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THE ROLE OF GIS IN ENVIRONMENTAL MONITORING

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Abstract: *The paper tries to analyze the role of GIS in environmental monitoring. When it comes to GIS environmental modelling applications, in many respects GIS software can be considered comparable to a programming language. Unfortunately, however, the typical environmental GIS users are focused on environmental issues and only rarely do they have the additional technical knowledge necessary to develop new GIS applications. As a consequence, most domain experts are forced to work with GIS that have predefined underlying data structures and 'standard' interfaces. We will try to understand the issues to be considered by the designers and programmers of such turn-key applications within the areas of environmental issue related monitoring. Some characteristic examples of applications will be given together with a closer look at the demands that the individual applications make. First it is useful to distinguish between the various types of environmental monitoring methods. In monitoring methods emphasis is placed on data collection, pre-processing, and quality control. Analysis techniques focus on using tools to manipulate and model data. Information systems, on the other hand, are more concerned with the storage and management of data.*

1. Introduction:

GIS, not surprisingly, has a very important role to play in environmental monitoring. GIS is ideally suited as a tool for the presentation of data derived from distributed measurement stations. Unfortunately, however, most GIS have some severe shortcomings when it comes to dealing with the typical data obtained from such measurements, namely time series data. The techniques for dealing with time series data are covered more thoroughly elsewhere. In a nutshell, time series are long consecutive runs of data, such as the temperature measured every half hour at a certain point. Since most standard GIS software packages do not possess adequate tools for handling temporal data, they must be extended or auxiliary applications interfaced. The time series data routinely collected for environmental monitoring very often have two significant analytical and display problems. First, they typically relate to points, when data based on areal units would often be more useful. Second, the temporal sampling incidence is often too frequent, resulting in large volumes of data. GIS offer relatively simple means of dealing with each of these problems. First, with regard to spatial resolution, a measurement point may be permanently assigned to a representative area using a simple point-to-area transform. A different option is to use standard GIS gridding and contouring facilities to interpolate between the point measurements across the whole study area. Second, with regard to temporal resolution, standard database selection capabilities may be used to extract data pertaining to a time value corresponding to other data to which it must be compared. Alternatively, standard descriptive statistical functions may be used to reduce data volumes. Any of these approaches may be used alone, or in combination. The illustrated system is a rather complex example implemented as a multi-user, client-server configuration. Apart from showing the basic system architecture, the figure also demonstrates how many functions may be involved in a GIS-based monitoring system. In particular, it should be noted how much of the system is actually dedicated to collecting, processing, and storing data rather than explicit spatial analysis and display operations.

Essentially GIS is only used at user workstations, whereas the major part of the system is dedicated to other tasks. This distribution is in most cases reflected in the corresponding implementation and running costs. As a rule of thumb at least 90 per cent of the cost involved in setting up an environmental monitoring system is related to the measurement program, the quality control, and processing of data; only a minor part is related to the programming of GIS-based analysis and display functions. Often the simple data analysis functions provided by standard GIS software packages are insufficient for dealing with the data monitoring requirements of environmental problems. The reasons for this are many, the most common being:

» The economic aspects of a project do not allow sufficient data to be collected to 'feed' the analysis tools;

» The characteristics of the data make simple extrapolation inappropriate;

» Several parameters are interconnected and the required data cannot be measured directly.

In such cases more complex techniques are needed to reflect the expected environmental situation. In such circumstances, the task of environmental monitoring goes much further than can realistically be achieved within a standard GIS.

2. Objectives of the Study:

1. To understand the environmental monitoring.

2. To understand the various field of environment which required the monitoring?
3. To understand the role of GIS in the environmental monitoring.

3. Research Methodologies:

The present study is based entirely on the secondary sources of data. The main secondary Source is the published government reports and various journals and other published works. The information and data for present paper is mainly secondary in nature. The reports and publications of different departments and agencies have been put in use. The systematic approach has been adopted for analysis. **.** An attempt has been made to highlight the data by using appropriate tables and maps. Data have been analyzed with the help of general statistical techniques

4. Environmental monitoring and modelling:

Environmental monitoring operations are typically very expensive to set up and maintain. Budget constraints often mean that monitoring programmes have to be scaled down and that many systems are barely adequate to meet their objectives. Chemical parameters, for example, are frequently of interest to those who study the environment, but unfortunately appropriate measurement instruments for such parameters are often very expensive to purchase and maintain. One possible solution to this problem is to combine a reduced field-based monitoring programme with mathematical modelling. Most often the elements of interest (chemicals, oxygen, sediment, smog, etc.) will behave in their carrying medium (water or air) in a very specific way that may be simulated. By setting up a mathematical model describing the dynamics of the carrying component (the water or the air flow) and by monitoring the parameters of interest close to the sources very good estimates of concentrations covering the complete area of interest can be obtained. As an example, a project measuring, for instance, nitrogen concentration using hundreds of sensors covering an entire area, may be transformed into the following combined monitoring/modelling programme:

» Monitor the driving forces for the dynamics, like atmospheric pressure, wind velocity and direction. Such parameters can usually also be monitored with rather inexpensive yet reliable equipment.

» Establish a mathematical description of the flow in the area, as a mathematical model.

» Monitor the parameter of interest at a few strategic locations, usually close to possible direct sources and near model boundaries.

» Using the proper advection/dispersion or similar Schemes in the calculation, the complete pattern of concentration may be calculated.

While such an approach of course introduces a number of uncertainties, it will in many cases present a cost effective alternative to pure monitoring by means of sensors; indeed in some cases it may be the only viable alternative.

5. Various field of environment which required the monitoring.

1. Ice/Glacier Monitoring:
2. Vegetation Change Monitoring:
3. Carbon Trace/Accounting Monitoring:
4. Atmospheric Dynamics Monitoring:
5. Erosion Monitoring and Control:
6. Flood Monitoring:
7. Monitoring in Agriculture:
8. Drought and Desertification monitoring:

6. Role of GIS in the monitoring of environmental related issues:

6.1. Ice/Glacier Monitoring:

The world-wide retreat of many glaciers during the past few decades is frequently mentioned as a clear and unambiguous sign of global warming. Rapid recession of the ice cap, permafrost, and glaciers have been noticed in Mt Kilimanjaro, New Guinea and South America, Canada, the United States, China, Siberia, European Alps, among others, with accelerated environmental consequences. Such include problems with roads, pipelines and buildings, threat to the stability of some mountain peaks and cable car stations, catastrophic release of water, among others. Glaciers, ice caps, and ice sheets are important components of Earth's natural systems, very sensitive to climate change and difficult for scientists to measure in terms of mass balance. However, satellite images of the ice sheets can track their growth and recession over the years. Raup et al. (2007) reported the success of using RS and GIS in glacier monitoring and provision of global glacier inventory by Global Land Ice Measurements from Space (GLIMS). The study stated that GLIMS' glaciers monitoring involves the creation of a global glacier database of images such as ASTER, Landsat, Synthetic Aperture Radar (SAR), air photos, maps and derived data, and the analyses producing information are performed using a variety of methods including both automatic algorithms and manual interpretation in a distributed environment. Field and satellite investigations were reported to have indicated many small glaciers and glaciers in temperate regions down-wasting and retreating. They concluded that RS/GIS and field investigations are vital for producing baseline information on glacier changes, and improving our understanding of the complex linkages between atmospheric, lithospheric, and glaciological processes.

6.2. Vegetation Change Monitoring:

Vegetation provides a range of ecosystem services such as food and shelter for wildlife, and it controls the Earth's climate by regulating evapotranspiration and sequestration of carbon. Vegetation however is increasingly endangered mainly due to anthropogenic and climatic influences.World forests increasingly appear finite, vulnerable, dangerously diminished, perhaps already subject to irreparable damage. A most significant intellectual challenge to ecologists and biogeographers is to understand vegetation spatio-temporal patterns. RS is one of the widely used approaches for providing scientific evidence of vegetation change. For example, Chen and Rao (2008) monitored vegetation using multi-temporal Landsat TM/ETM data in an ecotone between grassland and cropland in northeast China between 1988 and 2001. Classification and change detection carried out showed accelerated land degradation of the grassland around the salt-affected soil near the water bodies due to variation in water sizes as a result of both climate change and anthropogenic activities.

6.3. Carbon Trace/Accounting Monitoring:

As an eligible action to prevent climate change and global warming in post-2012 when Kyoto protocol expired Reduced Emission from Deforestation and Degradation was adopted in 2010 as a component under United Nations Framework Convention on Climate Change (UNFCCC) requiring among other things, carbon accounting which involves taking forest carbon stock. Studies have demonstrated the efficacy of RS and GIS in carbon accounting. Using a combination of field measurements, airborne Light Detection and Ranging and satellite data, Asner (2012) assessed high-resolution estimates of above ground carbon stocks in Madagascar. High carbon estimates were noticed in the remote areas while low estimates were recorded in areas of high human activities. The study concluded that high resolution mapping of carbon stocks is a veritable way of carbon monitoring as a climate change mitigation strategy. Carbon stock within the two classes were calculated and linked to a multi-temporal set of SPOT satellite data acquired in 1991, 2004 and 2009 together with forest prediction for 2020 for the study area. These results are important spatial information regarding the priorities in planning and implementation of future activities in the area.

6.4. Atmospheric Dynamics Monitoring:

Early civilian satellite instruments were launched largely to meet the needs of weather forecasting, among other applications. Meteorological satellites are designed to measure emitted and reflected radiation from which atmospheric temperature, winds, moisture, and cloud cover can be derived. Hecker and Gieske (2004) listed a range of application of satellite data in the monitoring of atmospheric dynamics. According to them, RS can be used for the determination of the atmospheric radiances, emissivity and surface temperature. Burrows (1998) measured the absorption cross-sections of NO2 using the global ozone monitoring experiment (GOME) flight model (FM) Satellite spectrometer. The spectra have a resolution of about 0.2 nm below 400 nm and of about 0.3 nm above 400 nm. The new absorption cross-sections are important as accurate reference data for atmospheric remote-sensing of NO2 and other minor trace gases.

6.5. Terrestrial Temperature Monitoring:

Evapotranspiration (ET) is an important part of the planet's hydrological cycle, and it is likely to change in a warming world as it is highly increased by high temperatures. Accurate ET estimation enables improvements in weather and climate forecasts, flood and drought forecasts, predictions of agricultural productivity, and assessment of climate change impacts. Hecker and Gieske (2004) posited that satellite data can be used for the determination of surface emissivity and temperature, rock emissivity mapping and thermal hotspot detection such as forest fires or underground coal fires, or to volcanic activity. Bradley (2002) modelled spatial and temporal road thermal climatology in rural and urban areas of west midlands UK using satellite land cover classification, field analysis of urban canyon characteristics, physical variables of albedo, emissivity and surface roughness within a GIS environment. It was suggested that the busier a stretch of road the likelier it is to have a higher road surface temperature and smaller diurnal range. Road surface temperature forecast especially in the winter months is essential for highway road ice formation monitoring.

6.6. Erosion Monitoring and Control:

Soils are the second largest terrestrial carbon (C) reservoir, containing about 3.3 times the amount of C in the atmospheric pool and 4.5 times that in the biotic pool. This reservoir becomes a carbon source as the rate of organic matter decomposition increases through erosion. Water erosion is the most significant type of soil degradation in all continents, except in western Asia and Africa where water and wind erosion are almost of equal significance. These are initiated by human overexploitation of natural resources. However, intensive use of natural resources calls for increasing detailed inventories. Santillan (2010) integrated RS, GIS and hydrologic models to predict land cover change impacts on surface runoff and sediment yield in a watershed of Philippines. The method quantifiably predicted the potential hydrologic implications useful for planners and decision makers as a tool for evaluating proposed land cover rehabilitation strategies in minimizing runoff and sediment yield during rainfall events in the ecosystem.

6.7. Flood Monitoring:

Climate change is expected to increase the risk of flooding for people around the world, both by raising global sea levels and increasing severe inland flooding events, hence there is continuous desire to predict flooding. Sanyal and Lu (2004) submitted that the conventional means of recording hydrological parameters of a flood often fail to record an extreme event, thus RS and GIS become the key tool for delineation of flood zones and preparation of flood hazard maps for the vulnerable areas. Successfully demonstrated the potential of using GIS for flood disaster Management for Allahabad Sadar Sub-District (India). The flood-prone areas were identified and various thematic maps include road network map, drinking water sources map, land use map, population density map, ward boundaries and location of slums were generated and stored for management and decision making. After processing and interpretation, flood map derived accounted for 96.7% of the flooded area, making the procedure suitable for mapping flooded areas even when satellite data are acquired some days after the event, thus overcoming the constraint of temporal resolution in the application of SAR imagery in hydrology.

6.8. Monitoring in Agriculture:

Soil quality, water availability or drought stress and climate change are three biophysical factors which need to be addressed for food security in the face of climate change. RS and GIS have been found useful for soil characteristics mapping, agro-climatic assessment, and land use suitability for crop production, irrigation management, precision farming, crop type mapping, and crop condition assessment, among others. Satellite data provide a real-time assessment of crop condition. Ines et al. (2006) combined Landsat7 ETM+ images and derived distributed data such as sowing dates, irrigation practices, soil properties, depth to groundwater and water quality as inputs in exploring water management options in Kaithal, Haryana, India during 2000–2001 dry season. Results showed that under limited water condition, regional wheat yield could improve further if water and crop management practices are considered simultaneously and not independently.

6.9. Drought and Desertification:

Drought as a situation when annual rainfall is less than normal, monthly/seasonal rainfall is less than normal and when river flow and ground water availability is decreased. Desertification is decline in the biological or economic productivity of the soil in arid and semiarid areas resulting from land degradation due to human activities and variations in climate. Satellites provide continuous and synoptic observations over large areas having the advantage of providing much higher resolution imageries, which could be used for detailed drought and desertification monitoring, damage assessment and long-term relief management. Advancements in the RS technology and the GIS help in real time monitoring, early warning and quick damage assessment of both drought and flood disasters. Data from NOAA Advanced Very High Resolution Radiometer (AVHRR), Landsat, SPOT and RadarSat are used operationally in the assessment of drought, frost impact on crop production and flooding.

Concluding remarks:

The current state of GIS in environmental monitoring remains very much focused on the fact that GIS is an ideal tool for producing ‘pretty pictures’ which can also, to a certain extent, be used as a programming tool for user interfaces. GIS is used to a much smaller degree as an active component of environmental monitoring systems. As the field matures it is to be expected that environmental monitoring and GIS will become much more closely integrated. At the same time, GIS are becoming more and more user-friendly. Basic terms tied to climate change have been explained in this study. Also highlighted are some areas where RS and GIS are applicable in climate change analysis and adaptation but the study has by no means covered all the possible areas of application of the tools in the subject matter. Issues considered in this review are snow/glacier monitoring, land cover monitoring, carbon trace/accounting, atmospheric dynamics, terrestrial temperature monitoring, biodiversity conservation, ocean and coast monitoring, erosion monitoring and control, agriculture, flood monitoring, health and disease, drought and desertification. Once data are collected and stored in well-organised databases, the possibilities for well-designed GIS applications are tremendous, not only within one database but also using combinations of different networked databases. The rapid development of network technology will no doubt also stimulate the development of distributed databases. New GIS products are now Internet aware and, together with advances in spatial database technology, possibilities exist for creating dynamic systems able to perform operations on distributed databases. Applications based on technologies such as 'data drilling' are now possible over the Internet. These types of application will be less and less sensitive to the original purpose of the database being queried. The trend towards network technology is also interesting because it offers the possibility for data aggregation. Almost all active environmental monitoring systems are local or regional systems aimed at monitoring specific components of the environment and helping to solve specific environmental problems. One consequence of the rise in environmental awareness is the need for exact information, as this is the only way for scientists and authorities to evaluate the most appropriate measures and regulations. In such situations it will be invaluable to be able to extract information from the increasing number of local monitoring systems and to aggregate that information into more globally-oriented monitoring systems. To achieve such a level of integration and corporation, a high degree of standardisation is required to be in place. Since almost all monitoring systems are established by government authorities a standardisation effort should have a good chance of success at least at a national level. By forming standards for how systems communicate on the network and how measurements are specified, with respect to quality, measurement method etc., it will be possible to utilise monitoring results made locally for other more general purposes in a larger scale monitoring effort. All in all, GIS will be a component of every environmental monitoring system within the next few years. This is quite simply because this type of data calls for the utilisation of GIS capabilities, and when one considers that GIS is becoming simpler to use and much cheaper to buy, it is hard to imagine a future for environmental monitoring systems without it.

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