APPLICATION OF GIS REMOTE SENSING

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Introduction

Several researches have pointed to the usefulness of GIS and remote sensing at both local and State levels. This paper seeks to address issues of availability and needs for remotely sensed data products among local users, especially the development of tailored applications using remotely sensed imagery. The development of prototype data products using Landsat ETM+ imagery, such as a tailored land use classification and a greenness map is essential.

The increasing availability and accessibility of new technology and data for local governments and agencies is proving helpful in day-to-day decision-making processes. In particular remotely sensed data and Geographic Information Systems have increasingly been used together for a vast range of applications, spanning from land use/land cover mapping to emergency management to characterization and monitoring of environmental and human health conditions.

The higher spatial and spectral resolutions, more frequent coverage and increased availability of new sensors will bring remote sensing to a more accessible level within local and state governments and help them deal with several issues in regional planning, resource management, public health and environmental protection.

This paper examines the prototype data products and discuss the possible uses for local application in terms of Land Cover/Land Use and Vegetation change detection. Also discussed are other potential applications, such as emergency management, flood mapping, air and water quality monitoring and related issues of scale and timing; and other relevant data sets and their integration with remotely sensed data.

Data Output

Various researchers and institutions have been working with sets of images covering parts geographical areas, acquired at different time intervals for example, images collected by Landsat 7 or 8 using the Enhanced Thematic Mapper Plus (ETM+) sensor.

The spatial resolution (ground cell or pixel size) varies between 15 and 60 meters and allows detection and mapping of quantities such as vegetation abundance and health, presence of standing water, forest clearing, agricultural usage and other land cover changes.

Interest to note are several ways of making use of the high-resolution panchromatic band and the improved thermal band, and of developing new products. The advantage of having such user-specific products is that they will be developed according to local government needs, compatible with higher resolution data sets already collected and available at the local level, allowing a better understanding of dynamics and features that can be integrated in decision-making processes.

A classic example of such integration would be a land cover/land use change study: the resolution of the Landsat data does not allow for detailed discrimination between features in the way that aerial photography or field surveys do. However, the availability of multispectral data can help better identify certain features and their condition, such as vegetation health monitoring. The availability of repeat coverage over a certain area will then permit the production of land cover maps for different periods and thus aid change detection studies. Changes that might be of interest can range from short-term phenomena like flooding or snow cover to long-term phenomena like urban sprawl or deforestation. Vegetation health monitoring can also be performed using images from different seasons. This could be useful in urban vegetation studies or to relate air pollution and vegetation health.

Land cover/land use classification.

Using the Landsat ETM+ scene from different time intervals, a maximum-likelihood classification be performed to produce the classified image. The maximum-likelihood approach is one of the methods used in supervised classification. This type of classification is used to cluster pixels into classes corresponding to user-defined “training areas” or “region of interest” (groups of pixels that represent areas or materials that the user wants to have mapped in the final product). The first step in the supervised classification is to identify representative training areas and to develop a numerical description of the spectral attribute for each land cover type of interest. This is followed by the classification process in which each pixel is assigned to the land cover class it is most likely to belong to. The maximum likelihood method requires a large number of computations to classify each pixel, making it time and memory consuming, but it is considered one of the most accurate classification algorithms.

The classification of the Landsat scene is commonly performed using 6 or more classes of land use/land cover to show the possibility of using a very simple classification scheme that can be used for many different applications, which also embrace the urban/suburban context. Such applications might include mapping and monitoring of new developments (housing, roads, commercial development, among others), golf courses or changes in density of vegetation and urban areas.

The correspondence between the unclassified image and the classified one may relatively be good. Given the exploratory nature of this product, no ground truthing may be performed and, consequently, no statistical accuracy tests would be conducted based on control areas on the ground. This could be an attempt to establishing whether such ‘tailored’ products could be developed to show an example of simplified classifications.

Looking at the “Regions of Interest” statistical distribution, it is possible to get a sense of their separability, that is, how well the classes can be distinguished from each other. The classes that are best distinguished are Water and Grass, Water and Soil, Water and Low Intensity Residential, and Grass and Soil. The two most poorly separated are;

Infrastructure and Low Intensity Residential. It is important to remember that this simply gives an idea of which classes are easier to separate based only on their spectral responses in the different bands and does not ensure a good result during the classification process.

Advantages of User-Specific Classification

The advantage of a user-specific classification, compared with other available products, lies within the word “tailored”; such classification will be produced based on inputs from local governments, according to their needs and potential uses of the product. The classes can be identified and selected based on specific applications by integrating Landsat data, with high-resolution data, such as aerial photography, data already available in many counties. The major advantage would be the possibility of having a regular updating of the product through repeat coverage, leading to appropriate land cover and land use change products.

The need for developing tailored classification schemes and updating land use/land cover maps user-tailored classifications has been emphasized both by local governments (county level) and by regional and state groups. In the case of county governments, where detailed land use maps may already be available, focus is on the idea of integrating their high-resolution data with satellite-derived products in order to refine existing maps and to get more diverse information. Such information might be related to vegetation or the possibility of aggregating multiple classes (based on the classification results) into fewer classes according to specific uses and applications. Producing an accurate, useful classification scheme for local governments using Landsat data would undoubtedly require a large amount of work, but once the methodology and the final products are in place, it could represent a significant improvement for data acquisition and integration in decision-making processes.

As for the regional and state level, given the difference in scale, the development of a tailored classification scheme will require fewer ancillary data and could be more easily automated. In this case, there is need for having a comparable set of land use/land cover classes for assessing landscape change, in particular between forest, agriculture, and development. Although limitations in the spatial resolution of the classified image are recognized, the possibility of having regular updates of such products is particularly appealing. Even county governments already provided with detailed maps need to get their data and maps updated more regularly through aggregation of data from different sources (satellite, aerial photography and ground survey). An example of a way to improve the resolution and make use of the repeat coverage is to calibrate the classification derived from satellite imagery with information from aerial photography and ground data, and then use that calibrated image to perform the classification on other images, looking both back and forward in time. This procedure minimizes the costs of collecting ancillary data to validate the classification in the future and therefore reduces both the costs and the time for the classification process itself. The integration of land use classification maps with other socioeconomic and demographic data, also aid in spatial analysis.

Vegetation Fraction Index and Urban/Vegetation Change Detection

Due to increase in population, most major metropolitan areas and neighboring suburban settlements are facing problems of urban sprawl, loss of natural vegetation and open space, and drastic change in land cover and land use. For years, land mapping at the county level has relied on aerial photography and field surveys because of the high spatial resolution required and the high level of details that can be obtained. However, satellite imagery may become increasingly important in identifying and monitoring soil conditions and various related land characteristics, such as vegetation and crops. Monitoring is one of the key uses of remote sensing, due to the availability of repeat coverage and associated high spatial and spectral resolution. Remote sensing is extensively used in monitoring changes in natural and semi-natural areas and, to a lesser extent, the effects of pollution on trees, soil, and water.

In areas such as the capital cities, where the effects of urban sprawl are of particular concern, remote sensing can be used to monitor urban/vegetation changes and be integrated with higher resolution data available at the county level. Also, new products and methodologies, can be developed for a vast range of applications and could potentially be updated regularly (annually or seasonally) according to user needs. Therefore, exploring possible products that might help local governments display and monitor such changes and use that as basic tools in day-to-day decision-making processes, is a welcome development. One such product, potentially very useful in studying urban sprawl and urban and suburban dynamics, is the Vegetation Fraction Index.

Estimates of vegetation fractions can be obtained through a linear spectral mixing model. The model assumes that the reflectance of each pixel of the image is a linear combination of the reflectance of each ‘material’ present within the pixel. Based on their spectral characteristics, ‘materials’ components can be recognized to describe the spectral variance in the scene: low albedo (water, shadow, and roofing), high albedo (cloud and roofing), and vegetation. The model has proven to be very accurate: a quantitative validation of Landsat-derived vegetation estimates with vegetation measurements from aerial photography showed an agreement to within 10% for vegetation fractions greater than 20%, across the full range of vegetation abundance (Small, 2001). Such a product allows one to identify the green areas and quantify the proportions of vegetation versus urban land in an immediate and easily interpretable way.

An even simpler model is a Greenness map, obtained by performing a Tasseled Cap Transformation on the original Landsat data. The Tasseled Cap Transformation on Landsat TM data performs an orthogonal transformation of the original data into a new three-dimensional space, consisting of a “Brightness” index, a “Greenness” index, and a third component related to soil features. In the case of Landsat MSS data, the Tasseled Cap Transformation generates four indices; a Soil Brightness Index, a Green Vegetation Index, a Yellow Stuff Index, and a Non-such Index, related to atmospheric effects (ENVI, 2000).

In order to visualize the differences between vegetation and non-vegetated areas, such as urban and water, only the Greenness Index has been displayed using a logarithmic green and white scale, where the deeper green corresponds to more vegetation. Performing the transformation on data obtained in two different periods permits showing changes in the proportion of urban and forested areas. The spatial resolution for some of these images (Landsat MSS) may not detect many minor changes.

In addition to the greenness maps which only show vegetation and urban areas in a qualitative way, greenness histograms give an idea of the distribution of pixels according to the greenness values, although properly quantifying such changes requires a quantitative method, like the Vegetation Fraction model.

Evaluation

Greenness maps and the consequent vegetation/urban change detection studies are straightforward to understand and interpret. The resolution of the Landsat data limits their use to tracking vegetation changes at a broader scale (regional, rather than county level).

The potential importance of such tools and products in monitoring vegetation health should be noted, given the availability of repeat coverage and of data collected at different wavelengths. This type of information could be integrated with higher resolution data, such as from IKONOS (increased spatial resolution: 4 m in the multispectral, 1 m in the panchromatic band) or AVIRIS (images collected in 224 contiguous bands, with ground resolution of 20 meters (high altitude) or 4 meters (low altitude)) in order to be more useful for local and county level applications.

Other Applications

Landscape Assessment

One of the key applications that can greatly benefit from satellite data, including medium resolution sensors such as Landsat ETM+, is regional landscape assessment and landscape change. Such studies can be pursued using the tailored land cover map or the vegetation maps.

The basic concept is that vegetation features can be distinguished from other features because of their different spectral responses in the visible and infrared regions. In the near infrared bands, vegetation has a peak of reflectance that water and urban do not have because of reduced absorption by chlorophyll and other pigments. Also, as previously described, the scale at which landscape assessment is done is usually regional. This allows the use of Landsat data even for the 1970s and 1980s, when the TM sensor was not yet available. The coarser resolution of MSS data can still be useful for regional-scale applications.

The priority for landscape studies will then be to determine which land cover classes are most important to identify based on specific needs. These needs vary from watershed management to forest cover or agricultural mapping to linking forest extent and closeness to residential areas for disease mapping and monitoring.

Air Quality

Air quality applications basically deal with use of remote sensing to determine the effects of air pollution on vegetation and would be particularly useful in urban and suburban areas. The change in spectral signature of a damaged plant gives an indication of the nature and the level of air pollution damage. Such changes can be detected by looking at the corresponding change in foliage colors and differences in structure and texture of the canopy. For small areas or within cities, this will require high-resolution sensors such as IKONOS. Assessing the effects of air pollution and separating them from those of drought or diseases are not easy tasks. Diseases can equally affect trees and make them change color and give a different spectral signature, which can be misinterpreted as an effect caused by pollution. Remote sensing data in this case must be integrated with field observations and measures of air pollution. The increasing number of studies of trees affected by specific diseases will allow mapping of their spectral signature and comparison with trees suspected of being affected by air pollution.

Water quality

Pure water reflects some of the incident radiation in the visible bands of the electromagnetic spectrum and absorbs almost all of it in the near- and middle-infrared bands. Therefore, in the infrared, water appears dark and is easily distinguishable from other land features. The spectral response of water may vary with the presence of suspended sediments, which increase the amount of radiation reflected. Some of these sediments, such as suspended solids from soil erosion, can significantly impact the spectral reflectance and be identified easily in the visible bands. Phytoplankton cannot be easily distinguished from inorganic materials by common satellites (Landsat). Even other more specific sensors such as SeaWiFS and MODIS require complex and sophisticated calibrations.

Water quality modeling and watershed management, traditional remotely sensed data (e.g., slope, soil, and land cover characteristics) can be used as input to hydrological models. Such models can then be used to estimate non-point source water pollution (e.g., derived from urban runoff, construction, agriculture, irrigation, and soil erosion). Non-point source water pollution is very common but also difficult to detect given the limitation of traditional in situ measurements techniques in identifying and modeling such diffuse sources of pollution. The integration of in situ measurements with remotely sensed data in GIS modeling can provide useful information on water quality applicable to many planning and management issues.

Floodplain Mapping and Emergency Management

Monitoring sensitive areas such as wetlands, parks, or land in urbanized watershed for emergency management usually requires high spatial resolution data in a timely fashion. Relatively stable areas can be monitored every one or two years, whereas more critical areas need to be monitored more often (at least seasonally (Lillesand, 2000)). In the case of disasters such as floods, storms, tornadoes, earthquakes, or fires, it would be ideal to have images both pre- and post-disaster. Even though the pre-disaster data would need to be updated less frequently (every one to five years), it is important that they are at a comparable high resolution (1-5 m) with the post-disaster data (less than 2 m). In disaster management, satellites with medium ground resolution, such as Landsat or SPOT, are not very useful, even though the temporal resolution is relatively high (16 and 26 days, respectively). Normally, panchromatic and near-infrared aerial photography or IKONOS panchromatic data acquired immediately after a disaster are the best ways to map the extent of the disaster and to estimate its effects. If clouds are present, imaging radar can provide the most useful information.

Health Applications

Before the formulation of scientific explanations for illnesses, there have been references to areas with “bad air” and “bad water.” Responsibility for controlling such environmental hazards in order to safeguard public health has increasingly fallen on the shoulders of local and regional governments. In turn, officials attempt to educate and solicit input and assistance from local residents. Key environmental health issues include human exposure to contaminated air, water, and soil and the spread of infectious diseases. Some of these health concerns are related directly to human activities, such as toxic spills and emissions, pesticide runoff, and radiation releases. Others can be naturally occurring, though are often indirectly affected by human-induced changes, such as arsenic in groundwater or vector-borne diseases.

Land cover, land use, and environmental conditions are useful predictors of potential risk. In order to monitor and control the spread diseases, local governments need to map the locations of for instance, dead birds and mosquito breeding sites (areas of standing water). To track high-risk areas for some diseases, focus may be placed on the suburban extensions of new developments into heavily vegetated areas. Identifying areas of high risk using traditional field surveys can be costly and time-consuming. Local governments could utilize remotely sensed imagery to more effectively select areas for surveillance and intervention.

Unfortunately, the resolution of satellites such as Landsat is not sufficient to identify many of the parameters needed to monitor vector-borne diseases. However, it would be possible to use the medium-resolution satellite data as a baseline for major features (vegetated areas and large wetlands). Those images could then be integrated with either high-resolution satellite (IKONOS) or aerial photography data and supplemented with data collected on the ground. Together, remote sensing and GIS could provide local and regional governments with useful tools and information to help address these types of environmental health issues. A similar approach might be used to determine routes of exposure from hazardous waste sites and spills. In addition, integrated remote sensing/GIS could be used to evaluate alternative sites for hazardous facilities such as incinerators, in order to minimize the impact on local populations and ecosystems.

Integration with Relevant Data Sets

Products derived from satellite imagery can be easily integrated into a GIS with other data layers relevant to specific applications. One of the most useful applications is the integration of land cover and land use change maps with population data derived from the National Census. The main interest is to determine the land cover and land use classes in which population changes are occurring, in terms of both total population density and population composition (by age, sex, and race). Another interesting application is to determine whether and to what extent population changes are occurring in the same areas where land use changes are occurring or have occurred.

The main issue in this case would be to find the proper scale to combine satellite-derived data (particularly if Landsat data are used) and population data, collected at the tract or block level. The integration of remotely sensed data with population data relates also to the broader topic of urban and suburban remote sensing and the resolution needed for many urban applications. The spatial resolution at which urban and suburban features and changes can be detected is usually more important than the spectral resolution. Therefore, if data are needed more frequently than every five or ten years (usually the case), IKONOS is probably the best source, although such data are currently quite expensive. Again, calibration of coarser resolution data (panchromatic Landsat, for instance) with higher resolution (panchromatic IKONOS) data could solve some of the resolution-related issues, reducing costs and potentially providing more frequent coverage.

References

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