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Monitoring Urban Land Use Transformation in a Virtual Geo-Library

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Abstract As countries become increasingly urbanized, having a good grasp of how urban areas are changing the landscape becomes increasingly important. Urbanized areas are the places where interactions between humans and the environment are the most intense. Understanding how urban areas are developing through remotely sensed data allows for the development of more sustainable practices. The Landsat satellite sensor, a remote sensing platform, has the ability to analyze global data rapidly, and is thus an invaluable tool for studying the growth of urban areas. In this study, we present a virtual geo-library as a geovisualization tool to facilitate analytical studies of the urbanization process in Malang City, East Java, Indonesia, using images derived from the Landsat sensor family (1989-2014). We provide a dynamic geovisualization through the virtual geo-library where users can access and understand valuable scientific information (e.g., urban area changes and land use transformation in higher land). This system is also equipped with tools to enable users to create automatic cartographic maps that they can print out as digital pdf format files.

Key words: urbanization, GIS, virtual geo-library, land use transformation, Indonesia

1. Introduction

Earth observation can help to provide geospatial data. Preparing geospatial information is important for documenting the extent of the earth’s surface phenomena in a given region. It helps to investigate the distribution, types, pattern, recurrence and statistics of failures, to determine natural-hazard and human-disaster susceptibility, vulnerability and risk, to study the evolution of landscapes and human-environment interaction that will shape the future. Technologies for processing, storing, analyzing and visualizing geospatial data have advanced significantly in recent years, enabling the building of national and global spatial data infrastructures (SDI). These new developments can contribute to improving predictions for, and monitoring of, the environment. However, these technologies have not yet been fully exploited for urbanized environment management. The successful implementation of geospatial technologies requires a solid base of political support, laws and regulations, institutional responsibility, and trained people. Knowledge should be transferred from geoscience specialists and international bodies to professionals and decision makers with different technological backgrounds working

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on environmental management.

The purpose of this study was to increase the geo-literacy level of local people regarding their urban environment. Geo-literacy is a way of thinking spatially [1]; it is the ability to visualize and interpret locations, the relationship between locations, movement, distance, direction, and landscape changes through space, and earth surface phenomena; it is the ability to understand human-environment interaction, and finally, to shape thinking and create higher awareness of disaster. Such literacy is necessary for the Indonesian people. Here, we propose the concept of a virtual geo-library, which is a geospatial information system based on information infrastructure technology to study earth surface phenomena. The main differences between traditional cartography and geovisualization is that the former focuses on the design and use of maps to communicate known information, whereas the latter emphasizes the discovery of unknown information through the development of highly interactive maps and associated tools for data exploration and final construction of spatial knowledge.

The specific objectives of this study were:

1. To measure the urbanization process in Malang City, Indonesia
2. To understand and improve the process of land use transformation in Malang City
3. To create a new version of a virtual geo-library for better geovisualisation and geospatial data dissemination
4. To provide all stakeholders with the ability to produce innovative solutions for ongoing problems

2. Materials and Methods

2.1 Study Area

Malang city is located in East Java Province, Indonesia. Malang is the second largest city in the province, after Surabaya City. The city population according to the 2010 Census was 820,243 [2]. Malang has a total area of 252,136 km². Malang City is an enclave located within the Malang Regency (Figure 1).

Malang City has been marked by steady economic and population growth. Along with population growth, urbanized areas have been rapidly expanding. The government could not control the urbanization process, which has led to the building of shanty towns along the rivers and rail tracks, and recently in higher lands as well.

2.2 Data

The analysis of urban land use transformation in this study was derived from four satellite images: Landsat 4, Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI derived from http://glovis.usgs.gov/. There is no difference in pixel resolution between Landsat 8 OLI and the other sensors used in this study; we used only 30-m pixel resolution for consistency. The date of acquisition of every image is listed in Table 1.
2.3 Land cover extraction

The main software used for analysing the data was ENVI. We employed an SVM (support vector machine) algorithm to extract the urban land use information. SVM is well known in the field of machine learning and pattern recognition, and has been introduced in the context of remote sensing [3-6]. It is a classification system derived from statistical learning theory. It separates the classes with a decision surface that maximizes the margin between the classes. SVM provides good classification results from complex and noisy data.

There are four types of kernels available in an SVM classifier: linear, polynomial, radial basis function (RBF), and sigmoid. The default is the radial basis function kernel, which works well in most cases. The mathematical representation of each kernel is presented below:

![Image](https://example.com/image.png)

**Figure 1** Malang City is an enclave located within the Malang Regency

**Table 1** Date of acquisition of the satellite images used in this study

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat 4 TM</td>
<td>March 28, 1989</td>
</tr>
<tr>
<td>Landsat 5 TM</td>
<td>July 29, 1996</td>
</tr>
<tr>
<td>Landsat 7 ETM+</td>
<td>August 4, 2001 and August 5, 2007</td>
</tr>
<tr>
<td>Landsat 8 OLI</td>
<td>September 1, 2014</td>
</tr>
</tbody>
</table>

1Derived from http://glovis.usgs.gov/
Linear
\[ K(x_i, x_j) = x_i^T x_j \]

Polynomial
\[ K(x_i, x_j) = (g x_i^T x_j + r)^d, \quad g > 0 \]

RBF
\[ K(x_i, x_j) = \exp\left(-g \| x_i - x_j \|^2\right), \quad g > 0 \]

Sigmoid
\[ K(x_i, x_j) = \tanh(g x_i^T x_j + r) \]

where \( g \) is the gamma term in the kernel function for all kernel types except linear; \( d \) is the polynomial degree term in the kernel function for the polynomial kernel; \( r \) is the bias term in the kernel function for the polynomial and sigmoid kernels; and \( g, d, \) and \( r \) are user-controlled parameters, as their correct definition significantly increases the accuracy of the SVM solution.

To employ the SVM algorithm, we must first have ROIs (regions of interest) selected to use as training pixels for each class. The more pixels, the better the results. The knowledge-based [7] method is used to assign segmented ROIs. In this study, we employ the RBF kernel in the SVM classifier.

2.4 Land cover classification validation
The extensive field work survey was conducted from January through February, 2015, to verify points using a Trimble Juno 3B handheld GPS (Global Positioning System). We then generated confusion matrices to calculate Kappa coefficients (k) and to derive overall accuracy. We obtained an overall accuracy assessment of 0.78.

2.5 Analysis of land use transformation
To assess the urban land use transformation, we compared all periods of analysis using a method in which the images were superimposed. The initial state map and final state map were compared to obtain change detection statistics. Instead of being based on administrative boundaries, the analysis of urban land use transformation in this study was conducted on a study area 30 × 35 km. The scale of the analysis of urban land use transformation was based on night-time light images of the study area (Figure 2) acquired from Suomi - NPP VIIRS (Visible Infrared Imager Radiometer Suite) sensor (available from https://earthdata.nasa.gov/labs/worldview/). We chose the area of dense urban night-time lights as the boundary for the analysis, since this indicated the extent of urbanization more clearly than the administrative boundary. Cartographic design was done using QuantumGIS (QGIS) open-source software.
2.6 Virtual Geo-Library development

Our objective was to develop an interactive WebGIS and geodatabase for land use transformation in the urbanized area, as well as human-environment interaction by providing a map and data in virtual geo-library services. We used Map Server to provide the web map service (WMS), using the same libraries as the QGIS; both are open-source software. Java, HTML and Active Server Pages were used to customize our application. Our Web-based tool facilitated the sharing of information globally, providing end-users with a cost-saving way to access up-to-date spatial datasets customized for a specific topic (i.e., urbanization) for users with a low education level and limited GIS knowledge.

The development of a virtual geo-library system consisted of a client viewer and server components (Figure 3). The interface of the client viewer was designed using HTML, CSS, and JavaScript, all of which were employed to facilitate the processing of user inputs/requests, or to transfer them to the MapServer. MapServer processed requests for maps and related information, and performed one or more map service functions, such as image and metadata services. In this virtual geo-library, image services are used for generating image-based map outputs, according to the user’s request. The MapServer handles incoming requests, tracks map services on the MapServer, and hands off requests to the Spatial Server.
A standard HTML viewer template was used in the Client Viewer to provide an interface for the WebGIS with basic mapping functions, including map display, pan, zoom in/out, navigation, and other functions. The most frequently used tools include visualization tools (zoom in, zoom out, pan), and the map and print tool. With these tools, the user can effectively perform operations that are very helpful for monitoring their urban environment.

Public users can access the application freely, but cannot update, change, or modify the information. Only an authorized administrator can update the latest information. All users can obtain tabular data information from this application with the analysis tool. Furthermore, they can print out the map of urbanization with the print tool. The virtual geo-library enables all stakeholders to access the latest information available from anywhere, at any time.

3. Results and Discussion

3.1 Private housing industry development and land sources

Uncontrolled urbanization in Malang is happening due to the growth of the housing industry, which occupies agricultural areas in the lowlands. As a result, farmland is diminishing and
surrounded by the high-class residential areas. Fragmented agricultural land appears in many locations. Urbanization is occurring not only in the lowlands, but also in the highlands. This is clear from the fact that the growing number of urban areas covered 21% of the study area in 2001, and 40% in 2014. The majority of this growth occurred in the highlands.

3.2 Agriculture land loss and movement to higher land
Agriculture land decreased first in lowlands and dramatically increased in higher land. This phenomenon occurred because farmers who lost their jobs in the lowlands transferred their farms to higher land. Most of the farmers in agricultural areas are labourers without land. When land owners moved to higher land, their labourers followed. As a result, the conversion of forest cover to agricultural land in the highlands took place rapidly, from only 3% in 2001, to 16% in 2014. Meanwhile, the forest cover has continued to decrease steadily, from 64% in 2001 to the drastically reduced 22% in 2014.

3.3 Virtual geo-library tools
Two important tools were developed in the current system: (1) Print menu; and (2) Analysis menu. The Print menu was developed to enable users to analyze the urbanization process through cartographic maps (Figure 4). The user is able to choose the period of urban-

![Figure 4](image_url)
ization, define the scale, and select the type of paper. When the user clicks “Print”, a new window will appear making it possible to print the map out as a hardcopy.

The analysis menu provides the user with the ability to conduct an analysis of land use changes from five different periods (1989-2014). From the dropdown menu, the user can choose the periods to be compared, and get information on the urban land use transformation in percentages. The graphical user interface (GUI) of the virtual geo-library is shown in Figure 5.

4. Conclusions

Results obtained in this study show that in Malang City, urbanization is happening in an uncontrolled manner. Fragmented agricultural land appears in many locations, and is currently occupying higher lands. The housing industry has also recently come to occupy higher land. Meanwhile, the forest cover has steadily decreased, from 64% in 2001 to 22% in 2014.

The innovative virtual geo-library developed in this study will open a new window and provide an analysis tool for all stakeholders in the area. Providing a virtual geo-library allows local people to develop their geo-literacy based on their local knowledge, combined with scientific findings. In this way, disasters can be mitigated and environmental issues can be anticipated. Their time-series land use transformation will be documented in the virtual geo-library system. Additionally, this system will be updated every five years, and accessible from anywhere. We expect this information to be highly valuable to local people in particular, as well as to others who need information about the region. Increasing data availability provides unprecedented opportunities and challenges for the research of spatial knowledge.

One of the innovations of this system is it is supported in the local languages. Another is the use of existing technologies combined with free open-source software. This system will not only provide valuable data to farmers, local government, and researchers, but can also help to broaden public awareness and development of sustainable management. This study offers much help to manage other earth resources in a more sustainable way, with less expensive software and methods of geospatial data collection and processing, supported by advanced technologies of geospatial data dissemination and delivery.
Figure 5. Graphical user interface (GUI) of the virtual geo-library
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