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Applications of Remote Sensing and GIS in Natural Resource Management

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Abstract

Remote sensing and Geographical Information System (GIS) offers an abundant opportunity to monitor and manage natural resources at multi-temporal, multi-spectral and multi-spatial resolution. It is an urgent need to understand the specialized capabilities of an ever-expanding array of image sources and analysis techniques for natural resource managers. In this review, we compile the various applications of remote sensing and GIS tools that can be used for natural resource management (agriculture, water, forest, soil, natural hazards). The information is useful for the natural resource managers to understand and more effectively collaborate with remote sensing scientists to develop and apply remote sensing science to achieve monitoring objectives.

Key words: *remote sensing, island, soil and water resources, irrigation, mapping,*

Introduction

In recent years, remotely sensed data has been widely used for its application in various natural resource management disciplines. With the availability of remotely sensed data from different sensors of various platforms with a wide range of spatiotemporal, radiometric and spectral resolutions has made remote sensing as, perhaps, the best source of data for large scale applications and study. The exhaustive data provided by remote sensing is now serves as an input data for several environmental process modeling (Melesse *et al.,* 2007). The integrated use of remotely sensed data, GPS, and GIS will enable consultants and natural resource managers and researchers in government agencies, conservation organizations, and industry to develop management plans for a variety of natural resource management applications (Philipson & Lindell, 2003). It is a potential tool to study change in land cover, forest density, coastal morphology, status of reef and biodiversity of islands even if, located in remote place.

Application in Agriculture

There has been increased emphasis on the potential utility of using remote sensing platforms to obtain real-time assessments of the agricultural landscape. Precision agriculture is a production system that promotes variable management practices within a field, according to site conditions. This system is based on new tools and sources of information provided by modern technologies. These include the global positioning system (GPS), geographic information systems (GIS), yield monitoring devices, soil, plant and pest sensors, remote sensing, and variable-rate technologies for applicators of inputs (Seelan *et al.,* 2003). Satellite remote sensing, in conjunction with geographic information systems (GIS), has been widely applied and been recognized as a powerful and effective tool in detecting land use and land cover change. It provides cost-effective multi-spectral and multi-temporal data, and turns them into information valuable for understanding and monitoring land development patterns. GIS technology provides a flexible environment for storing, analyzing, and displaying digital data necessary for change detection and database development. Satellite imagery has been used to monitor discrete land cover types by spectral classification or to estimate biophysical characteristics of land surfaces via linear relationships with spectral reflectances or indices (Steininger, 1996). In Andaman Island it was used to identify and map rice growing areas and assessment of soil constraints.

Application in Soil Science

In nature soil properties are spatially variable therefore it should be estimated as continuous variable rather than point values to have higher accuracy and wide applications (Burrough 1993). Further, the traditional method of soil analysis and interpretation are laborious, time consuming, thus becoming expensive hence, *kriging* and its variants have became widely recognized as an important spatial interpolation technique in land resource inventories (Hengl *et al.* 2004). In this context, with the advancement of geographical information system (GIS) and remote sensing technology, predictive soil mapping techniques have been developed. The *in situ* point measurements of soil quality can be made a regression analysis with exhaustive satellite derived indices and the correlation is upscale to larger areas spatially. The spatial maps are also an ideal input for spatially distributed models. Gopal Krishan *et al.,* (2009) used vegetation cover, slope and erosion status derived from remote sensing data to delineate four major land degradation categories viz., undegraded, moderately degraded, degraded and severely degraded. Similarly remote sensing and GIS was successfully used for natural resource mapping and soil taxonomic study by Velmurugan and Carlos, (2009). The procedure for land resource mapping is given in Fig. 1.

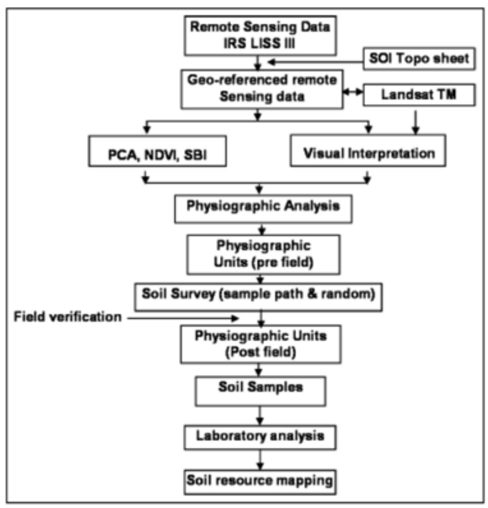

Fig. 1. Procedure for land resource mapping

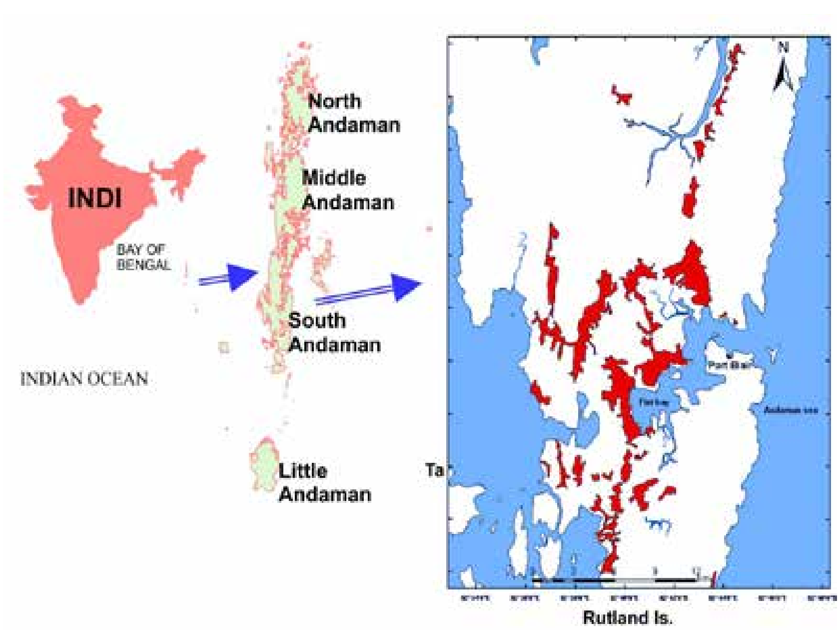

Fig. 2. Mapping of rice growing areas of South Andaman

Application in Crop-Irrigation Demand Monitoring

Agriculture is the major consumer of water, utilizing more than 70% of the global fresh water. Hence, the role of irrigation water plays a significant part in increasing land productivity. Land surface evapotranspiration (ET) is one of the main components of the water balance that is responsible for water loss (Michailidis *et al.,* 2009) and it is of prime interest for environmental applications, such as optimizing irrigation water use, irrigation system performance, crop water deficit, etc. Also, poor irrigation timing and insufficient applications of water are universal factors that limit agriculture production in many arid and semi-arid agricultural regions. In the context of these problems, remote sensing technology has been emerged as an effective tool to monitor irrigated lands over a variety of climatic conditions and locations over the last few decades. It helps in determining when and how much to irrigate by monitoring plant water status, by measuring rates of evapotranspiration and by estimating crop coefficients. The effective use of surface water and the monitoring of consumptive use of water using remote sensing techniques has been a topic of great interest for irrigation water policy makers.

Application in Crop Modelling

It is possible to combine crop models and remote sensing in the way of evaluate yield variables from remote sensed data for each time step in the model simulations, thus the use of remote sensing allows us to fill the missing model parameters during the recalibration in field scale (Batchelor *et al.,* 2002). Additionally, getting data from crop models in field scale -remote sense allows transferring the results from field scale to regional scale (Priya and Shibasaki, 2001). Many ways of using remote sensing data with crop models have been suggested (Wiegand *et al.,* 1986 and Dele´colle *et al.,* 1992). One way is estimating LAI (leaf area index) values by remote sensing for calibrating into the crop models. Other way is early estimates of the final yield but this method needs many remote sensing data during the growing season to use in crop models. Baret *et al.,* (2006) combined remote sensing observation with crop models for providing stress quantification through assimilation approaches. Crop and soil model with GIS can be used to detect methane emission from fields (Matthews *et al.,* (2000) similarly it is used to estimate global food production and the impacts of global warming using GIS and crop model. There are several ways to reduce crop model uncertainty with remote sensing. One possibility is remote sensing images can be used classify agricultural fields and crop types, In this way crop models can be selected to use with this classification corresponding to soil input data. Remote sensing can also be used to estimate crop growth indicator that can be integrated with crop models.

Application in Water Resource management

Water as a resource is essential to support human existence. The availability of fresh water for human use has been declining over the years, whereas the demand of growing population is increasing. In this context, there is an urgent need to monitor and obtain a better understanding of its use, which will provide information that can assist towards the development of effective water management strategies and infrastructures. This can be of crucial importance, particularly to regions on which the amount of water available is limited.

Understanding the complex water system requires a holistic approach to integrate the concepts and ideas from different disciplines for sustainable water resource management. A field scale study brings first insights to develop a detailed understanding about the manifold processes of the water cycle. However, the political decisions are made at regional to national level and thus it is crucial to reasonably upscale field scale studies to regional or national level. Hydrological models are generally used for this purpose but often suffer problems of data scarcity or lack of quality input data. Remote sensing technologies would then be a promising tool to integrate with the models for getting continuous input data in data scarce regions. The launch of several Earth Observation (EO) sensors from advanced satellites provides world-wide continuous measurements on various hydrological components which are essential input data for hydrological modeling. The data gaps due to lack of on-the-ground monitoring of water resources around the world are now available using satellite acquisition. Thus, satellite products and sophisticated computational techniques for the management of water can play an important role in present and future of water resources. The satellite remote sensing for hydrological applications includes, but not limited to rainfall (Global Precipitation Measurements (GPM) and Tropical Rainfall Measuring Mission (TRMM); Soil moisture (Soil Moisture Active Passive (SMAP) and Soil Moisture Ocean Salinity (SMOS); Actual Evapotranspiration (Surface Energy Balance System); Mapping Evapotranspiration with Internalized Calibration (METRIC) and Surface Energy Balance Algorithm for Land (SEBAL); Groundwater level monitoring by Gravity Recovery and Climate Experiment (GRACE) (Bastiaanssen *et al.,* 1998; Liu, 2012; Sun, 2013).

Using satellite data and GIS, water bodies such as rivers, lakes, dams and reservoirs can be mapped in 3D. The spatial water availability maps can be generated. The concerned authorities can use the information for identifying the sites or regions that need effective protection and management and decisions can be made regarding the sustainable management of water resources in the identified regions.

Application in Water Quality Monitoring

Regular monitoring of water quality is required to manage and improve the quality for human consumption purpose. In situ measurements and laboratory analysis of water samples are currently used to evaluate water quality. Though such measurements are accurate for a point in time and space, they do not give either the spatial or temporal view of water quality needed for accurate assessment or management of water bodies. Furthermore they are expensive and time consuming and cannot satisfy the regional or national monitoring need. Remote sensing techniques can be used to monitor water quality parameters (i.e., suspended sediments (turbidity), chlorophyll, and temperature). Optical and thermal sensors on boats, aircraft, and satellites provide both spatial and temporal information needed to monitor changes in water quality parameters for developing management practices to improve water quality. Remote sensing has been also used to measure chlorophyll concentrations spatially and temporally based on empirical relationships with radiance or reflectance (Ritchie *et al.,* 1994). The empirical relationships (algorithms) between the concentration of suspended sediments and radiance or reflectance for a specific date and site were developed to predict the water quality for several years (Ritchie and Cooper, 1991).

Forest Management and wildlife habitat analysis

Forest is a vital organ of our ecosystem; they impact human lives in several ways, despite of having huge importance the world forest has been declining at an alarming rate. Being a renewable resource, forest cover can be regenerated through sustainable management. Hence, using remote sensing data and GIS techniques, a forest manager can generate information regarding forest cover; types of forest present within an area of interest, human encroachment extent into forest land / protected areas, encroachment of desert like conditions and so on. This information is crucial for the development of forest management plans and in the process of decision making to ensure that effective policies should put in place to control and govern the manner in which forest resources can be utilized. The suitability and status of sites / forest area for a particular species of wildlife can also be assessed using remote sensing data using multicriteria analysis.

Application in Natural Disaster Management

Extensive multi-temporal spatial data is required for the management of natural disasters such flooding, earthquakes, volcanic eruptions and landslides. In this context satellite remote sensing is an ideal tool that offers information over large areas and at short time intervals, which can be utilized in various phases of disaster management, such as prevention, preparedness, relief, reconstruction, early warning and monitoring. Along with remote sensing, GIS techniques are required to handle huge spatial data sets and hence have been gaining importance in disaster management (Van Westen, 2000).

Conclusion

With the rising pressure on natural resources due to the increasing human population, remote sensing and GIS can be used to manage these precious limited resources in an effective and efficient manner. Geospatial information are quite useful in the identification and analysis of factors that affect the utilization of these resources. Hence, with the detailed understanding of these factors, sound decisions can be arrived at that will ensure the sustainable use of natural resources to meet the needs of the current as well as future generations.

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