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Enhancing Water Resource Management Using Remote Sensing and GIS: Application to Dam and Reservoir Site Identification in North-East India

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Abstract

This paper focuses on the broader application of Remote Sensing (RS) and Geographic Information Systems (GIS) technologies to enhance water resource management by identifying suitable dam and reservoir locations in North-East India. The study highlights how these technologies can help in managing water resources by integrating topographical, hydrological, and environmental data. Multi-criteria decision analysis (MCDA) is used to balance various socio-economic and environmental factors, ensuring the selected sites are sustainable and minimize disruption to local ecosystems. The study is applicable to regions with similar environmental challenges and presents a scalable approach for other parts of India.

Introduction

The paper introduces the pressing issue of water resource management in India, especially in the context of the North-East region where water availability is heavily dependent on monsoon rainfall. Given the region's unique geographical and environmental characteristics, traditional methods of dam and reservoir site identification are often insufficient. Remote Sensing and GIS technologies have emerged as critical tools for optimizing site selection by offering accurate spatial data and predictive models. The introduction emphasizes how integrating these technologies can revolutionize water management strategies, making them more efficient and ecologically sustainable. The study focuses on their application in identifying dam and reservoir sites across North-East India, specifically in areas facing water scarcity or flood risks.

Enhancing water resource management through the integration of remote sensing and Geographic Information Systems (GIS) has become an essential practice in modern hydrological studies. This approach is particularly valuable in regions with complex terrains and diverse environmental conditions, such as North-East India. The region, known for its hilly landscapes, dense forests, and abundant river systems, presents unique challenges and opportunities for dam and reservoir site identification. This paper delves into how remote sensing and GIS can be utilized to improve water resource management by providing a comprehensive framework for identifying optimal sites for dams and reservoirs in North-East India.

North-East India is a region characterized by its rugged topography, which includes a variety of landforms such as mountains, valleys, and river basins. The Brahmaputra River and its tributaries, along with other major river systems like the Barak and the Teesta, play a crucial role in the region's hydrology. The area's geographical complexity makes the process of locating suitable sites for dams and reservoirs both challenging and critical. Effective water resource management in such a context requires advanced techniques that can handle the intricacies of the terrain and hydrological conditions.

Remote sensing, which involves the acquisition of information about the Earth's surface from satellite or aerial sensors, provides a wealth of data that is crucial for water resource management. Satellites equipped with various sensors capture imagery across different spectral bands, allowing for detailed analysis of land cover, vegetation, and water bodies. In the context of dam and reservoir site identification, remote sensing offers several advantages. It provides high-resolution images that help in mapping and analyzing the terrain, identifying water resources, and assessing land cover changes. These capabilities are particularly useful in North-East India, where the terrain's variability can affect traditional site selection methods.

GIS complements remote sensing by offering powerful tools for spatial data analysis and management. GIS allows for the integration of various data layers, including topographical maps, land use data, hydrological information, and remote sensing imagery. This integration enables the creation of comprehensive spatial models that can assess the suitability of different locations for dam and reservoir construction. GIS can perform complex spatial analyses such as watershed delineation, flood risk assessment, and land suitability modeling, all of which are critical for making informed decisions about water infrastructure projects.

The process of integrating remote sensing and GIS for dam and reservoir site identification involves several key steps. Initially, remote sensing data is acquired from satellites like Landsat, Sentinel, or ASTER. This data undergoes preprocessing to correct for atmospheric and geometric distortions, ensuring its accuracy and reliability. The next step involves analyzing the data to classify land cover types, such as forests, agricultural areas, and water bodies. This classification helps identify areas that are suitable for dam construction and those that may be environmentally sensitive or otherwise unsuitable.

Topographic analysis is another critical component of the site selection process. Using digital elevation models (DEMs), GIS can analyze the terrain to assess factors such as slope stability and elevation. This analysis helps in identifying areas with favorable topographic conditions for dam construction, such as locations with stable slopes and adequate elevation for water storage. In addition to topographic analysis, hydrological modeling is performed to evaluate the water availability and storage capacity of potential sites. GIS-based hydrological models use data on river networks, rainfall patterns, and watershed characteristics to predict the potential impact of dam construction on local water resources.

Environmental impact assessment is an integral part of the site selection process. The integration of remote sensing and GIS allows for a comprehensive evaluation of the potential environmental impacts associated with dam and reservoir projects. This includes assessing changes in land use, vegetation cover, and effects on wildlife habitats. By using spatial analysis techniques, GIS can identify areas that may be affected by dam construction and help in developing mitigation strategies to minimize environmental harm.

In the context of North-East India, the application of remote sensing and GIS has provided valuable insights into the identification of potential dam and reservoir sites. The region's diverse topography and hydrological conditions require a tailored approach to site selection. Remote sensing data, combined with GIS analysis, helps in addressing these challenges by providing detailed information on land cover, topography, and hydrology. Case studies from various parts of North-East India illustrate how these technologies have been used to identify suitable sites for dam and reservoir construction, taking into account factors such as terrain stability, water availability, and environmental impact.

For example, in the Brahmaputra River basin, remote sensing and GIS have been used to map flood-prone areas and assess the potential for flood control reservoirs. Similarly, in the Barak River basin, these technologies have helped identify sites with high water storage potential and minimal environmental impact. The use of remote sensing and GIS in these case studies has demonstrated their effectiveness in enhancing water resource management by providing a comprehensive and data-driven approach to site selection.

The integration of remote sensing and GIS also offers significant benefits for monitoring and managing existing water infrastructure. By continuously updating remote sensing data and integrating it with GIS, water resource managers can track changes in land use, vegetation, and water bodies over time. This dynamic monitoring capability helps in adapting management strategies to changing conditions and ensures that water resources are managed effectively and sustainably.

Changes in land use/cover (LULC) have emerged as a key topic in contemporary research on sustainability and global change (Alqurashi & Kumar 2014). Rich in vegetation areas like wetlands and woods have been drastically transformed into agricultural land and human settlements as a result of urbanization and industrialization. In turn, this land conversion affects a number of hydrological processes, including the rate of soil erosion, the deposition of sediment in rivers and dams, and the pattern of stream flow within a catchment area (Ganasria & Dwarakisha 2015). Accurate measurement of the historical and current land cover/land use characteristics is necessary for the evaluation of watersheds and the formulation of management strategies. This is because changes in these parameters reveal the hydrological and ecological processes occurring within a watershed. Such changes can be monitored by remote sensing and GIS techniques; however, the extraction of change information from satellite data depends on an efficient and precise change detection technique (Dhanasekarapandian et al. 2015). Regardless of the underlying causes, digital change detection techniques based on multi-temporal and multi-spectral remotely sensed data have shown to have a great deal of promise for understanding the dynamics of the landscape. They can be used to map, identify, and monitor changes in land use/cover patterns over time. Decision-makers can assure sustainable development and comprehend the dynamics of our changing environment with the use of land use/land cover (LULC) change analysis (Iqbal & Khan 2014). Researchers worldwide are paying more attention to land use changes as a result of global developments, and large-scale land use changes brought about by urban expansion are attracting attention (Huang et al. 2008). The public's free access to NASA's Landsat picture library has made it possible to monitor land cover anywhere on Earth at a reasonable cost through remote sensing (Boori et al. 2014). Before implementing any kind of land use practices in the study region in the future, it is imperative to take into account the current socio-economic scenario (Nagarajan & Poongothai 2011). For many planning and management tasks involving the earth's surface, understanding changes in land use and cover is crucial (Pradeep et al. 2014).

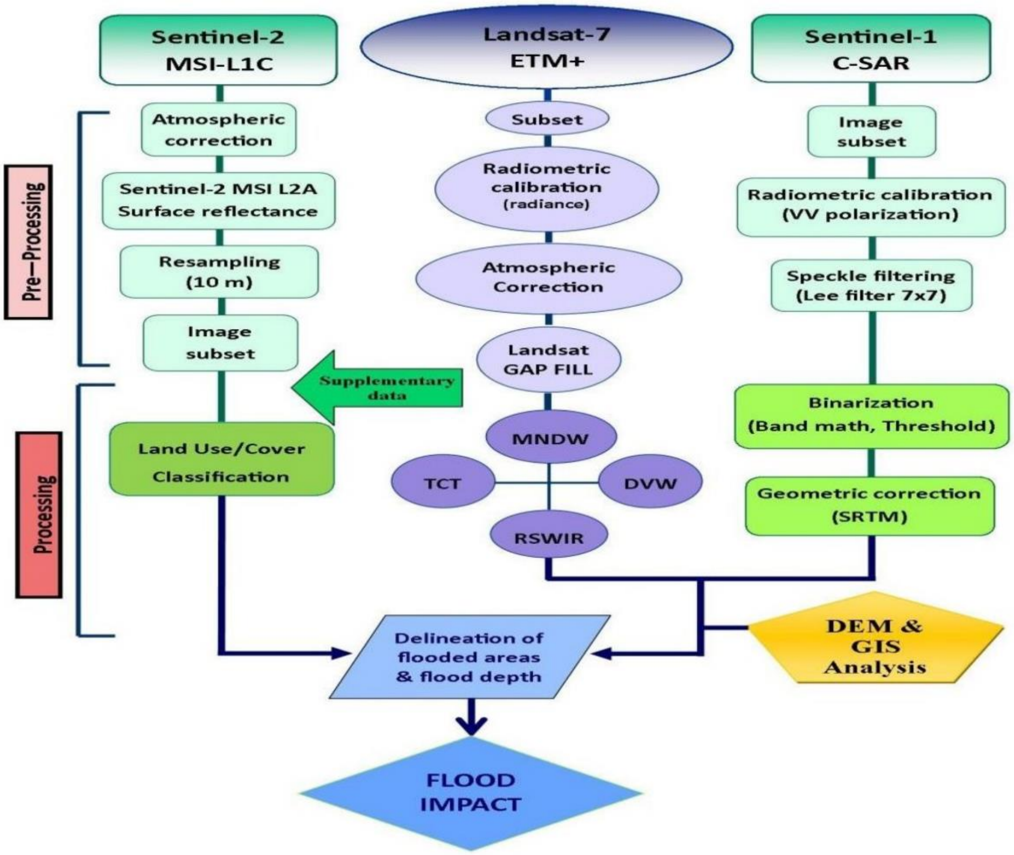

Fig: Approaches of Remote Sensing.

Review of Literature

The literature review presents a comprehensive overview of existing research on water resource management using RS and GIS technologies. The review covers international case studies that demonstrate the effective use of RS and GIS in dam site selection and water management. Additionally, it explores research specific to India, with a particular focus on the North-East region, where these technologies have been underutilized. The review highlights the benefits of using satellite imagery and GIS for monitoring topographical features, hydrological flows, and environmental impacts in the long term. The studies reviewed emphasize the need for integrating multiple criteria, such as slope, land use, and proximity to rivers, for effective decision-making.

Research in the Satluj basin up to the Bhakra dam was conducted by Panhalkar et al. (2014) in order to forecast runoff, erosion, sediment, and nutrient transfer from agricultural watersheds under various management strategies. His goal in doing the study was to estimate the runoff of the basin by utilizing the geospatial database to derive the parameters needed for runoff modeling. The digital elevation model and land use map of the study area were obtained by the authors through the utilization of remotely sensed data. The average monthly values of every meteorological parameter were determined using software programs like ENVI and ERDAS. After supplying all the input data required for model setup, the SWAT model was simulated for thirty years (from 1980 to 2010). According to the authors, the sediment production was found to be highest in the months of April and May, with a total sediment loading of around

51.27 T/HA each year. Validation of the stream flow has been done using RMSE and r2 approaches on Kasol's observed data. It was estimated that the average yearly surface runoff would be 79.67 mm. The authors also mentioned how crucial runoff modeling is to reservoir management at the Satluj basin's Bhakra dam.

utilizing meteorological data from three weather stations within the watershed, Adeniyi et al. (2015) investigated the viability of utilizing the SWAT model to simulate the sediment output at the upstream watershed of Jebba Lake in Nigeria during a 26-year period (1985 to 2010). Measured flow data collected between 1990 and 1995 was used for calibration and validation. From May to December 2013, sediment samples were taken from three locations within the watershed using the USDH-2A suspended sediment sampler. Using the coefficient of determination (R2), Nasch-Sutcliffe efficiency, and net system error (NSE), the authors assessed the model. They came to the conclusion that the model met the watershed's estimates for sediment output and stream flow with satisfactory performance. According to the model's expected results, the watershed's annual sediment yield was 255.8 tons/ha/yr between 1985 and 2010, yielding approximately 8.31x 109 tons of sediment. The study also found that the reach's sediment concentration (measured in milligrams per liter) throughout the simulation period was highest in a few subbasins, with values of 446.3, 376.8, and 365.4 mg/l, respectively.

According to research done by Ndomba & Griensven (2011), sediment yield is defined as the total amount of sediment that a basin exports over time and that will eventually enter a reservoir at the basin's downstream limit. The study focused on the suitability of the SWAT Model for modeling sediment yield in Eastern Africa. They also mentioned that the SWAT model has special benefits for applicability to basins with scant records and for studying the effects of basin change. Additionally, it was discovered that a brief field survey and a brief time series of hydrological and meteorological data were sufficient to end the model validation. The main management strategies for lowering soil loss/sediment yield and, consequently, sedimentation issues in the reservoir are determined by a variety of farming practices that are captured by PUSLE and CUSLE parameters, according to the authors' findings. Additionally, they demonstrated how well the SWAT model performed in these study areas and other Eastern African regions, indicating that the program can accurately estimate the sediment output for catchments with even the most inaccurate gauges. Rather of using observations at interior places in the river basin, they have "lumped" the distribution of the parameters by the use of sediment observations near the outlet. Although more high-resolution spatial input data would not directly enhance the model's performance, the authors argue that it might help provide a more accurate depiction of the spatial variability. They come to the conclusion that since the DEM is typically employed to calculate slopes, a high resolution DEM is particularly crucial for erosion modeling.

Due to sedimentation issues with the dam, Mohammad et al. (2012) conducted research on the application of the SWAT model for the assessment of runoff and sediment load from the right bank valleys of the Mosul dam reservoir in the River Tigris located in Iraq. The authors' work covered a 21-year simulation period from the start of the dam's operation in 1988 to 2008. They discovered that the average annual sediment load for the three valleys under consideration—Valleys One, Two, and Three—was 35.6*103, 4.9*103, and 2.2*103 tons, while the average sediment concentration was 1.73, 1.65, and 2.73 kg/m3. They also observed that these valleys contributed significantly to the reservoir's sediment load. In the valleys, the average yearly rate of erosion is 78.9, 62.4, and 43.9 tons/km2, respectively. The authors come to the conclusion that check dams must be built in strategic locations in order to hold runoff water, trap sediment loads, and then discharge the flow into the reservoir with the least amount of sediment.

Research Methodologies

This section details the methodologies employed to collect and analyze data. It starts with the collection of satellite imagery (e.g., from Landsat, Sentinel), topographical maps, and hydrological data. GIS software is used to overlay various layers of spatial data, such as elevation, rainfall patterns, land use, and proximity to water bodies. Multi-criteria decision analysis (MCDA) is applied to assess various factors that affect dam site suitability, including environmental sensitivity, socio-economic impact, and hydrological flow patterns. The methodology also involves ground-based data collection for validating the spatial data obtained from remote sensing.

Changes in land use pattern are found to be a major cause of differences in the rates of soil erosion and sedimentation. The amount of sediment load in the reservoir, which is mostly the result of soil erosion, is also influenced by the type of soil, rainfall, and land use pattern. It has been discovered that forest cover retains top soil, which reduces erosion. However, as forests are converted to agricultural and urban areas, erosion rates rise and sedimentation occurs in reservoirs and other bodies of water. Therefore, the goal of the current study is to examine how changes in land use affect the sedimentation of the Khoupum Reservoir.

The land use/cover map is created using a geographic information system and satellite remote sensing. GIS technology can be used to compare the locations of various features and their relationships with one another in satellite imagery, as well as to analyze and comprehend trends. The pattern of land use and cover has a major impact on soil erosion in a given location. The amount of silt in aquatic bodies increases as forests are cleared for construction, agriculture, and other purposes. Sedimentation rises as a result of various factors including bad agricultural practices, soil type, and increased rainfall in the studied area.

Results and Interpretation

The results of the study include detailed GIS maps that identify optimal locations for dam and reservoir construction in North-East India, with particular attention to Manipur. The results are discussed in terms of the environmental and socio-economic criteria applied in the analysis. Key findings show that certain regions exhibit high potential for water retention and minimal ecological disruption, making them ideal candidates for dam construction. Hydrological models also predict the long-term water retention capabilities of the selected sites, offering insights into their potential benefits for flood control and irrigation.

The forecast period runs from January 2011 to December 2025. Figure displays the expected annual sediment yield, while Figure displays the expected average sediment load.

Based on modeling, the total amount of sediments that reached the reservoir in 2025 was 16, 02,128 tonnes, as depicted in Figure.This suggests that in 2025, sedimentation may cause the loss of around 39.3 Mm3 of the capacity.2025 may see an average of 20.17% of the capacity filled by silt. Deforestation and intense rainfall are the main causes of the increase in sedimentation. One of the factors contributing to increased sedimentation is the river's strong flow.

Additionally, as might be predicted, the strength of the inflow is particularly high during monsoon seasons. Since nearly 39.3 Mm3 of the reservoir's capacity may be lost to sedimentation in 2025 if appropriate conservation measures are not taken, management practices, awareness campaigns, and conservation measures can also be implemented to reduce further siltation in the reservoir.

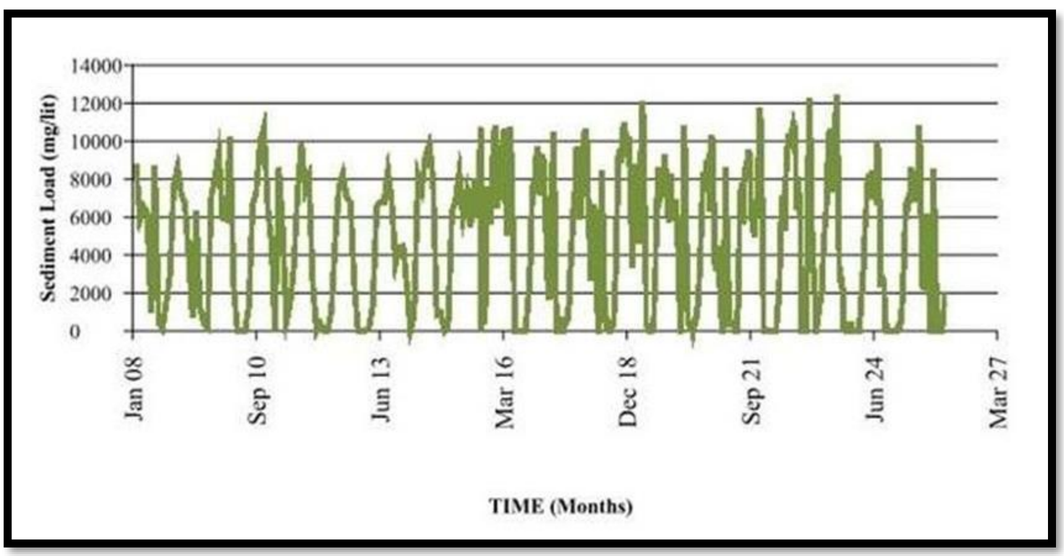

FIGURE: PREDICTED SEDIMENT LOAD OF KHOUPUM RESERVOIR

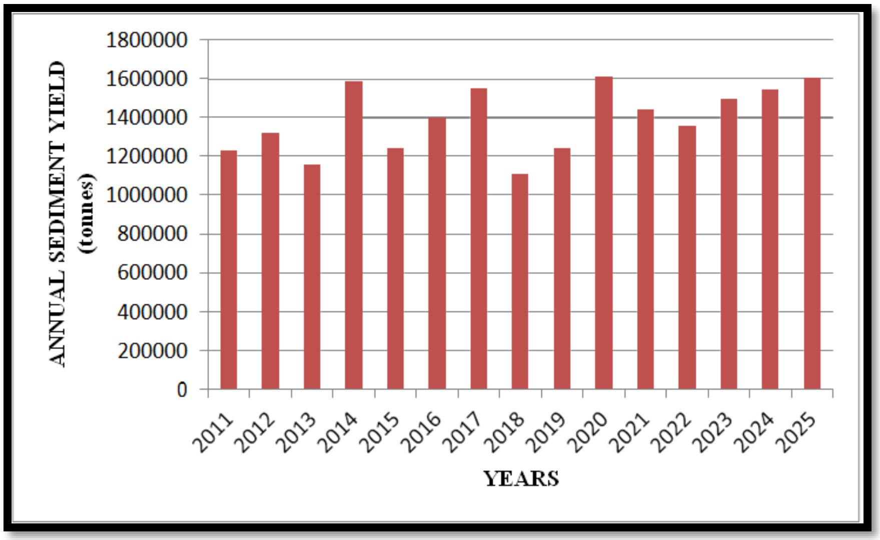

FIGURE: PREDICTED YEARLY SEDIMENT YIELD

Discussion and Conclusion

The discussion section delves into the broader implications of the findings, emphasizing how the integration of RS and GIS can significantly improve the decision-making process for water resource management. It discusses the scalability of the methodology and its application in other regions with similar environmental challenges. The conclusion highlights the advantages of using these technologies for long-term sustainable development, suggesting that they offer a more nuanced and precise approach to site identification compared to traditional methods. Recommendations for future research include incorporating climate change models and enhancing community involvement in the planning process.

In conclusion, the advanced integration of remote sensing and GIS represents a powerful approach to enhancing water resource management, particularly in regions with complex terrains like North-East India. By leveraging satellite imagery and spatial data analysis, these technologies provide valuable insights into the suitability of potential dam and reservoir sites. This approach not only improves the efficiency of site selection but also helps in addressing environmental and hydrological challenges. As the field of remote sensing and GIS continues to evolve, it is expected to play an increasingly important role in the sustainable management of water resources and the development of infrastructure projects in North-East India and beyond.

Since water shortage is getting worse every day, finding a suitable dam site while taking socioeconomic and biophysical issues into account is still a challenge that needs to be researched. This research can be expanded in the ways listed below:

Water shortage occurs when the River's water flow decreases during a lean period. Therefore, improving water flow in the River or its tributaries during a dry spell may be a potential subject of future study for this field.

When evaluating the population that would use the stored water, the suggested water reservoir site's capability for water storage comes into play. Future research in this area may focus on estimating the proposed site's capacity for storing water.

A variety of factors determine whether joining the suggested locations together is appropriate. Future work on this project may include a proper examination of these aspects to identify and incorporate significant factors in the interlinking purpose of the reservoir site.

A lot of landslides happen in steep areas. Therefore, a future objective for this work could be a more thorough investigation of the soil type at the suggested site as a landslide prevention method.

Future directions for this research may include looking at more socioeconomic factors to minimize the environmental and social impact at the suggested location while providing the most possible benefits to society.

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