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Applications of Geospatial and Remote Sensing Technologies in Management of Natural Resources

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INTRODUCTION

In recent years, the application of remotely sensed data has become increasingly prevalent across various disciplines of natural resource management due to its ability to provide comprehensive and detailed observations of the Earth's surface. The availability of data from diverse sensors on multiple platforms, offering a broad range of spatiotemporal, radiometric, and spectral resolutions, has positioned remote sensing as an invaluable source for large-scale environmental studies and applications. These high-resolution datasets enable the precise monitoring of land cover changes, forest density, coastal morphology, and the health of coral reefs and biodiversity, even in the most remote locations (Melesse *et al.,* 2007). Remote sensing technology has seen significant advancements, resulting in the production of more detailed and accurate data that can be integrated with other geospatial technologies like GIS (Geographic Information Systems). This integration allows for the development of comprehensive management plans by consultants, natural resource managers, and researchers working in government agencies, conservation organizations, and industry. By utilizing remote sensing data alongside GIS, we can better understand and manage natural resources, ensuring sustainable practices and conservation efforts. The exhaustive data provided by remote sensing now serves as crucial input for various environmental process modelling efforts, allowing for the simulation and prediction of environmental changes and impacts. Remote sensing data can be used to model climate change effects on ecosystems, track deforestation rates, assess water quality, and predict natural disasters such as floods and landslides. These applications highlight the versatility and importance of remote sensing in natural resource management. Furthermore, remote sensing enables the study of phenomena that are difficult or impossible to observe directly, such as the movement of wildlife in dense forests or the extent of underwater ecosystems. This capability expands the scope of environmental research and management, providing insights that were previously unattainable. The use of remote sensing also enhances the efficiency and accuracy of data collection, reducing the need for time-consuming and often costly fieldwork. By providing timely and accurate data, remote sensing supports informed decision-making and policy development, helping to address pressing environmental challenges. Additionally, the integration of remotely sensed data with GIS facilitates spatial analysis and visualization, enabling the creation of detailed maps and models that communicate complex information in an accessible manner. These tools are invaluable for engaging stakeholders, raising public awareness, and guiding conservation efforts. As technology continues to evolve, the potential applications of remote sensing in natural resource management are expected to grow, offering new opportunities for innovation and improvement. The combined use of remote sensing and GIS represents a powerful approach to understanding and managing the natural world, promoting sustainable development, and preserving biodiversity. This article deals with the advancements in remote sensing technology and its integration with geospatial tools that have revolutionized the field of natural resource management, providing essential data for environmental monitoring, process modelling, and decision-making.

CONCEPT OF REMOTE SENSING (RS) AND GEOGRAPHIC INFORMATION SYSTEMS (GIS)

Remote sensing is defined as the science and techniques of obtaining information about an object, land area, phenomenon, or ecosystem process using a device that is not in direct contact with the object, area, or phenomenon under investigation (Lillesand *et al*., 2015). Remote sensor systems detect and measure the electromagnetic energy emitted, transmitted, or reflected by a target, providing data for further analysis and practical applications. Typically, sensors on board Earth Observation (EO) systems measure the Electromagnetic Radiation (EMR) emitted or reflected by targeted objects. The elements of remote sensing are outlined as follows (Fig.1):

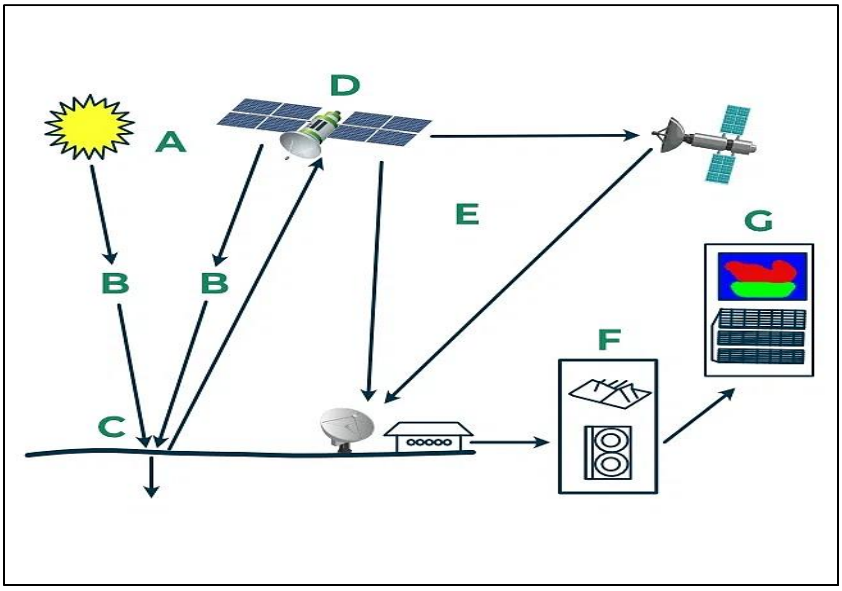

Fig. 1**:** Elements of remote sensing (*Source: Canadian Centre for Remote Sensing, Fundamentals of Remote Sensing (CCRS), 2009*)

I. **Energy Source (A):** The remote sensing process is initiated by an energy source, such as the sun or radar, which emits EMR to illuminate the target.
II. **Emitted Energy (B):** The EMR travels through the atmosphere to reach the target, with some energy loss occurring due to atmospheric interference.

III. **Target on Earth (C):** Upon reaching the target, the EMR may be absorbed, transmitted, reflected, or emitted in varying amounts.
IV. **Sensor (D):** Positioned on a platform such as a satellite or aircraft, the sensor captures the EMR that the target scatters or emits.
V. **Radio Links (E):** The captured EMR is transmitted by the sensor to a processing station, where it is converted into a digital or analogue image, typically in electronic form.
VI. **Ground Links (F):** The generated image is analyzed and interpreted to extract valuable information about the target.
VII. **Application (G):** The extracted information is applied to understand and address specific problems within various fields.

A Geographic Information System (GIS) is concisely defined as the system that creates, manages, analyses and maps all types of data (ESRI, 2022). Over time, GIS has evolved from a specialized computerized system tailored for specific applications into a versatile and comprehensive system. This system encompasses both hardware and software tools, facilitating the creation, management, analysis, and presentation of spatial data (Wieczorek and Delmerico, 2009). In GIS environment each dataset is organized and managed as a layer, which can be visually combined using analytical operators, a process known as overlay analysis. This capability allows GIS users to merge layers using operators and visual displays, empowering them to explore crucial questions and derive answers from spatial data (Fig. 2).

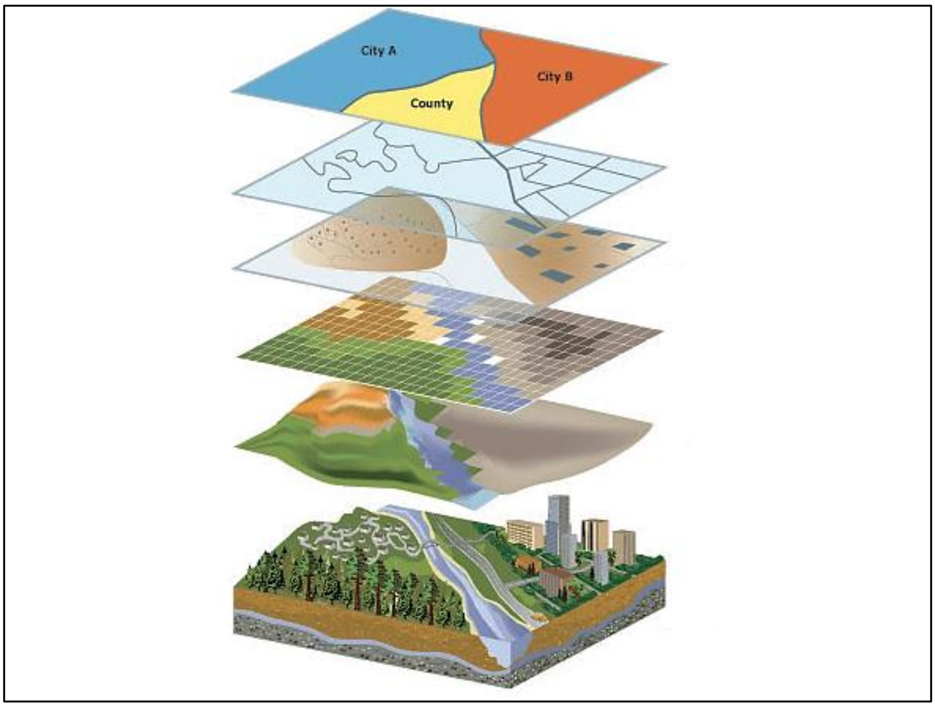

Fig. 2: Visualization of the utility of GIS, layering spatial information (*Source: ESRI, 2018*)

APPLICATION IN AGRICULTURAL SCIENCES

There has been an increasing emphasis on leveraging remote sensing platforms for real-time assessments of agricultural landscapes. Precision agriculture, which advocates for variable management practices tailored to specific site conditions within a field, relies on a suite of modern technologies. These include use of geospatial tools like Global Positioning System (GPS), Geographic Information Systems (GIS), yield monitoring devices, soil and plant sensors, pest detection sensors, remote sensing, and variable rate technologies for input application (Seelan *et al*., 2003). Satellite remote sensing, in conjunction with GIS, has emerged as a powerful tool for detecting changes in land use and land cover. It offers cost-effective access to multispectral and multitemporal data, which are essential for understanding and monitoring patterns of land development. GIS technology provides a flexible platform for storing, analysing, and visualizing digital data crucial for change detection and database development. Satellite imagery enables the monitoring of discrete land cover types through spectral classification and the estimation of biophysical characteristics of land surfaces using spectral reflectance or indices. These integrated approaches facilitate informed decision-making in agriculture by providing timely and detailed information on crop health, soil conditions, and environmental changes, thereby enhancing productivity and sustainability efforts in farming practices. The advancement of GIS and RS technologies has led to the development of predictive soil mapping techniques. These techniques involve integrating in situ soil quality measurements with regression analyses using comprehensive satellite-derived indices, allowing correlations to be extrapolated over larger spatial areas. The resulting spatial maps serve as valuable inputs for spatially distributed models. Velmurugan and Carlos (2009) demonstrated the successful application of remote sensing and GIS in mapping natural resources and conducting soil taxonomic studies. These methodologies harness the power of remote sensing's ability to provide detailed and multispectral data, combined with GIS analytical capabilities, to enhance the understanding and management of soil resources and land degradation processes on a broader scale.

APPLICATION IN CROP MODELLING AND WATER RESOURCE MANAGEMENT

The integration of crop models with remote sensing technology offers a powerful approach to enhance agricultural assessments. By utilizing remote sensing data to evaluate yield variables at each time step within crop model simulations, it becomes possible to fill in missing model parameters during recalibration at the field scale. Furthermore, the combination of field-scale data from crop models with remote sensing enables the transfer of results to regional scales, facilitating broader agricultural assessments. Various methodologies for integrating remote sensing data with crop models have been proposed, including the estimation of Leaf Area Index (LAI) values for model calibration and the early prediction of final yields, which requires continuous remote sensing data throughout the growing season (Wiegand *et al*., 1986). Remote sensing, when combined with GIS and crop models, also supports the detection of methane emissions from fields (Matthews *et al*., 2000), as well as the estimation of global food production and the impacts of climate change. Strategies to reduce uncertainties in crop modelling through remote sensing include field and crop type classification using remote sensing imagery, which informs the selection and adaptation of crop models based on corresponding soil input data. Additionally, remote sensing aids in the estimation of crop growth indicators that can be integrated into crop models, thereby enhancing their accuracy and applicability in agricultural management and planning.

For effective water resource management, a comprehensive approach is essential, integrating insights from various disciplines to ensure sustainability. The deployment of advanced Earth Observation (EO) sensors aboard satellites offers continuous global measurements of key hydrological components, crucial for hydrological modelling. These satellite-derived data and advanced computational techniques are pivotal for both current and future water resource management strategies. Satellite remote sensing plays a critical role in hydrological applications, encompassing monitoring of rainfall (e.g., Global Precipitation Measurements (GPM) and Tropical Rainfall Measuring Mission (TRMM)), soil moisture (e.g., Soil Moisture Active Passive (SMAP) and Soil Moisture Ocean Salinity (SMOS)), and actual evapotranspiration using methods like Surface Energy Balance System, METRIC, and SEBAL. Additionally, groundwater levels are monitored through technologies such as Gravity Recovery and Climate Experiment (GRACE) (Liu, 2012).

By leveraging satellite data in conjunction with GIS, water bodies such as rivers, lakes, dams, and reservoirs can be accurately mapped in three dimensions. This spatial mapping enables the generation of maps depicting water availability across different regions. Decision-makers can utilize this information to pinpoint areas requiring enhanced protection and management strategies. Consequently, informed decisions can be made to ensure sustainable management of water resources in identified regions, fostering effective stewardship and conservation efforts.

MANAGEMENT OF FOREST RESOURCES AND WILDLIFE HABITAT

Using remote sensing data and GIS techniques, forest managers can gather comprehensive information on forest cover types, identify human encroachment into forested or protected areas, and monitor the encroachment of desertification processes, among other critical factors. This data plays a pivotal role in developing effective forest management plans and guiding decision-making processes. By analysing remote sensing data, managers can assess the suitability and current status of forest areas for specific wildlife species using multicriteria analysis. This capability enables informed policies to be implemented for the sustainable utilization and governance of forest resources, ensuring their preservation and appropriate management for future generations.

CONCLUSION

In conclusion, the integration of remote sensing and GIS technologies has revolutionized natural resource management across various disciplines. These advancements have provided detailed insights into Earth's surface, facilitating precise monitoring of environmental changes, effective land use planning, and sustainable resource management. From agriculture to water resources, and from forest management to wildlife conservation, the combined use of remote sensing and GIS continues to drive innovation, enhance decision-making processes, and promote environmental sustainability on a global scale. As technology evolves further, these tools will play an increasingly crucial role in addressing current and future challenges in natural resource management.

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