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Investigating the Potential of Remote Sensing for Sustainable Urban Renewal and Regeneration: A Review

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Abstract

Today, urban design is a major issue in terms of sustainability. Urban renewal and generation are crucial for maintaining a sustainable environment for future generations. Remote sensing (RS) has become a valuable tool for managing urban areas, as well as powerful tool for urban development. With continuous advancements in technology and analysis techniques, its impact is likely to grow even further in real-estate industry. This review explores the use of remote sensing in urban renewal and regeneration. The study emphasises research activities in urban planning, land use mapping, and environmental monitoring utilising remote sensing methods. The study found that remote sensing can help decision-makers and stakeholders create long-term strategies that consider environmental, social, and economic factors for sustainable development.

Keywords: Remote Sensing, Sustainable Development, Urban Renewal, Environmental Monitoring.

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Introduction

Today designing cities and creating a new environment is critical in engineering. As various programs and models are emerged to customize the project impacts, made the decision of the planning, initiating stages are very critical to stakeholders and decision makers. Field survey is the most common approach in the planning process **[1]** to collect detailed information about a site but it can be time-consuming and expensive, in the case of existing of external consultants in the project. As the technology progressed further, many additional aspects were taking into account to project the profitability of the project as well as protect the environment from severe negative impacts. These days, remote sensing is crucial for managing natural resources and keeping an eye on the environment **[2]**. This helps decision-makers reach wise options and ensure long-term economic prosperity. Remote sensing provides valuable insights into the spatial and temporal dynamics of urban areas, leading to make remote sensing playing a crucial role in urban renewal and regeneration **[3]**. Some of the valuable insights are mapping and monitoring urban lab use and cover, assessing urban infrastructure and amenities, monitoring urban environmental quality, and identifying and prioritizing urban renewal projects **[4]**. Using remote sensing, investors, stakeholders, and environmental organizations can interact with provided information and decision makers by applying higher standards that meet the global aims and expectations and raise economic prosperity **[5]**. The concept of urban renewal emerged in 1949 and originated at United States of America (USA) **[6]**. The aim of the housing act is to restructure and reuse the inner city into slums, as well as develop its infrastructure. In England, urban renewal refers to upgrading the housing status in poor urban cities **[7]**. Singapore considers as a leader in urban renewal and regeneration. Singapore builds urban redevelopment authority (URA) to be the main responsible for transforming Singapore's skyline and creating sustainable cities **[8]**. URA designs notable projects in Singapore that include the Marina Bay Sands resort, the Gardens by the Bay, and the Singapore Sports Hub. Moreover, South Korea made a significant progress in urban renewable through building new community development corporation (NCDC), which established new sustainable communities. Accordingly, countries' regulations are constantly changing at all levels of government from local to federal laws **[9]**. The regulations established to smooth the urban renewal to be compatible with the surrounding neighborhood and not displace residents or businesses. One of these laws is preserving the historic laws to protect the buildings and sites that have historical or cultural significance **[10]**. Moreover, environmental impact assessments nowadays are required for major projects to lessen the project's impacts on the environment. Remote sensing plays an affordable role in urban renewal through identifying areas in need of redevelopment, monitoring the progress of redevelopment projects, assessing the environmental impacts of redevelopment projects, planning for future development **[11-12]**. In Baltimore (Maryland), remote sensing was used to identify and find the vacant areas that need to refine and urbanize, leading to revitalizing many of its neighborhoods **[13]**. While in Michigan (USA), remote sensing was used to track the progress of the city's blight removal program to figure out the effectiveness of the stated program and track the additional areas where additional work is needed **[14]**. In China, remote sensing is being utilized to project the further development of the current state **[15]**. China promotes smart growth of the cities and avoids urban sprawl. On this basis, the research aims to figure out the latest endeavors of the countries to build sustainable cities through utilizing the remote sensing for urban renewal and regeneration. In addition, the research aims to discuss the approach of the governments in aligning their regulation to spread out the definition of urban renewal.

Background

Today remote sensing plays a crucial role in decision-making. Policymakers and stakeholders are now taking environmental, economic and social aspects in implementation new urban areas around the world **[16]**. Therefore, the current research discusses the application of remote sensing on urban infrastructure from planning to implementation considering different aspects.

Urban Planning and Decision-making

A solid understanding of remote sensing in urban planning is essential today for all people that involved in the decision-making process. Urban Sprawl is unprecedented pace and cleaning out rural landscapes. This phenomenon offers several challenges for sustainability, infrastructure, and social equity. Therefore, several tools were emerged to manage this dynamic process and present proper solution in the urban planning stage. Steurera and Bayr in 2020 **[17]** use land use data derived from remote sensing to measure urban sprawl in three keyways, identifying urban land use change by utilizing satellite imagery or other remotely sensed data to map the extent and distribution of different land-use types like built-up areas, vegetation, water bodies, and agricultural land. The emerged comparison across different periods, urban sprawl progression can be monitored. Also, Steurera and Bayr stated that using

remote sensing can monitor area changes as an indicator of urban growth through metrics, namely patch size, connectivity, and fragmentation, in order to measure the compactness of the urban area. Urban Sprawl indicators are key features derived from the land-use data to take the environmental, social, and economic into considerations **[18-21]**. Gielen et al. **[22]** proposed a new pathway to figure out the urban sprawl throughout the population density. Gielen et al. consider the structure of urban development, the land mix and connectivity of the street network to point out the population density in Valencia, Spain. The results are highly information for the decision makers as well as the stakeholders in the planning process. Ortiz et al. **[23]** explore that potential of deforestation contributions to urban renewal and regeneration. They found that using remote sensing and geospatial analysis to manage the deforestation pattern within Delhi, India. Using remote sensing, Ortiz et al. reveal the remote sensing in monitoring deforestation trends and informing urban planning and regeneration strategies. Also, Rousta et al. **[24]** utilized high-resolution satellite imagery to map deforestation in Atlanta, Georgia. The authors in **[24]** found that remote sensing to detect deforestation helps the decision-makers as well as planners to mitigate the deforestation and improve urban climate resilience. While Wei et al. **[25]** emerge a new monitoring approach using remote sensing by tracking Haidian District of Beijing transformations to identify the status of infrastructure in the area. Wei et al. found dramatic alterations in the landscape of these urban villages and the emergence of new structures or infrastructure.

Urban Infrastructure Assessment

Ampofo in 2022 **[26]**, assesses the vulnerability of urban infrastructure to various threats using remote sensing. Ampofo mentioned the power of collecting data to monitor the changes in urban areas, make environmental risk assessments using satellite images. Also, the author highlighted the capability of remote sensing to manage the watershed sustainability through mapping of watersheds and their hydrologic features to characterize the soil erosion areas during the infrastructure assessment. Butenuth et al. **[27]** highlighted the importance of using remote sensing as an alternative approach of traditional infrastructure assessment methods for disaster management. The remote sensing improved the accurancy of the assesssment based on real evidence by using multi-sensor, multi-temporal alongside with geographic information system (GIS). While Schnebele et al. **[28]** provide a comprehensive overview of various remote sensing techniques used for evaluating pavement conditions and informing maintenance decisions. The authors in **[28]** stated



Fig. 1: Utilization of Remote Sensing for Pavement Testing in USA [28]

Several remote sensing techniques such as satellite, airplane, unmanned aerial vehicle and vehicle, as shown in **Figure 1**.

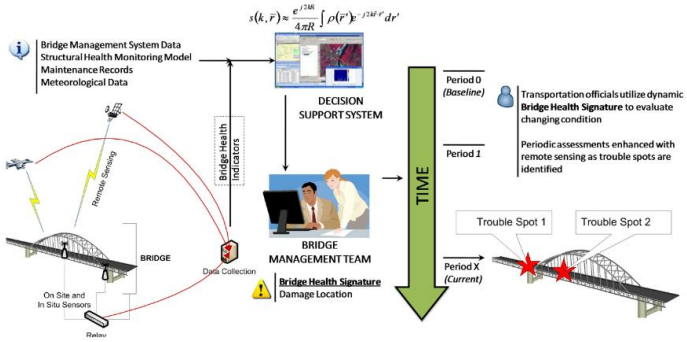


Fig. 2: Shows the Whole Systematic Procedures for Bridge Assessment using Remote Sensing Techniques [29]

Another study performed at Michigan Technological University in in cooperation with Center for Automotive Research Michigan Department of Transportation **[29]**, investigated the condition of bridges in order to improve bridge inspection and maintenance procedures. The researchers in **[29]** utilized three distinctive remote sensing techniques, including LiDar to provide high resolution 3D of bridge structures, Infrared imaging for identifying variation in temperature to provide internal damage or moisture infiltration, and ground penetrating radar which detects subsurface defects (**Figure 2**).

Urban Land Use and Land Cover Mapping

Monitoring the land use and land cover (LULC) makes a comprehensive baseline assessment for urban renewal by providing historical data of land changes during the time. In this area, Dewan and Yamaguchi **[30]** emerged the imaginary data sensed from 1960 to 2005 in Bangladesh. As shown from spatial patterns in **Figure 3**, Dewan and Yamaguchi point out the expansion of urban areas on account of decreasing the green areas in Bangldesh. Dewan and Yamaguchi highlighted the importance of monitoring the LULC to detect unsustainable changes. On this basis, Kabeja et al. **[31]** declared that understanding the changes of LULC is essential for future urban planning during the rainstorms, waterflooding in Beijing, China. Therefore, Kabeja et al. found that the major changes in LULC were detected in certain areas during the rainstorms and waterflooding events, which their findings improve the preparedness of the city to face the natural disasters.

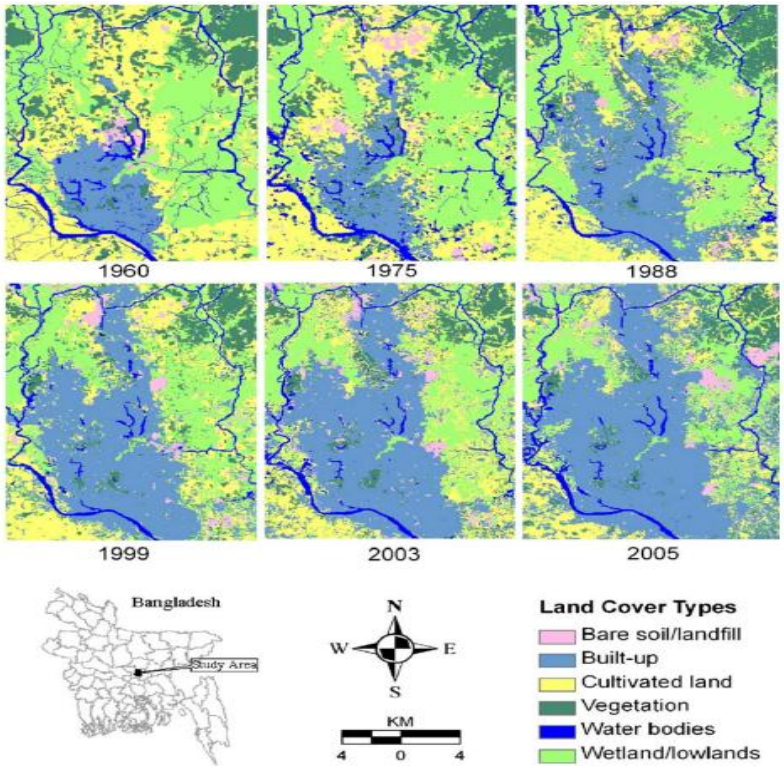


Fig. 3: Illustration of Land Cover Classification Remote Sensing Images from 1960 to 2005 in Bangladesh [30]

Monitoring land use/cover can be a sufficient tool to build a powerful database to measure the built-up areas as well as urban fragmentation **[32]**. These observations are a valuable tool to authorities, decision-makers and stakeholders to apply the best practices of sustainable development adaptable to the current changes **[33,34]**. While Prokop **[35]** used high resolution remote sensing images to detect LULC degradation over 50 years by the human activities that emerge anthropogenic pressure on the land. Building upon this, LULC changes is a helpful tool in supporting planning decisions across various sectors. Tewabe and Fentahun **[36]** confirm the needed proper control on land practices as well as active participation of inhabitants to oversight the LULC. The study area in **[36]** was lake tana, Ethiopia, which as revealed in **Figure 4,** the emerged LC from forest or grassland to build residential regions and expand the agriculture areas has a significant impact on water management as well as soil degradation. Therefore, building a strong database and monitoring these changes are critical to the authorities to suppot the right decision in different sector.

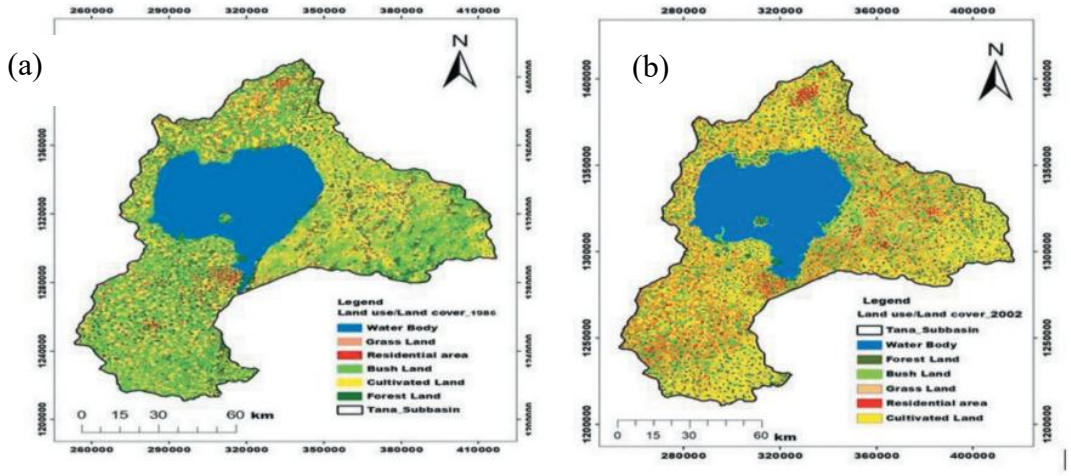


Fig. 4: Land Cover in Tana Lake, Ethiopia (a) 1986, (b) 2002 [36]

Urban Environmental Monitoring

Variations in the growth and content of urban vegetation serve as indicators of the city's environmental conditions. Consequently, the degree to which vetegation is prevalent or absent indicates the state of the environment in urban areas. Nguyen et al. **[37]** proposed a new tool in Phuket, Thailand using remote sensing spatial information and machine learning algorithms to provide a valuable index in land use dynamics. The authors found 155 suspicious projects in protection areas, leading to increasing 1.61 χ 10^6 tCO_2 of greenhouse gas emissions to the atmosphere. That makes additional environmental costs about 9.2 million USD (**Figure 5**).

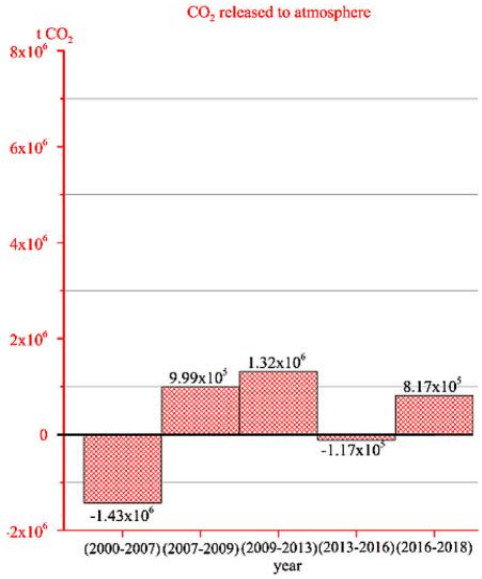


Fig. 5: Shows the Amount of CO2 Emission Occurred in Phuket [37]

In addition, an integration methodology to watch the ecological effects of open-pit mining through remote sensing technologies and a novel index called the moving window-based remote sensing ecological index (MW-RSEI), as shown in **Figure 6 [38]**. The proposed index effectively identified areas with reduced vegetation cover, increased land surface temperature, and altered soil moisture. The findings in **[38]** are valuable to study the spatial and temporal dynamics of the ecological impacts compared to traditional RSEI calculations to study the impacts of open-pit mining, which has catastrophic environmental impacts. Through the tool, the results show the prevalence of ecological degradation in urban areas. Moreover, the greenness and dryness indices were dramatically impacted, which may affect the vegetation density in the study area.

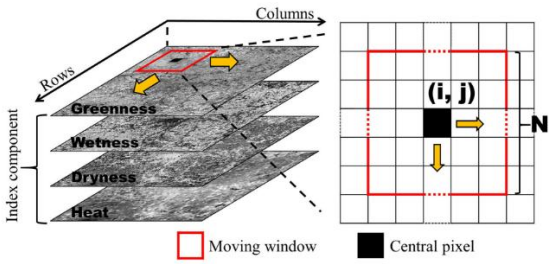


Fig. 6: Shows the Principle of Moving Window Approach based Remote Sensing Ecological Index (MW-RSEI) [38]

Several authors discuss significant numbers of environmental indexes to assess the environmental conditions, as depicted in **Table 1**. These indexes are highly valuable to decision makers to evaluate the urban areas using remote sensing techniques.

Table 1: Summary of Environmental Indexes Using Remote Sensing Techniques

Environmental index	Measure	Remote Sensing tool	Ref.
NDVI	Green vegetation	Reflectance in blue, red, and near-infrared bands	**[39]**
EVI	Dense vegetation areas	Reflectance in blue, red, and near-infrared bands	**[40]**
LST	Temperature of Earth's surface	Thermal infrared data	**[41]**
SMI	Soil moisture content	Reflectance in microwave and optical bands	**[42]**
WQIS	Water quality	Reflectance in visible and near-infrared bands	**[43]**
BAI	Areas affected by wildfires	Reflectance in shortwave infrared bands	**[44]**
UHII	Temperature difference between urban and rural areas	Thermal infrared data	**[45]**
AQI	Air pollution levels	Aerosol optical depth (AOD) from satellite data	**[46]**
NDWI	Presence of liquid water	Reflectance in green and near-infrared bands	**[47]**
LSE	Thermal radiation emitted by the Earth's surface	Thermal infrared data	**[48]**
NDBI	Identifies and quantifies urban areas	Reflectance in near infrared and mid-infrared bands	**[49]**
NDVI-RE	Vegetation stress and chlorophyll content	Reflectance in red, near-infrared, and red-edge bands	**[50]**
LAI	Total leaf area per unit ground area	Reflectance in different spectral bands, often combined with land cover information	**[51]**
NDSI	Snow cover	Reflectance in green and near-infrared bands	**[52]**
NDBSI	Detects areas of bare soil	Reflectance in near infrared and red bands	**[53]**
LSWI	Total water content in the land surface	Reflectance in shortwave infrared and thermal infrared bands	**[54]**
FCD	Density of vegetation cover in forests	Reflectance in green, red, and near-infrared bands, often combined with LiDAR data	**[55]**
MAI	Mangrove forests	Reflectance in green, red, and near-infrared bands, often combined with texture analysis	**[56]**
ABI	Detects and quantifies the presence of harmful algal blooms in water bodies.	Reflectance in visible and near-infrared bands, often combined with fluorescence data.	**[57]**
CMI	Identifies and masks out clouds in satellite imagery to improve the accuracy of surface feature analysis.	Reflectance in visible, near infrared, and thermal infrared bands.	**[58]**
GVMI	vegetation water content and drought conditions on a global scale.	Reflectance in shortwave infrared bands.	**[59]**
CRHI	the health and condition of coral reefs using a combination of remote sensing and field data	Reflectance in visible and near-infrared bands, often combined with hyperspectral data.	**[60]**

Social and Economic Analysis

In the modern world, a great deal of attention is being devoted to the patterns in all activities, from planning to resource utilization, which generates value and benefits for people, to evaluating the social and economic behavior

of certain urban regions. Remote sensing is considered as an innovative to assess the land use/cover to figure out the social and economic patterns of urban areas. Xie et al. **[61]** make a model to map the povery and sustainable development efforts. The model achieves high accuracy comparable to household surveys, also identifies complex features like roads, urban areas, and various terrains. While in 2019, Watmougha et al. **[62]** integrate the remote sensing technology with socioeconomic indicators to assess poverty in rural areas. Watmougha and coworkers emphasized that factors such as household income, education, and access to resources, can offer insights into poverty levels. The research affirms that the accuracy of remote sensing to predict the poverty reached 62% in Kenya, through monitoring how spaces utilized by human population and formulize a relationship between the household wealth and remote sensing features.

Limitations and Challenges

Limitation of sensor resolution utilized in remote sensing may diminish its ability to differentiate fine details **[63]**, in addition, the impact of satellite revisit times and cloud cover could be prohibiting the ability of remote sensing to observe the rapid changing phenomena **[64]**. The wide range of wavelengths captured by sensors limiting the ability to detect certain features **[65]**. Moreover, clouds, aerosols, and atmospheric conditions can scatter electromagnetic radiation, affecting data quality and availability **[66]**. The huge quantity of remote sensing data poses challenges in storage, transmission, and processing, which, in turn, requires significant computational resources. correction for accurate analysis is needed due to imagery can exhibit geometric distortions due to sensor orientation, Earth curvature, and terrain variations, as well as calibration and correction because of variations in atmospheric conditions and sensor calibration can affect image brightness and spectral information. While extracting meaningful information from imagery requires specialized expertise and techniques, often involving complex algorithms and knowledge of spectral signatures, access to specialized software for image processing and analysis can be limited, hindering research and application development. The data interpretation challenges summarized by subjectiveness of images, and accordingly, interpretation influenced by analyst experience, expertise, and biases **[67-69]**. Different analysts may draw different conclusions from the same data. Accurate interpretation often requires additional knowledge about the study area, such as land cover types, vegetation patterns, or geological features. Despite these limitations, remote sensing remains a powerful tool for gathering information about Earth's surface and environment **[70]**. The recent technological advancements and development of new techniques are continuously addressing these challenges and expanding the capabilities of remote sensing.

Future Research and Development

There is recent development in remote sensing technologies to enhance the monitoring of urban dynamics using high-resolution satellite and drone imagery, LiDAR technology to enhance the analyzing 3D structures of buildings and infrastructure, identifying areas in need of repair or renovation, and Real-time sensor networks through Monitoring air quality, noise levels, and traffic patterns for improved urban planning and resource management. Also, remote sensing can integrate in social and economic evaluation through analysis of social media data and mobile phone records to understand population movement, demographics, and socioeconomic patterns **[71]**. Remote sensing has the potential to monitor climate vulnerability and resilience by mapping floodplains, heat islands, and other risks to inform city planning and adaptation strategies **[72-74]**. Meanwhile, remote sensing can support sustainable development strategies in green infrastructure management, energy use optimization and waste management by tracking waste collection routes and identifying illegal dumping sites to improve waste management systems **[75]**.

Conclusion

The study emphasizes the need of using remote sensing as a long-term approach for monitoring components that might affect urban regeneration. The analysis showed how social and economic factors influence urban design considerations. The real-estate industry is turning towards sustainable development, making remote sensing a valuable tool for decision-making. However, there are limitations and expertise required for using it properly.

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