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Monitoring Residential Land Use Changes with Multi-Resolution Satellite Imagery: A Case Study from Vietnam

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Abstract: ***This article presents a novel method for detecting residential land use changes by integrating medium-resolution historical satellite images with recent high-resolution imagery. The core of the technique involves generating a residential area mask from the latest high-resolution data, which guides focused analysis on previous imagery. This method enhances classification accuracy and significantly reduces processing time compared to conventional approaches. Applying this technique to Hoai Duc District in Vietnam, the study reveals substantial urban expansion between 2005 and 2022. The proposed approach offers a cost-effective and practical solution for urban development monitoring, supporting improved planning and sustainable growth management.***

Keywords: urban expansion, land use monitoring, residential classification, remote sensing, Hoai Duc district, Vietnam

1. Introduction

The rapid pace of urbanization and infrastructure development in major cities has led to significant changes in land use, particularly in residential areas. These changes pose challenges for urban planning, environmental protection, and sustainable development, requiring timely and effective monitoring solutions to ensure optimal living conditions and ecological balance [1].

Residential zones, although occupying a relatively small portion of the Earth's surface, are highly dynamic and subject to frequent transformation. The conversion of natural landscapes—such as forests and agricultural land—into urban settlements can result in environmental degradation, including reduced air and water quality [2].

Accurate monitoring of land use changes in residential areas is essential for evaluating population capacity, guiding urban expansion, and supporting spatial planning. Traditional classification methods often struggle with limitations in resolution and temporal coverage, especially when relying on single-source satellite imagery.

To address these limitations, this study proposes a novel technique that integrates medium-resolution satellite imagery from earlier years with recent high-resolution imagery. The method utilizes an object-oriented classification approach and introduces a "residential area mask" derived from the latest high-resolution image. This mask is then applied to older imagery to focus the classification process on relevant areas, improving both accuracy and computational efficiency. The proposed technique offers a promising solution for detecting and analyzing residential land use changes over time. This study aims to develop and validate an improved classification method for monitoring residential land use changes over time using multi-resolution satellite imagery.

Understanding residential land use dynamics is crucial for sustainable urban planning, especially in rapidly developing regions. By improving classification accuracy and reducing data processing requirements, this method contributes to more efficient monitoring of urban growth and land use policy implementation.

2. Study Area and Data used

2.1 Study Area

The experimental area selected for this study is Hoa Duc District, situated in the western part of Hanoi, Vietnam. With a total area of 84.93 square kilometers, the district is strategically located near the capital's urban core, making it a key zone for suburban expansion and infrastructure development. Over the past two decades, Hoa Duc has undergone significant transformation, driven by rapid urbanization and increasing demand for residential and commercial space. Economically, the district is characterized by a diverse structure. Commerce and services contribute approximately 46% to the district's Gross Domestic Product (GDP), reflecting the growing presence of retail centers, logistics hubs, and service-oriented businesses. Meanwhile, agriculture still plays a role, accounting for 7.5% of the GDP, and remains vital for local livelihoods and food supply.

Hoai Duc hosts a mix of land use types, including industrial zones, high-rise residential complexes, small-scale settlements, and shopping centers that are either operational or under construction. These developments are concentrated along major transportation corridors and newly established urban clusters, indicating a shift toward more intensive land use.

Despite the urban growth, agricultural land continues to occupy a substantial portion of the district. This land supports the cultivation of rice, vegetables, fruits, and flowers, as well as the raising of poultry and freshwater fish, contributing to both local consumption and regional markets. The coexistence of urban and rural landscapes makes Hoa Duc an ideal case study for analyzing land use changes, especially in residential zones where transitions from agricultural to built-up land are most evident [3].

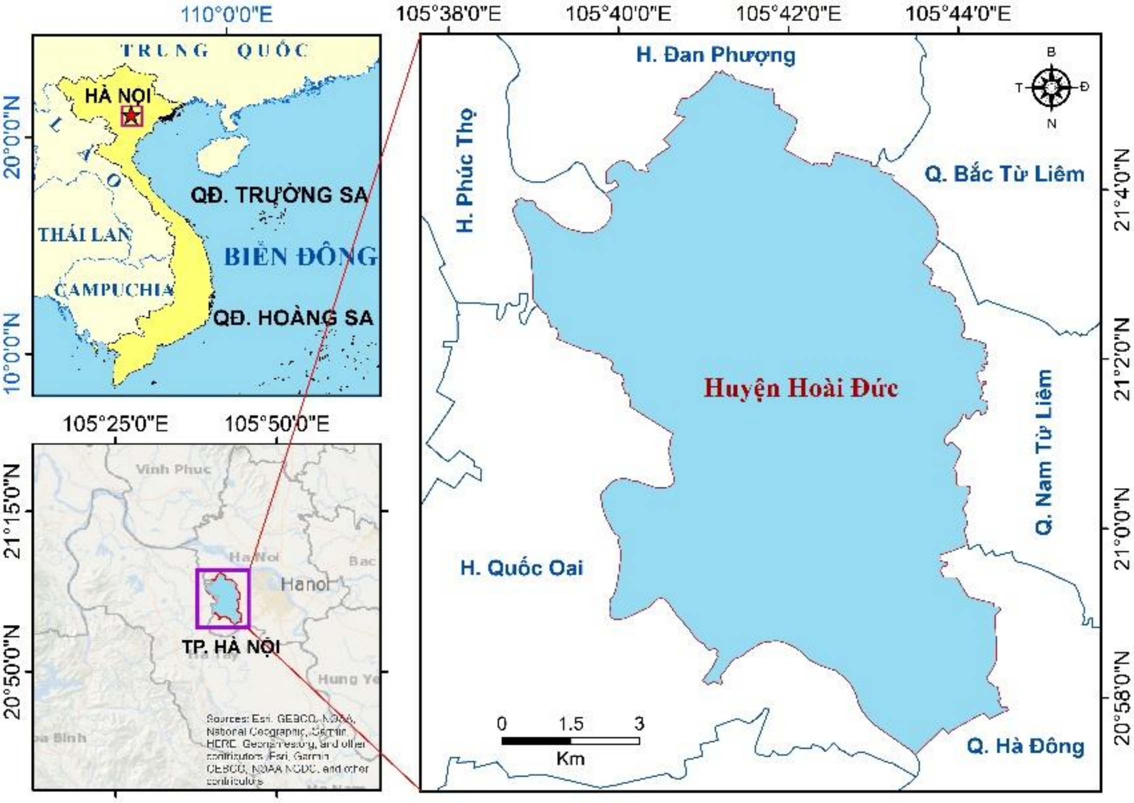

Figure 1: Study area

2.2 Data used

This study utilizes a combination of satellite imagery and geospatial datasets from multiple sources and time periods to support the analysis of land use changes in residential areas. The primary dataset is the Landsat 7 satellite imagery from the year 2005, which provides medium-resolution data suitable for long-term land cover monitoring. This imagery was obtained from the United States Geological Survey (USGS), a reliable source of historical Earth observation data.

To complement the medium-resolution data, high-resolution satellite imagery from 2022 was acquired using platforms such as Google Earth Pro and SAS. Planet. These images offer detailed visual information, allowing for precise identification of residential structures and boundaries. The high-resolution data is particularly valuable for generating the "residential area mask," which serves as a reference for analyzing older imagery.

In addition to raster imagery, vector data in the form of administrative boundary shapefiles was collected from DIVA-GIS. These shapefiles define the spatial extent of the study area and facilitate accurate georeferencing and alignment of satellite images. The integration of vector and raster data ensures consistency in spatial analysis and supports the overlay of classification results with official geographic boundaries.

All datasets underwent preprocessing steps, including geometric correction, atmospheric correction, and image enhancement, to improve visual clarity and analytical accuracy. The preprocessing also ensured that all images were projected into a common coordinate system, enabling seamless comparison across different years and resolutions.

The combination of multi-source and multi-temporal data provides a robust foundation for detecting and quantifying changes in residential land use. Table 1 summarizes the datasets used in this study, including their formats, acquisition years, and sources.

Table 1: List of Collected Data Sources

Data Type	Format	Year	Source
Landsat 7 Satellite Imagery	Raster	2005	United States Geological Survey (USGS)
Administrative Boundaries	Shapefile	2022	DIVA-GIS
High-Resolution Satellite Imagery	Raster	2022	Google Earth Pro / SAS.Planet

3. Methodology

The method proposed in this study is designed specifically for analyzing residential areas, which are known to expand steadily over time. According to previous research [2], areas that have already been developed tend to show a clear shift in land use—from natural or agricultural land toward urban land types.

Building on these findings and observations from our own study, we developed a new approach called the "Residential Area Mask". This technique allows us to process satellite images from different years and resolutions—both medium and high—together in a unified way. The key idea is to use the most recent high-resolution image to identify and outline residential zones, then apply that outline (or "mask") to older images to focus the analysis only on those areas. This process is illustrated in Figure 3.

The following software tools were employed during the research process:

- SAS.Planet: for downloading high-resolution satellite imagery from Google Earth Pro;
- ArcGIS 10.7: for data analysis and visualization;
- eCognition 10: for object-oriented image classification.

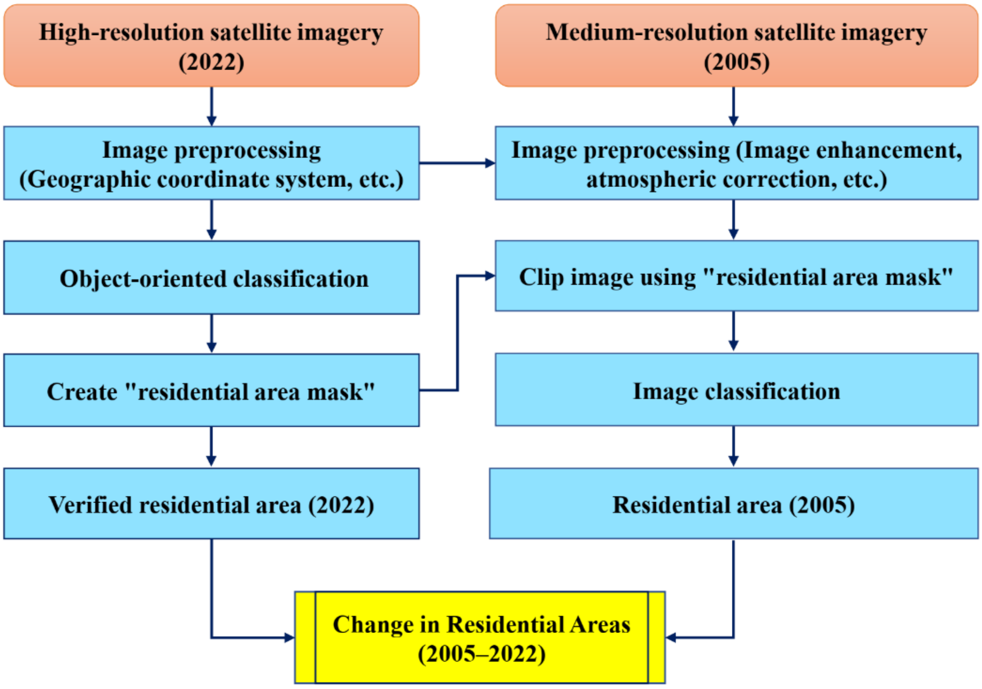

Figure 1: Experimental Workflow of the "Residential Area Mask" Method

The core idea of the proposed method is straightforward: we use freely available satellite images from the internet, including both medium-resolution (such as Landsat and Sentinel) and high-resolution imagery (such as those from Google Earth). The high-resolution image from the most recent year—2022 in this case—is first processed to identify residential areas. This step involves thematic classification, and the result is a "residential area mask", which outlines the zones where people live.

Next, we take older medium-resolution images, such as those from 2005, and apply preprocessing techniques to improve their quality, reduce noise, and ensure they are aligned with the high-resolution image using the same coordinate system. Once aligned, we use the residential area mask to clip the older image, focusing only on the parts that correspond to residential zones.

Because residential areas generally expand outward from established cores, using the 2022 mask over the 2005 image allows for focused historical analysis. This allows us to classify only the clipped portion of the image, rather than the entire scene. This targeted approach reduces the amount of data to process and improves classification accuracy.

For the classification step, we use an object-oriented method, which has proven to be highly effective in previous studies [4,5]. This method analyzes image segments as meaningful objects rather than individual pixels, making it well-suited for detecting changes in complex urban environments.

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Figure 2: Original High-Resolution Image (2022)

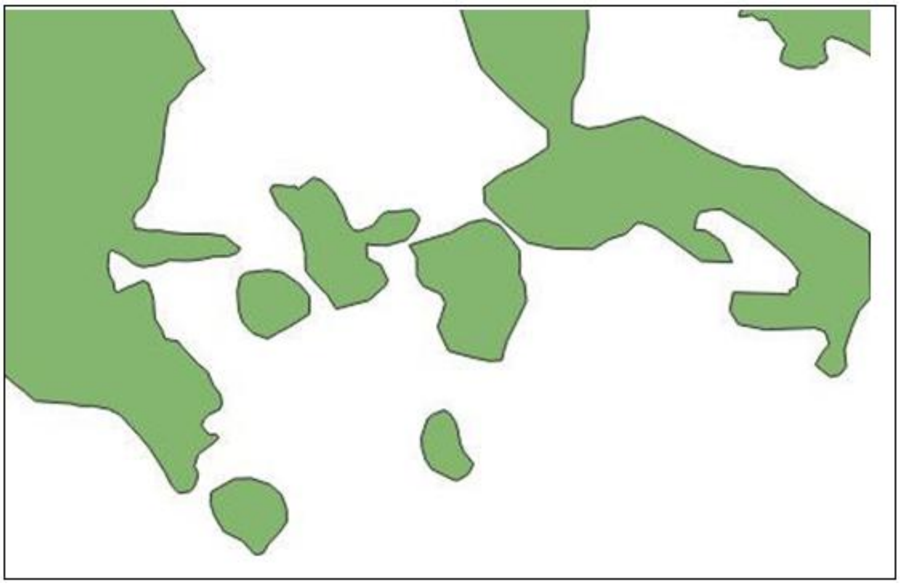

Figure 3: Residential Area Mask

4. Results and Discussion

To assess the effectiveness of the proposed technique, we compared classification results from the original imagery with those from the clipped subset. The object-oriented classification process consists of two main steps: segmentation and classification.

Figures 4 and 5 illustrate the segmentation results of the analyzed images, representing the initial step in object-oriented classification. The left side shows the original image, while the right side displays the clipped image. It is evident that certain objects are inaccurately segmented—for instance, objects 1 and 2 in Figure 4. In contrast, the classification results of the clipped image reveal improved segmentation accuracy. Reducing the image size enhances segmentation precision; however, the resulting objects tend to be smaller, which may complicate the use of certain spatial features during the subsequent classification stage.

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Some objects, such as objects 3 and 4 (Figure 4), which may be easily mistaken for vacant land (although they are not buildings in reality), are also excluded when applying the proposed method.

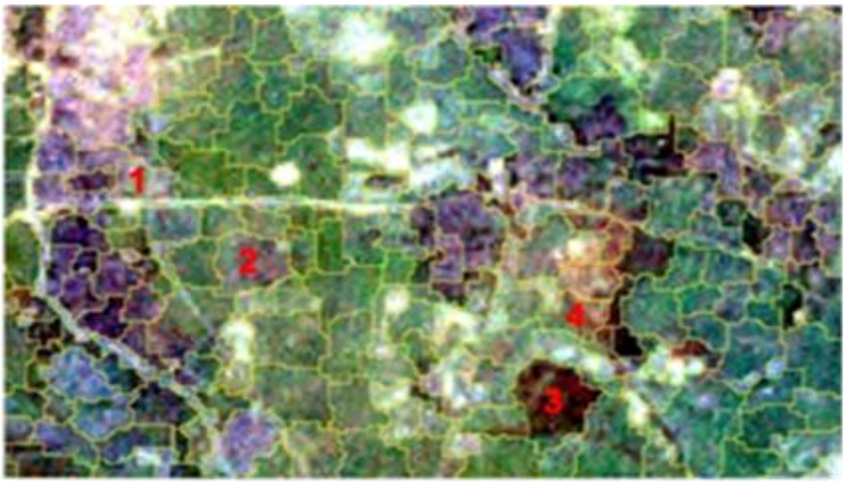

Figure 4: Segmentation Result of Landsat Image (2005)

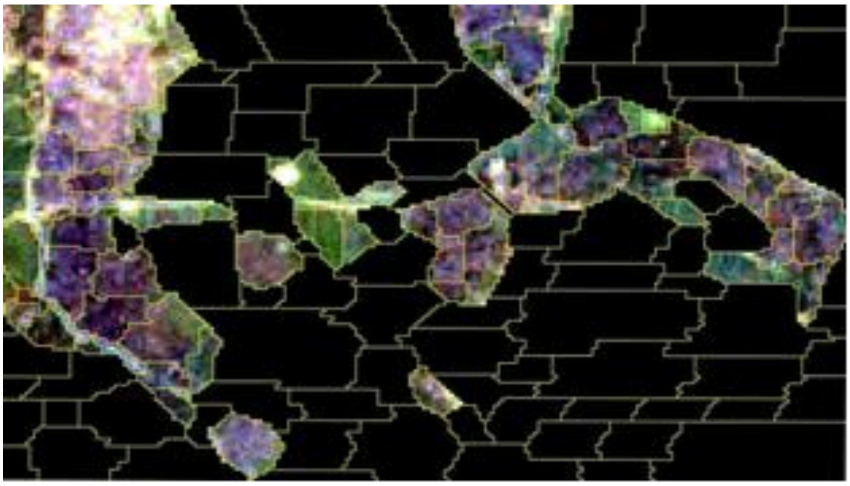

Figure 5: Segmentation Result of Clipped Landsat Image (2005)

The classification results of satellite imagery, along with the observed changes in residential areas between 2005 and 2022, are presented in Figures 6 to 8. These figures visually demonstrate how urban development has progressed over time, highlighting the expansion of residential zones within the study area. To better understand the scale of this transformation, we conducted a quantitative analysis based on the classified imagery. In 2005, the total area identified as residential was approximately 23,042,161 square meters, which accounted for 27% of the entire study region. By 2022, this figure had increased significantly to 34,663,876 square meters, representing 43% of the total area. This marks a substantial growth in residential land use—an increase of over 11.6 million square meters in just 17 years.

This expansion reflects the rapid pace of urbanization in Hoa Duc District, driven by population growth, infrastructure development, and changes in land use policy. The increase in residential area not only indicates a shift from agricultural or undeveloped land to built-up zones but also suggests growing demand for housing and urban services.

The results confirm that the proposed method is effective in detecting and quantifying such changes. By focusing the classification process on residential zones using the "residential area mask," the technique provides more accurate and targeted insights into urban growth patterns. These findings are valuable for urban planners, environmental analysts, and policymakers who need reliable data to guide sustainable development strategies.

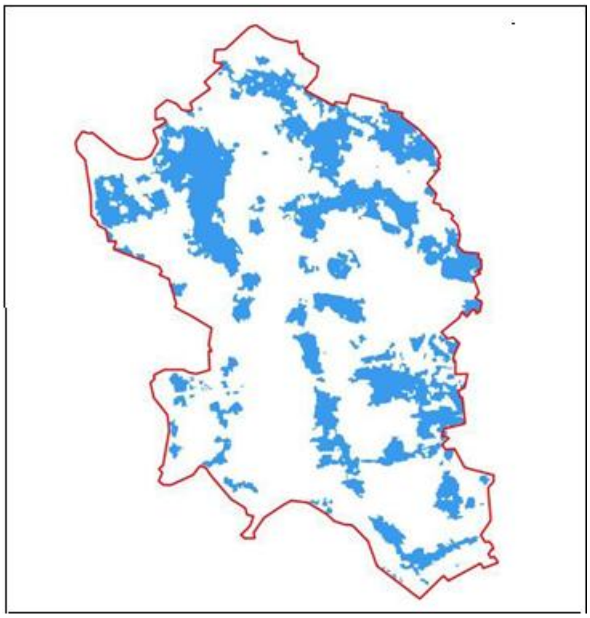

Figure 6: Residential Areas in 2005

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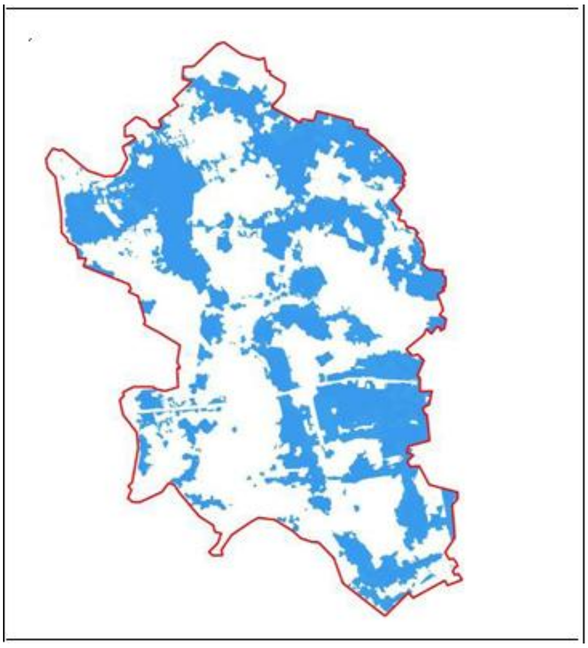

Figure 7: Residential Areas in 2022

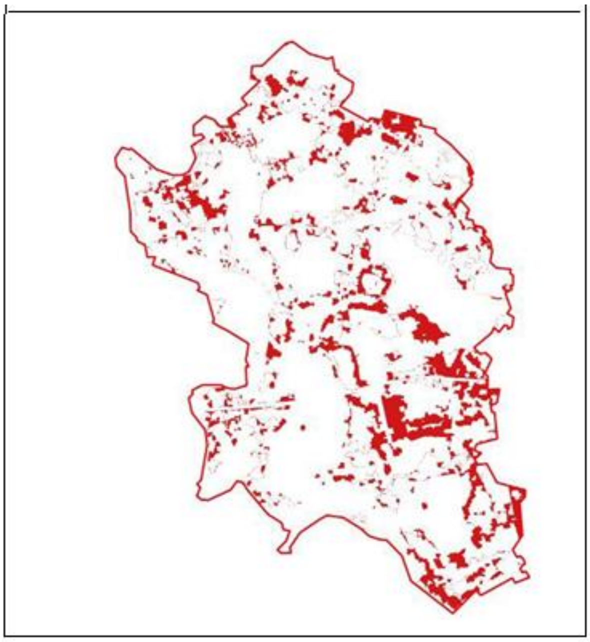

Figure 8: Changes in Residential Areas between 2005 and 2022

5. Conclusion

This study introduces a practical and efficient method for monitoring residential land use changes by combining multi-resolution satellite imagery. The use of a “residential area mask” significantly improves classification precision and reduces processing effort. Applied to Hoai Duc District, this approach reveals rapid urban expansion between 2005 and 2022. The method holds potential for broader application in other urban regions, providing planners and policymakers with a valuable tool for sustainable development management.

The results show a clear expansion of residential areas in the study region, confirming the method’s effectiveness. Moreover, this approach may be adapted for monitoring other dynamic land cover categories, providing a practical tool for urban planning and environmental oversight.

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