archive of Turkey (SIAT).

These basic information layers, available for most of the country, constitute an important asset for creating a digital information system for Turkey, which aims to be an information-based society that is integrated with digital global community.

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