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Remote Sensing and GIS Applications in Environmental Sciences – A Review

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Abstract

Remote sensing and Geographic Information System play a pivotal role in environmental mapping, mineral exploration, agriculture, forestry, geology, water, ocean, infrastructure planning and management, disaster mitigation and management etc. Remote Sensing and GIS has grown as a major tool for collecting information on almost every aspect on the earth for last few decades. In the recent years, very high spatial and spectral resolution satellite data are available and the applications have multiplied with respect to various purpose. Remote sensing and GIS has contributed significantly towards developmental activities for the four decades in India. In the present paper, we have discussed the remote sensing and GIS applications of few environmental issues like Mining environment, Urban environment, Coastal and marine environment and Wasteland environment.

Keywords: *Remote sensing; Geographic Information System; Environment.*

1. INTRODUCTION

The environment is something we are very familiar with our day to day life. It's everything that makes up our surroundings and affects our ability to live on the earth, the air we breathe the water that covers most of the earth's surface, the plants and animals around us, and much more. In recent years, scientists have been carefully examining the ways that people affect the environment. They have found that we are causing air pollution, deforestation, acid rain, and other problems that are dangerous both to the earth and to ourselves. These days, when you hear people talk about "the environment", they are often referring to the overall condition of our planet, or how healthy it is.

With the start of a new millenium, human kind faces environmental challenges greater in magnitude than ever before because the scale of the problem is shifting from local to regional and even to globally. Indeed, the footprint of human activity continues to expand to the point that it is exerting a major effect on nearly all of the Earth's systems. Global environmental problems such as global climate change, threat of biological and chemical warfare and terrorism, and unsustainable development in many parts of the world are evolving as significant issues for the future of the planet and of mankind. At local and regional scales, acidification of surface waters, loss of biotic integrity and habitat fragmentation, eutrophication of lakes and streams, and bioaccumulation of toxic substances in the food constitute some of the many examples of how human- induced changes have impacted the Earth's systems and its environment (Tim and Mallavaram, 2003).

Several developmental projects are taken up in the all over the world either for industrial or

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power sectors. Whatever the developments may be, the impacts are leading to deterioration of environment in the adjoining area and surroundings. The lack of adequate data base on the pre-establishment stage, developmental stage and the post developed stage, environmental impact studies (EIS) with respect to every sector need to be studied in an integrated manner attaching top priority for environmental conservation. The damage to agriculture, quality of life in terms of ambient air quality by way of air pollution, dust falls etc. Clearance of forest due to hydro power projects, increased urbanization, industrialization, mining etc., need an alternative strategies suitably to compensate the losses without causing much difference to the already existing environment and the available natural resources.

This review shows that the application of remote sensing and GIS in the field of broad environmental issues like mining environment, Urban waste management, Coastal, wetland and marine environment management which could be identifiable from aerial photographs and satellite imagery.

1.1 Remote Sensing

"Remote Sensing" is the science and art of acquiring information (spectral, spatial, temporal) about material objects, area, or phenomenon, without coming into physical contact with the objects, or area, or phenomenon under investigation. Without direct contact, some means of transferring information through space must be utilized. In remote sensing, information transfer is accomplished by use of electromagnetic radiation (EMR).

Remote sensing technology has many attributes that would be beneficial to detecting, mapping and monitoring invaders. Remote Sensing using space-borne sensors is a tool, par excellence, for obtaining repetitive (with a range from minutes to days) and synoptic (with local to regional coverage) observations on spectral behavior of various environments. i.e., Land surface changes (degradation), water quality, soil and atmosphere etc. Integrated GIS and remote sensing have already successfully been applied to map the distribution of several plant and animal species, their ecosystems, landscapes, bio-climatic conditions and factors facilitating invasions (Stow et al., 1989, 2000; ; Rowlinson et al., 1999; McCormick, 1999; Haltuch et al., 2000; Los et al., 2002). Remote sensing (satellite) imagery is available for most of the world since 1972. The multidate nature of satellite imagery permits monitoring dynamic features of landscape environments and thus provides a means to detect major land cover changes and quantify the rates of change (Joshi et al., 2004). The interpretation and analysis of Landsat TM image since 1987, provided a comprehensive information of the area especially regarding the various land uses and the associated environmental problems. The use of remote sensing is becoming increasingly frequent in environmental studies. In the 1970s and 1980s satellite images were mostly used in simple interpretations or as a map background (Merifield and Lamar 1975, Rib and Liang 1978).

1.2 Multispectral remote sensing

Multispectral remote sensing is generally based on acquisition of image data of Earth's surface simultaneously in multiple wavelengths. Due to that, we can use the fact that different types of surfaces reflect the light of different wavelengths with various intensity. Different spectral behavior is leading to detailed classification of specific types of land surfaces (depending on the spatial, spectral and radiometric resolution of the used sensor). Multispectral remote sensing involves the acquisition of visible, near infrared, and short-wave infrared images in several broad wavelength bands. Different materials reflect and absorb differently at different wavelengths. As such, it is possible to differentiate among materials by their spectral reflectance signatures as observed in these remotely sensed images, whereas direct identification is usually not possible. NASA's Landsat, one of the more common multispectral imagers, is widely used for monitoring a wide range of landscape scale properties. Prior to the Hyperion and other airborne hyperspectral data, mostly multispectral remote sensing data were used to map the feasibility of environmental impacts in almost the world. Multispectral satellite data are highly useful for monitoring temporal changes and continuous monitoring of environmental impacts due to mining activities. Similarly Synthetic Aperture Radar images are useful in detecting land use morphological changes due to mining activities.

1.3 Hyperspectral remote sensing

The hyperspectral data has significant advantages over the multispectral data, which has hundreds of contiguous spectral bands with narrow spectrum. The high spectral resolution and reflectance spectra allow direct identification of individual materials based upon the reflectance characteristics (Pieters and Mustard, 1998). It allows measurements of materials spectra, making it possible to identify an area specific mineral, rocks, soils and vegetation of the changes over time with high resolution (Frederick and Henderson, 2000). Due to its unique capability to resolve mineral absorption features, it has been successfully applied for the detection of mine waste (Swayze et al., 2000).

1.4 Geographic Information System

Geographic information systems (GIS) are used to collect, store, analyse, disseminate and manipulate information that can be referenced to a geographical location. GIS can be used to representative application areas of foster effective short-and-long term decision making, socio-economic and environmental problems, transportation, local government and business. Burrough and McDonnell (1998) has defined GIS is a powerful set of tools for collecting, storing, retrieving, transforming and displaying spatial data from the real world for a particular set of purposes. Application of GIS is revolutionizing planning and management in the field of environment. The technology that has given vast scope to the applicability of remote sensing and field based analysis is ‘Geographic Information System (GIS).

The field and science of GIS have been transformed over the last two decades. Once considered a Cinderella technology in selected disciplines and application domains, GIS has grown quite rapidly to become a multi-billion industry and a major player in the broader field of the ubiquitous information technology. Advancements in computer hardware and software, availability of large volumes of digital data, the standardization of GIS formats and languages, the increasing interoperability of software environments, the sophistication of geo-processing functions, and the increasing use of real-time analysis and mapping on the Internet have increased the utility and demands for the GIS technology. Apart from that, researchers, resource planners and policy makers are realizing the power of GIS and its unique ability to enhance environmental issues (Tim and Mallavaram, 2003). GIS can be a powerful tool for understanding these processes and for managing potential impacts of human activities on environment.

1.5 Applications

In the present review, an approach has been made to review the applications of Remote sensing and Geographic Information System applications to the mining environment, urban environment management, coastal and marine environment, wasteland environment etc.

2. MINING ENVIRONMENT

The application of Remote sensing techniques in the mining environmental study has unique advantages, because of its multispectral mode, synoptic view and repetitive coverage. The advancement of high resolution multispectral satellite data, imaging spectrometry is an excellent tools to study the environmental impacts due to mining activities. To monitor the land use changes due to opencast strip mining, effect of underground mining and subsidence, evolution of dumping of mine wastes, deforestation and erosion due to mining activities Remote sensing techniques have successfully applied (Gupta, 2005).

The impact due to mining causes rapid and drastic environmental changes. Because of complex problems and frequent changes in the landscape in the mining area, monitoring of these environmental changes is becoming extremely difficult. Mining causes direct landscape changes and in many cases it enables the emission of hazardous substances into the environment. The extent of this change varies from minor to extreme events. Hyperspectral remote sensing techniques could provide vital information on various environmental aspects such as land use, land cover changes, vegetation condition, soil water quality and acid mine drainage locations.

The field and laboratory based radiometric techniques have been successfully used to predict certain properties of water bodies, grasslands, minerals and rocks, forests, crops and several other surface features from their reflectance spectra (Milton (1987). Environmental monitoring data obtained from adjacent locations of mining area water quality, mineralogical and gecochemical studies (Amonoo-Neiser & Busari, 1980; Clement et al.,1997). Mularz (1998) mapped the problem of environmental monitoring and land-use/land cover changes over the lignite open-cast mine and power plant area was investigated using airborne remote photography along with Landsat TM and SPOT imageries in the central part of Poland to discriminate, assess and even to measure these destructive phenomena.

The degradation of land use due to coal mining using remote sensing techniques at Jharia coal filed have been studied by Prakash and Gupta (1998). The open cast mining activities like lignite and other materials lead to loss of fertile agricultural land, elimination of surface water bodies and ground water depletion in deeper aquifers. Oxidation process at surface of dumped mine waste may produce acid water drainage, which can affect the surface and groundwater quality (Ramanathan et al, 2000).

(Das and Nizamuddin, 2002) have successfully utilized the hyperspectral sensor ('Hyperion') data to map the mineral abundance, lithological mapping and processing methodology for detecting iron and manganese mines in parts of Singhbum district, Orissa and spectral signature and spectral mixture modelling techniques utilized for targeting laterite & bauxite ore deposits. Levesque et al., (2001) used the hyperspectral remote sensing data to monitor and assess the rehabilitation of mine tailing sites. Chevrel et al, (2001) effectively utilized airborne hyperspectral remote sensing sensors in the six mining areas (Europe and Greenland) to study the mining related contamination and its impact on vegetation. Different primary granites and subsequent kaolinization in the mining area were identified using hyperspectral data analysis (Ellis et al., 2004). Lalan kumar et al, (2007) applied the application of Geographical Information system to underground mining studies including land ownership and mineral claims, exploration management production and mine site.

Multi-date infra red Landsat images were utilized to study the environmental changes in Sierra Leone, West Africa, especially to understand the impact on hydrogeomorphology (Akiwumil and Butler, 2007). An attempt has made to delineate the magnesite ore deposits in Salem using hyperspectral remote sensing data, which reveals that potential of using narrow band hyperspectral data for further mapping of impact mining on environment (Sathish Kumar et al., 2011). The management and controlling factors of environment affected due to mining to be adopted both during production and after closure. Sufficient data collection and accurate processing should be done with respect to place and time for control and planning the environmental management.

3. URBAN ENVIRONMENT MANAGEMENT

Urbanization is an index of transformation from traditional rural economies to modern industrial one. It is a progressive concentration of population in urban unit. During the last fifty years the global population is increased dramatically, as a result most urban settlements are characterized by shortfalls in stock housing and water supply, urban encroachments in fringe area, inadequate sewerage, traffic congestion, pollution, poverty and social unrest making urban governance a difficult task to maintain healthy urban environment. High rate of urban population growth is a cause of concern among India's urban and town planners for efficient urban planning. Therefore, there is an urgent need to adopt modern technology of remote sensing which includes both aerial as well as satellite based systems, allowing us to collect lot of physical data rather easily, with speed and on repetitive basis, and together with GIS helps us to analyze the data spatially.

Floods cause damage to natural resources and environmental quality and indirectly contribute to increasing poverty, which in turn further add to the vulnerability of both natural and human systems mostly urban area compare to the rural areas. The environment and flood linkage has been recognized, and many environmental programs such as reforestation, forest protection, upland fixed cultivation and resettlement, could be been implemented through remote sensing and GIS.

GIS has been widely used in characterization and assessment studies which require a watershed-based approach to manage the water level and waste management in the urban locations. Basic physical characteristics of a watershed such as the drainage network and flow paths can be derived from readily available Digital Elevation Models (DEMs). When faced with challenges involving water quality and quantity due to natural as well as human-induced hazards (e.g., droughts, hazard material spills, floods, and urbanization), planning becomes extremely important so as to mitigate their impacts and ensure optimal utilization of the available resources (Tim and Mallavaram, 2003).

Remote sensing can provide an important source of data for urban land use/land cover mapping and environmental monitoring (Patkar, 2003). A numbers of significant studies were made for environmental quality management. Uncontrolled urbanization has been responsible for several problems, our cities facing today, resulting in substandard living environment, acute problems of drinking water, noise and air pollution, disposal of waste, traffic congestion etc. To minimise these environmental degradations in and around cities, the technological development in related fields have to address to these problems caused by rapid urbanization, only then the fruits of development will percolate to the most deprived ones. The modern technology of remote sensing which includes both aerial as well as satellite based systems, allow us to collect physical data rather easily, with speed and on repetitive basis, and together with GIS helps us to analyze the data spatially, offering possibilities of generating various options (modeling), thereby optimizing the whole planning process.

The dynamic nature of urban environmental necessitates both macro and micro level analysis. Therefore, it is necessary for policy makers to integrate remote sensing with urban planning and management. The trend towards using remotely sensed data in urban studies began with first-generation satellite sensors such as Landsat MSS and was given impetus by a number of second generation Satellites: Landsat TM, ETM+ and SPOT. The recent advent of a third generation of very high spatial resolution (5m/pixel) satellite sensors is stimulating. The high resolution PAN and LISS III merged data may be used together effectively for urban applications. Data from IRS P-6 satellites with sensors on board especially LISS IV Mono and Multispectral (MX) with 5.8 m/pixel spatial resolution is very useful for intensive urban studies (Rai and Kumra, 2011).

4.COASTAL AND MARINE ENVIRONMENT

Coastal zones in India are constantly undergoing wide-ranging changes in shape and environment due to natural as well as human development activities. Natural processes such as waves, erosion, changes in river courses etc., cause long time effect at slower rate; but manmade activities, such as settlement, industrial activities, recreational activities, waste disposal etc., affect the coastal environment at comparatively much faster rate. Continued loss of these wetlands may lead to the collapse of coastal ecosystems. It is, therefore, necessary to monitor coastal zone changes with time. Remote sensing technology in recent years has proved to be of great importance in acquiring data for effective resources management and hence could also be applied to coastal environment monitoring and management (Ramachandran, 1993, Ramachandran et.al., 1997, 1998).The high temporal resolution provided by the satellite data is found to be a major improvement in studying the behavior of suspended sediments in the coastal waters, which would help in understanding the movement of sediments and pollutants (Nayak et.al., 1996).

GIS in addition to providing efficient data storage and retrieval facilities also offers a cheaper option of monitoring forest conditions over time (Ramachandran et al., 1998). Remote sensing and GIS are increasingly used in mangrove forestry worldwide to assist in gathering and analysing images acquired from aircrafts, satellites and even balloons. The notable advantages of using GIS include the ability to update the information rapidly, to undertake comparative analytical work and making this information available as required. The area covered by mangroves in the islands of Andaman was calculated using SPOT 1993 and IRS 1D LISS III 2003 imageries. The change in mangrove area within a span of ten years has presented in the form of a table (IOM report, 2003). Twumasi and Merem (2006) assessed change within a coastal environment in the Niger delta region of Nigeria using remotely sensed satellite imagery and GIS modeling, quickened the analysis of the spatial distribution of environmental change involving land use, land cover classification, forest and hydrology and demographic issues facing the Niger Delta and successful implemented some of the strategies could lead to effective management of the coastal environment in the Niger Delta region.

Satellite based remote sensing techniques have proved successful in providing a comprehensive, reliable and up-to date information on land use/land cover in the offshore areas of east coast of Andhra Pradesh in the most cost effective manner. Environmental Sensitivity Index (ESI) and Reach Sensitivity Index (RSI) identified through modern methods like Digital Image processing and GIS for preparedness in case of oil spill incidents in offshore areas (Saxena et al.,2008).

The combination of remote sensing and GIS technologies provides an ideal solution for understanding the spatial/temporal distribution of oil spills in the marine environment and is considered as the core of the oil spill monitoring system. The advantages of the remote sensing and GIS provides the ability to extract the oil pollution parameters such as location and spill areas including spatial and temporal information allows the users to establish the major cause and source of oil spills and then outline the risk areas to save the marine environment. One of the major advantages of GIS is the ability to extract oil pollution parameters such as location, size and spill areas. Spatial and temporal information (oil spill distribution at sea and its evolution in time) allows the users to establish the major cause and source of oil spills, and then outline the risk area (Eljabri and Gallagher, 2012).

The products derived from geospatial technologies support informed decision making with respect to marine spatial planning and management.

5. WASTELAND ENVIRONMENT

Wetlands consist of 3 - 6% of the earth's land surface, while they make available supplies and services such as: water quality maintenance, agricultural production, fisheries, and recreation floodwater, retention, provision of wildlife habitat, and control of soil erosion (Acreman and Hollis, 1996). Wetlands are transitional lands between Terrestrial and aquatic system that provide many goods and services including flood water retention, water quality maintenance, wildlife habitat, and soil erosion control. To prevent further loss of wetlands, and conserve existing wetland ecosystem for biodiversity and ecosystem services and goods, it is important to inventory and monitor wetlands and their adjacent uplands. The area of wetlands are reducing constantly for the last few decades due to wetland reclamation, population pressure, water diversion, dam construction, pollution, biological incursion, desertification, climate change, and misguiding policies (Augustine and Warrender, 1998; Chen, 2002). Remotely sensed data have been utilized to measure the qualitative and quantitative terrestrial land-cover changes (Seto et al., 2002). During last two decades a diversity of remotely sensed data and change detection methods have been developed and assessed (Finlayson et al., 1999; Rogan, et al., 2002; Healey et al., 2005).. Remote sensing (RS) data and Geographic information systems (GIS) are appropriate tools for monitoring of the wetland distribution area and spatial-temporal dynamic multiplicity (Emadi et al., 2010) Satellite remote sensed data have been widely utilized for inventorying and monitoring wetlands and can also provide information on surrounding land use and their change over the time (Ghobadi et al., 2012). Ghobadi et al., (2012) successfully utilized the Multi-temporal remote sensing data and GIS for wetland mapping in the southwest of Iran near to the Karkheh River using four Landsat images 1985 (Landsat MSS), 1999 (Landsat ETM+), 2002 (Landsat ETM+) and 2011 (Landsat ETM+) and found that, increase in agricultural activity, climate change and construction engineering projects caused wetland surface area reduction.

Satellite remote sensing has many advantages for inventory and monitoring of wetlands and also provide information on surrounding landuse and their changes over time. Landsat MSS, TM, and SPOT are common data type for wetland classification and its spatial-temporal dynamic change (Munyati, 2000; Paula and William, 2000; McHugh et al., 2007)

Due to temporal revisit capability of the satellite data, it allows to monitor the wetlands either seasonally or yearly. The use of remote sensing data for land cover classification is less costly and less time-consuming than aerial photography for large geographic areas. For wetland studies such as monitoring and inventory use and apply satellite remote sensed data can suitable in developing countries, where the budget are restricted and the data about the wetland like wetland area, landuse, and wetland losses are limited (Ozemi and Bauer, 2002).

Remote sensing has served as an efficient method of gathering data about glaciers since its emergence. The recent advent of Geographic Information Systems (GIS) and Global Positioning Systems (GPS) has created an effective means by which the acquired data are analyzed for the effective monitoring and mapping of temporal dynamics of glaciers. A large number of researchers have taken advantage of remote sensing, GIS and GPS in their studies of glaciers.

6. CONCLUSION

For every establishment sector there is also an equally important to draw out the base line information needs for environmental appraisal before undertaking any major programmes which might endanger the quality of life. This essentially calls for concerted effort by all the industrial, mining and urban sectors to evolve ecologically sustained growth in terms of energy, power, irrigation and all other basic resources. The remote sensing and GIS provides hands on tools to monitor, estimate, evaluate manage and controlling factors the environmental endangers to save the life and society.

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