EXPERIENCE WITH ENVIRONMENT MONITORING OF CRACOW REGION (POLAND) BASED ON GIS

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ABSTRACT

The multipurpose environmental monitoring was built for Cracow region. The aim of the project was to establish a local system that supports monitoring of short and long term changes in terrestrial ecosystems and simultaneously support sustainable development of the region.
For environment monitoring the three following software packages were used: IDRISI, GRASS and ERDAS Imagine 8.1.
The geographic, terrain relief, thematic data and pollution influence information was collected and registered creating the database of sources. Those bases were converted and transferred to the fundamental geographic database.
Using databases, software, and hardware assessment of soils erosion susceptibility was investigated and a proper map was created as well as land-use, digital hypsometric and other maps showing various pollution of water, air and soils.

1. INTRODUCTION

With reference to twelfth session of the International Co-ordinating Council for the Programme on Man and the Biosphere (MAB) held at UNESCO Headquarters in Paris 1993, as well as UNESCO'S United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro 1992 - one of the priority themes is esta-blishing Global Terrestrial Observing System (GTOS), designed to detect the responses of terrestrial eco-systems to global change. The Programme suggests setting up laboratory regions for land use planning and appropriate forms of sustainable development. Having financial support (Grant) of the Committee for Scientific Research of the Polish Government - the multipurpose monitoring system was built up for Cracow region.
Much of the material presented in this paper has been developed during three years of project realisation by my 17-persons team. To the five main project performers belong: Władysław Mierzwa, Stanisław Mularz, Krystian Pyka, Andrzej Wróbel and myself.

2. STUDY AREA OF CRACOW LABORATORY REGION

The study area is located in the southern part of Poland and around the city of Cracow approximately in the centre of the square-shape site of 40 x 40 km. The range of the terrain height of the area is 188m to 480m in rela-tion to the sea level and is morphologically diversified. In the centre of the area, from West to East the only relatively flat part presents the valley of *Vistula* River.
The valley divides this area into two sub-areas, both morphologically diversified. This is a result of geologic structure, which is responsible for the majority of relief features. The north sub-area has an upland nature with tablelands forms and dip rectilinear valleys. The south sub - area have a upland relief dendritic type.
Morphologically the study area is a jointer zone of the three provinces: Carpathian Mountains, Sub-Carpathians Dell and Silesian Upland.
Laboratory region contains also a dozen of smaller river valleys. Several industrial plants are located in this region. Some of them like steel-works and heat-generating plant are responsible for the main part of the industrial pollution of all environmental components, mainly air, water, soil and vegetation cover.
The Cracow region is densely populated. From the ecological point of view, the study area belongs to the most polluted regions of Poland. The range and character of degradation and negative transformations classify the ecological state of the area as catastrophic.

3. RESEARCH WORK OF THE PROJECT

The need for an integrated system for detecting and monitoring terrestrial responses to global change has been recognised a long time ago. The aim of the project was to establish a local system that supports monitoring of short, and long term changes in terrestrial ecosystems. Such system provides ecological knowledge for sustainable development of biosphere. The knowledge which possess data about the natural resources, about farming and industry local soils and waters etc. However, it always has to be up-to-date information. This kind of monitoring support sustainable development in ecological regions.
The following main tasks were carried out in the project (Sitek, 1993):
- methodology elaboration for information collection and its incorporation in GIS data base stored directly from the terrain or by remote sensing;
- usability estimation of different Geographic Information Systems and data manipulation techniques with relation to management, analysis and display data of different polluted environmental elements;
- digital terrain model generation for study area;
- acquisition (acquire, access and storage) of spatial data for the „laboratory region",
- creation and supplement (acquire, store, update and correction) of the GIS database containing variety elements of environmental pollution;
- presentation of environmental compilation for data visualisation and dissemination,
- selecting of an optimum data set for multispectral classification including texture features.

Another tasks was connected with computer hardware completion, and with purchase of Landsat and ERS-1 imagery.
The main goals of the project were:
- to develop a method introducing the up-to-date information about environment and its pollution into the GIS data base using the field measurements and remote sensing techniques for data acquisition,
- development of methods which bring accurate updates of the various spatial data entities and ancillary environmental pollution information in the selected Cracow area,
- creation of integrated databases that embody requirements with respect to services of monitoring Cracow's polluted environment,
- development of ways and forms of data presentation of environment condition born from the GIS analysis and manipulation.

4. SELECTION OF GRID-BASED GIS

Grid - cell (often called a *raster*) data structure GIS creates a matrix that is superimposed over the terrain. The attribute information is collected within a systematic array grid cells. For environmental monitoring purposes grid-cell GIS is expected to be a real - time decision support system. In polluted areas, the information stored in a GIS is dynamically changing from hour to hour (or day to day) - both in time as well as in space - since those phenomena are dynamic and are constantly changing.
For analysing and displaying dynamic phenomena, we used a multi-step computing process, requiring several particle processes and detailed compilations. Therefore, for monitoring of polluted environment, we had to apply dynamic GIS that is a grid - based microcomputer GIS and image processing system. A number of companies on the market offers various geographical information systems.The following software packages were compared: ERDAS Imagine 8.1, ER Mapper 4.0, PCI 5.1, GRASS 4.1, IDRISI 4.1 and ILWIS 1.21. The first three, one can include in commercial packages, and the last three, to the university packages which are rather not expensive. GRASS is available free of charge in INTERNET. All those packages may be useful for environmental pollution data analysis.
The differences between software packages concern rather the ways of work realisation and the degree of user friendliness, rather than the possibilities those work realisation. All systems accomplish (in 90 %) the same tasks. But during execution of some tasks like, for instance, interpolation for surface with limited data points - one can notice wide difference delivered from those packages. Besides, not any system is equipped with possibility of discontinuity line allowance. Therefore other software like SCOP and SURFER were applied in cases where analysis had to take discontinuity places into consideration.
For environment monitoring of Cracow region purposes, the three following software packages were used: IDRISI, GRASS and ERDAS Imagine 8.1.
For the recording of description and attribute data and for base management, system FoxPro 2.5 PL for Windows was applied.

5. TYPES AND SOURCES OF INFORMATION

Databases of sources or investigation and analyses of surface patterns and biophysical processes in polluted areas contain the following groups of information (Fig.1):
- geographic phenomena,
- terrain relief,
- thematic data concerning geology, pedology, land-use, hydrography, demography - connected with state of population's health etc.,
- data delivering sources of pollution and pollution influence on environment.

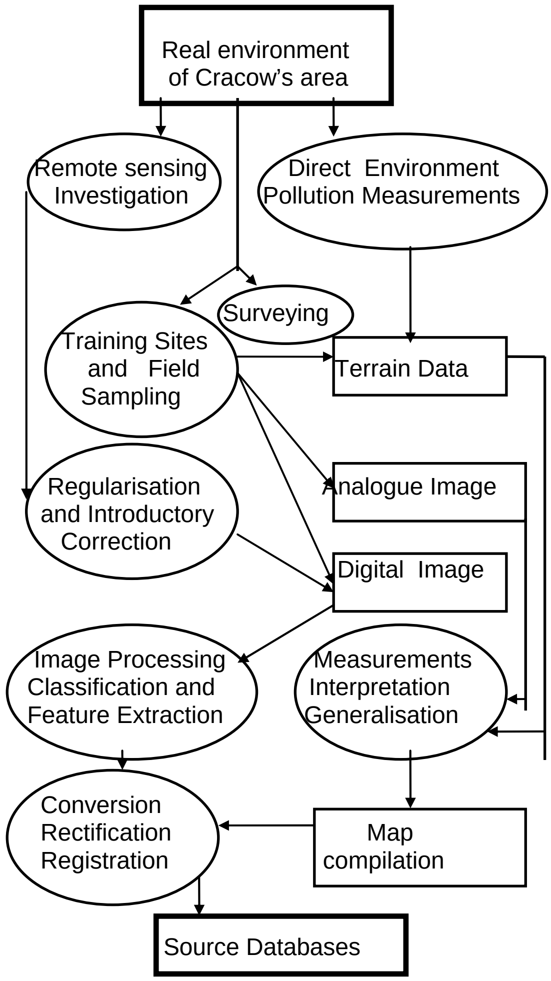

Fig.1. Conceptual diagram of data processing and creation source database. Products are in boxes and processes are enclosed in rounded boxes.

Geographic phenomena information is the basic framework for various GIS analysis. This information use of multiple data layers varying in their structure, level of accuracy and spatial consistency. The framework may be composed by communication system, building areas, land-use, administration borders and hydrography. For the needs of Cracow project those layers were extracted from existing topographic maps (1:25000 and 1:50000) which are most common data source of vector data for GIS. Features of interest were extracted using digitizer tablets. For modernisation of these data up-to-date Landsat TM imagery and 1:10000 maps was used.

Terrain relief is presented by digital terrain model (DTM). Digital *raster* structure is used for DTM Storage. Compilation of this structure was performed by software for creation of DTM using cartographic data. Topographic maps at 1 : 50 000 scale presented in so-called „65 map projection system" were used for the digitising procedure. In cases where too little density of contour line occurred (at build-up areas) the greater scale maps (1 : 25 000 and 1 : 5 000) were used. (Pyka, Sitek, 1993).

The whole tested area (1600 km^2) was divided into 100 parts each equal 4 x 4 km in agreement with the maps cartographic grid. The interior of each grid cell must be filled out in uniformly by height points with density not lesser then 80 for flat ground and 208 for mountainous country. Altogether 43 thousand of points were digitised with mean density 26 points/km^2 (minimum density 5 points/km^2 and maximum density 60 points/km^2).

The Summagraphic II and Drawing Board II Calcomp digitizers as well as DIGITIZE software supporting the IDRISI 3.0 data format was used for compilation of 100 files. This files was transferred into ASCII files setting up data base (dBase III) with array: Nr, X, Y,Z.

The interpolation of DTM Cracow region was executed by SURFER and SCOP software packages. Finally this data was transferred to IDRISI format.

At first the DTM was compiled with 50 m interpolated point interval grid in both directions, but as a final was generated model with grid - nodes equal 30 m. This kind of digital raster structure corresponds with pixel size of TM LANDSAT scanner and better render course of discontinuity lines.

Thematic data is directly or indirectly connected with terrain surface (Fig.2). To the first one belongs data from pedology, geology, hydrogeology, hydrography, land use and the like. The indirect thematic data is helpful to environmental pollution analysis and refer to meteorological, demographic, the state of population's health and the like information.

For the project needs the thematic information was extracted from various maps or the lists, tables and other registers which came from the reports, analysis etc. Paper maps were converted into digital form using the specialised program-TOSCA that supports the IDRISI (Version 4.0) data format.

Soil - agriculture map 1 : 100 000 consist of 19 soil types layers and 16 classes of land use. Hydrogeologic data has collect from 1:50 000 and 1:25 000 maps of underground water storage reservoirs. Seventeen layers were selected. Geologic information was extracted from 9 sheets detailed geologic maps 1:50 000 separating lithologic and stratigraphic data. All this information creates the spatial and attribute database.

The attribute database was completed additionally by meteorological and demographic information. The meteorological data was composed in 2 tables. One presenting the description of measuring stations and the other (for each station) containing following information: data of measurements direction of wind power, fog, precipitation, temperature, atmospheric pressure. Demographic data is placed in one table showing area of territorial division, population general, in age productive, after productive and before productive.

Environmental pollution elements were incorporated also into attribute database (Fig.2) but database format is more complicated than for thematic database. The emission of contamination is located into two kinds of description tables. One table contains the following data: identifier of the work place, name of the factory, address and coordinates of emission point. The other table, separate for each year shows emission data in the following fields: identifier of work place, dust emission, sulfur dioxide emission, nitrogen dioxide emission, carbon monoxide emission, hydrocarbons emission, other pollution emission total gases emission, production of solid wastes, waste management, yearly waste storage, the sum of waste accumulation.

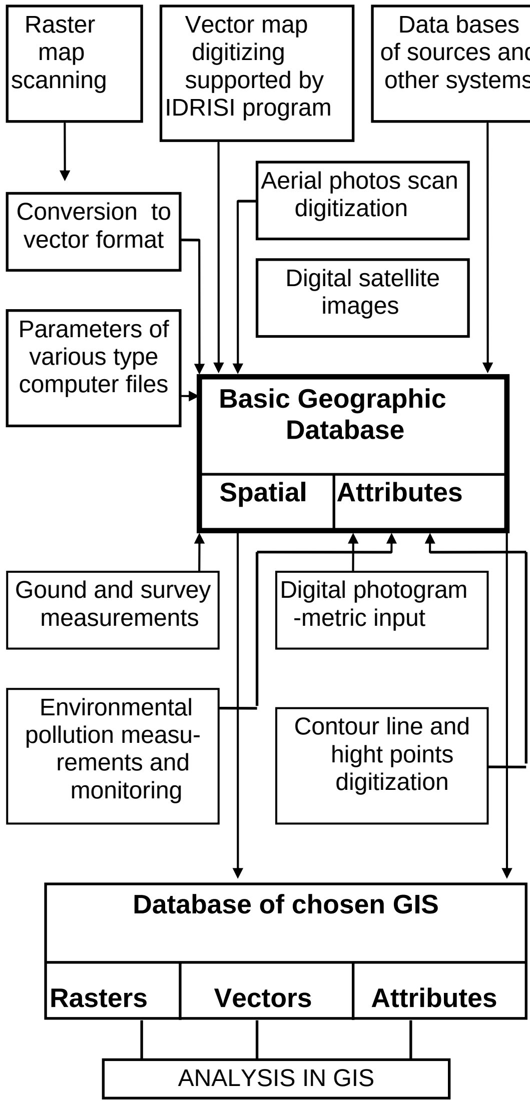

Fig.2. Diagram of creation and supply the basic database

At the object, points and streets segments the noise level was measured creating in database noise monitoring layer. And the table contains object identifier and address and field with noise level measured in consecutive years.

Air pollution measurements are very often executed (one or several times per day) therefore for each station separate table containing one year measurement is assigned with fields showing concentrations of pollution's and dates of measurements. Moreover, description table was created with following data: number of station, name of measurements results file, parish, district/village, address, station owner, station type, date of foundation

and closing down X,Y co-ordinates, co-ordinate system, logical fields for queries.
The similar table was created for soil pollution and water pollution as well as waste storages.

6. DATABASE CREATION AND SUPPLY

Database for environmental pollution monitoring based on GIS analysis is created throughout **Basic Geogra-phic Database** (Fig.2). Various databases of sources supply the basic database. This base begins with geo-referenced measurements of the environment - direct in the terrain or by remote sensing. These measurements use varied pathways into a digital spatial database. As it is visible (Fig.1 and Fig.2) ground and survey measure-ments may be introduced directly into the database. They may be interpolated to compile a map and entered to da-tabase through *raster* scanning or vector digitising. Aerial photographs and analog satellite imagery after human in-terpretation is converted to GIS.Digital imagery after ima-ge processing and analysis is send to basic database.

All these information originated from ground, maps and *analog* image data requires digitising, geo-referencing and registration in basic geographic database. Therefore they entail additional conversions or transformations.

The environmental pollution measurements were incor-porated into attribute basic database. For recording of these measurements and other descriptive data, FoxPro System was used (Zabrzeska, Wróbel, 1994).
The system enables completion and modernisation in a simple way the information which is stored in the database. All this data was divided for thematic groups: pollution emission, noise pollution, measurements of air, soil and water pollution as well as waste storage yards. 34 industrial plants were stored in database which emits to the atmosphere: dust, SO_2, NO_2, CO, hydrocarbons and other gaseous pollutants.
Information taken from State Health Supervision Office in Cracow concerning results of SO_2 and dust concentration measurements executed at 28 chosen station every day was stored in a database. Additionally this data measured at 53 station presenting monthly, yearly and seasons values (summer and winter) were stored.
Soil pollution data was collected from 66 stations located at agriculture, forest, garden and orchard areas. At each station once every 4 years measurements of soil pollution by chromium, cadmium, nickel, lead and fluorine were analysed. Additionally in gardens by copper, zinc, iron and sulphur.
Pollution measurements of surface waters were executed at 64 stations located along Cracow area rivers every month. Only the concentration values of 30 characteristic parameters specified at each stations were stored in databases.

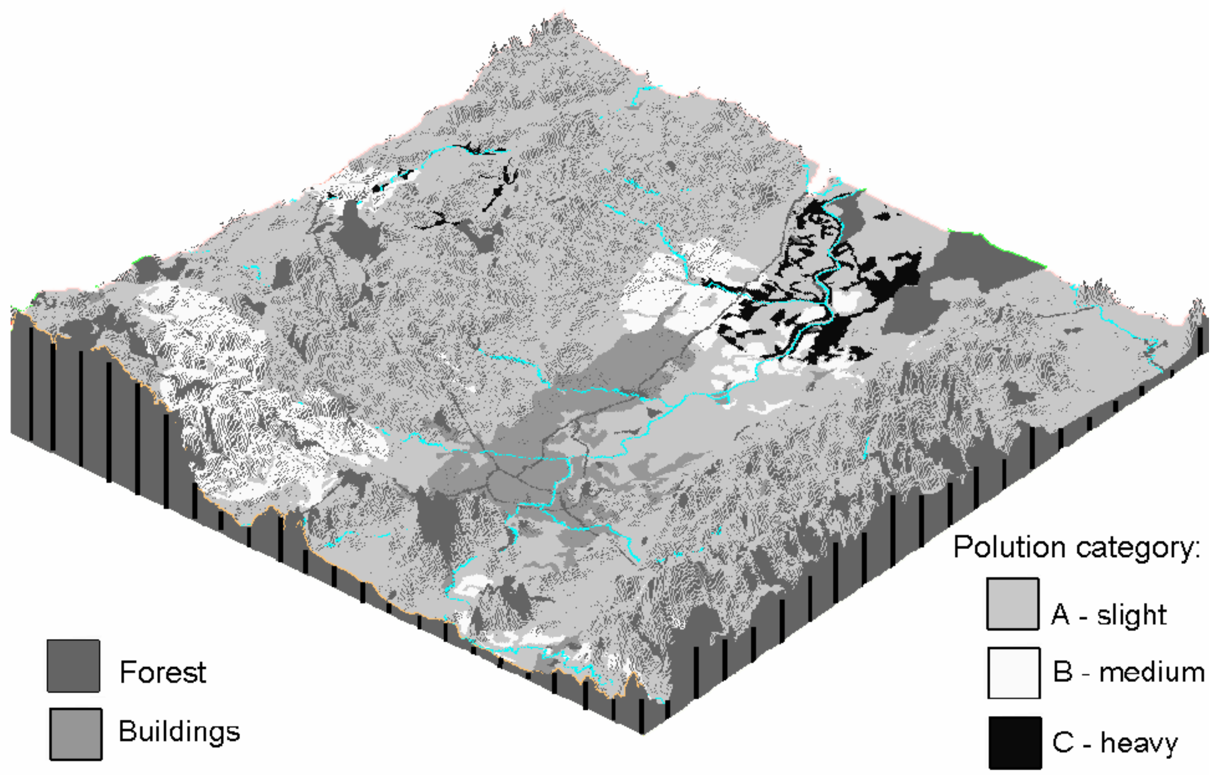

Fig.3. Heavy metals soils hazard over the DTM test area

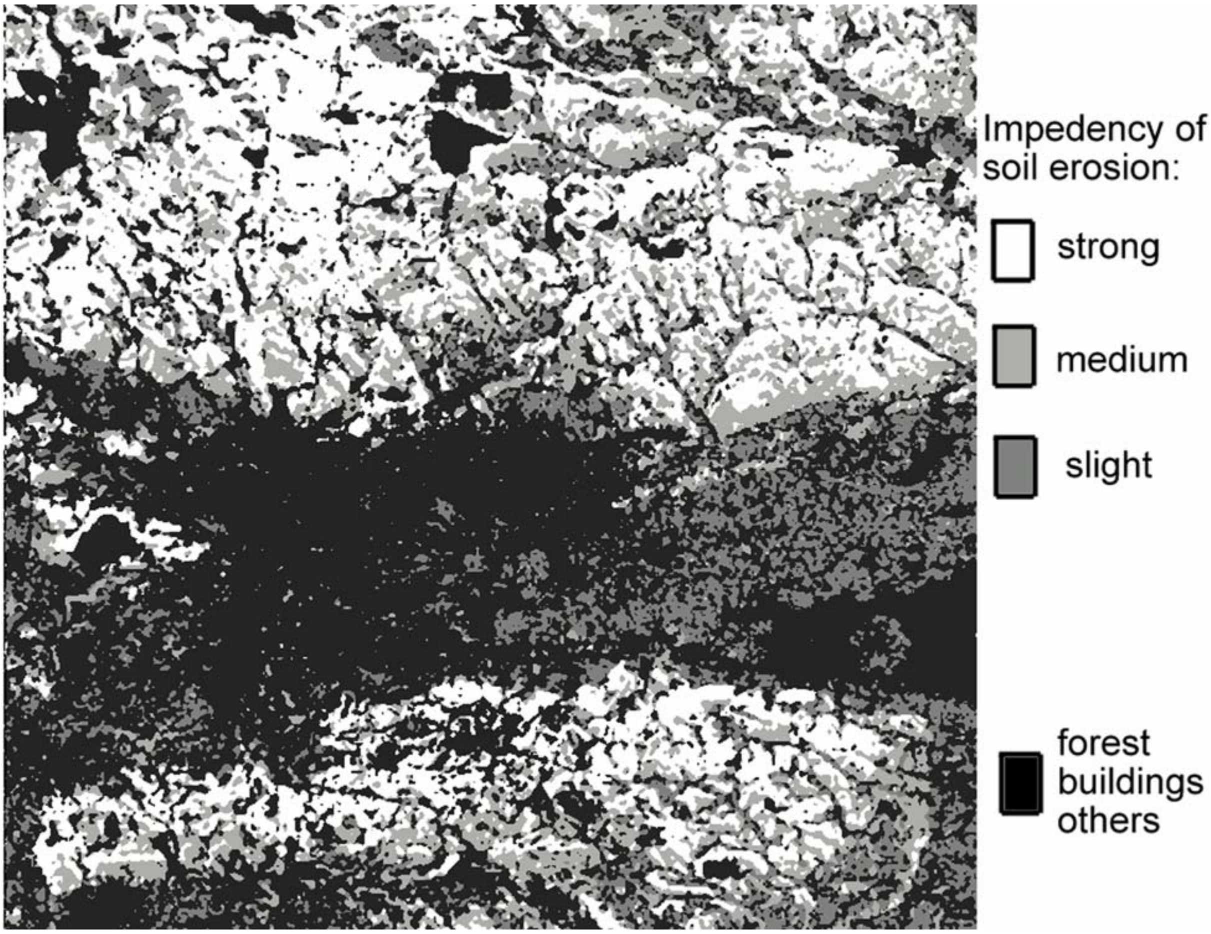

Fig.4. Soil erosion potential map

Data and location about waste material of 10 industrial and 12 municipal yards are also incorporated to basic geographic database.

Very often separate set of information (for instance: *landuse*, geological, pollution etc.) is stored partly in spatial database and partly as a table in attribute database (Fig.2). In spatial database points, lines and surfaces with their identifiers are located but other information is put together in tables (relation) - in attribute database.

7. EXAMPLES OF DATA PRE-PROCESSING, SELECTION AND GENERATION NEW INFORMATION USING GIS.

An application software was compiled to expand the IDRISI system. Large spatial and attribute data sets, IDRISI, GRASS, ERDASS and other software packages were applied for various investigations and analysis concerning environmental monitoring. One of this investigation done by two members of our team: S.Mularz and W.Mierzwa concern soil degradation assessment polluted by the industrial dustfall. Using the above mentioned GIS software, data sets containing main pollutants, the genetic soils type, land use categories terrain topography, rainfall and atmospheric conditions an attempt was made to correlate the dustfall data with the soil type and data agriculture use (Mularz, Mierzwa, 1993).

Most dangerous pollutants accumulating in soils are heavy metals because through the crop cultivation they impend to the human and animals health. The correlation between dustfall and soil contamination of Cd and Pb was calculated using IDRISI modules INPERPOL and REGRESS. Then the three soil pollution by Cd and Pb zones were distinguished A - low, B - medium and C - high. Using modules DISTANCE and OVERLAY the buffer zones and soil contamination category were delineated. The result map is presented in on Fig.3.

Another example presented by S.Mularz (Mularz, 1993) is a simple illustration of GIS possibility for monitoring purposes. Digital Elevation Model (DEM), soils data obtained from Cracow District „The Soil Argriculture Map" - with 6 soil categories for (1 : 100 000 scale), land - use and land - cover, derived from the soil - agriculture map and from LANDSAT TM image supervised classification procedure, as well as rainfall data were used for investigation and assessment of soils erosion susceptibility. This data generated from various data sources (cartographic, satellite or airborne images and terrain survey), create multiple layers of raster data planes form database. The GIS database gives information on location spatial arrangement and spatial relationship of the attributes and parameters describing the soil features and some natural conditions. For calculation and GIS analysis including map digitizing procedure, image processing and manipulation of database the IDRISI Version 4.1 package was used. The following hardware configuration has been used (Mularz, 1994) :

- Personal computer based on the Intel 80486 at 50 MHz with math co-processor, 520 Mb hard drive, 4 Mb RAM and SVGA graphics adapter capable of emulating 8514/A card,
- MAG colour monitor,
- a Microsoft mouse - compatible and 80486 CPU,
- HP Laserjet and HP Paintjet graphics printers for hard-copy output,
- CALCOMP digitizer with SSCII output.

(USLE) the Universal Soil Loss Equation (Wischmeier and Smith, 1978) was used for quantitative soil erosion assessment of Cracow region (Mularz, 1993). The model combine natural factors (slope steep, slope length, rainfall and genetic susceptibility of each soil type to the erosion and factors referring to human activity - land use/land cover and conservation practice. These major factors which determine or contribute to soil erosion process were used in USLE model allowing computation showing for each pixel the influence of all factors for erosional effect. The six land categories were determined and statistical evaluation of these categories were calculated.

After reclassification the result map was compiled with six categories: weak, slight, moderate strong very strong and severe soil erosion susceptibility. Finally, as it can be seen on the soil erosion map (Fig.4 taken from Mularz, 1994), only three categories were determined: slight medium, strong and fourth category showing non - agriculture areas (urban, forest, water and waste-land). The map shows that strong and medium categories are the most frequent at the Cracow area.

Several cross tabulation analyses were performed to evaluate the results. This shows that for instance strong erosion class exists for slope interval between 3^0 and 25^0. That loess soil is heavily exposed to the erosion process, that the wheat complex is affected by medium and strong erosion but range-land and grass-land belong to slight erosion category.

8. CONCLUDING REMARKS

The densely populated Cracow region belongs to the most polluted regions in Poland. Establishment the local system supporting monitoring changes in terrestrial ecosystems was an absolute necessity. Various types and sources of information and impediments to the integration of the multiple spatial, temporal, terrestrial and remote sensing data was a reason that as a tool for the environmental monitoring - the integrated Geographic Information System was chosen. These technologies allow the coupling remotely sensed measurements with other spatial and environmental pollution data describing not only Earth surfaces but also biophysical representation. These and GIS data have been profitably merged for joint analysis of the phenomena under investigation.

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