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Polina Lemenkova

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Using *K-means* algorithm classifier for
urban landscapes classification in
Taipei area, Taiwan
Seminar at
National Taiwan University (NTU)
Taipei, Taiwan, China

Polina Lemenkova †

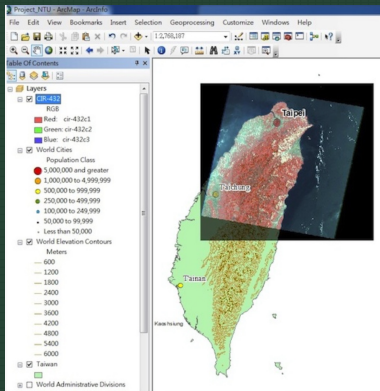
May 22, 2013

† pauline.lemenkova@gmail.com

Table of Content

1. Summary
2. Human Factors
3. Land Cover/Use Types
4. Taipei
 - Urban Area
 - Urbanization
 - Regional Differences: Urban Space
5. Ecosystems
 - Functions
 - Structure
6. Urbanization
 - Urbanization: Trends
 - Urbanization: Consequences
7. Statistics
8. Environment
9. Techniques
10. Data
 - Landsat TM Images
 - Preliminary Data Processing
11. Methods
 - K-means Algorithm
 - K-Means Clustering
 - K-means Classification: ENVI GIS
 - Land Cover Types
 - ENVI GIS Classification by K-means Method
 - Combining Classes
 - Creating Region Of Interest (ROI)
 - Subset Data via ROI
 - Regional Division of Taipei
 - Statistics of Change Detection
 - Post-Classification Data Processing
 - Statistical Processing
 - Computed Areas of the Land Cover Types
12. Results
13. Conclusions
14. Discussion
15. Thanks
16. Literature
17. Bibliography

Summary



Study area: overlay of the Landsat TM image with vector map of Taiwan Island and elevation contours. ArcGIS visualization.

Research Area

Taipei urban landscapes, Taiwan R.O.C.

Research Aim

Apatio-temporal analysis of urban dynamics in study area during 15 years (1990-2005)

Research Objective

Application of geoinformatic tools, remote sensing data for urban studies of Taipei

Research Methodology

GIS based spatial analysis

Study area is located in Taiwan R.O.C., Taipei city capital area.

Study Area

Location

Taipei is located on the north of the Taiwan Island

Significance

Taipei is the Taiwan's core urban political & economic center

Characteristics

- Taipei: favorable **topographic** location, **climatic** and **geographic** settings
- Advantageous conditions for habitation here during centuries.

Examples

Geographic Settings

- Geomorphology: Taipei is characterized by flat relief and several rivers of Tamsui basin with alluvial soils.
- Physical geography: Natural borders of the city are formed by surrounding mountains and hills (Tsou & Cheng, 2013).
- Geology: Rich sediments from the upstream area maintain soils fertility, creating favorable resources for agricultural activities (Huang et al., 2001).

Human Activities Affecting Landscapes



View of from Taipei-101 skyscraper
(Taipei World Financial Center),
Photo: author, 2013.

Urban growth and city sprawl affects ecosystems.
Consequences of human impacts include:

- landscape degradation
- changes in land cover and land use types
- decrease in biodiversity richness within the city
- deforestation, urbanization, and wetlands destruction (Chen and Lin, 2013)
- decrease in species, losses of rare and extinct species (McKinney, 2006; Shochat et al., 2004; Ramachandra et al., 2012)

In turn, modified land use types:

- affect hydrological components in the surrounding watersheds
- cause changes of the land use **patterns**
- change primary descriptors of the landscape patterns: **composition, configuration, connectivity, variety** (Lin et al., 2007)
- modify **abundance** of patch types within a landscape

Land Cover vs Land Use Types: Conceptual Difference

Land Cover

Land cover data documents how much of a region is covered by forests, wetlands, impervious surfaces, agriculture, and other land and water types. Water types include wetlands or open water.

Land Use

Land Use shows just how people use the landscape – whether for development, conservation, or mixed uses. The different types of land cover can be managed or used quite differently.

Examples

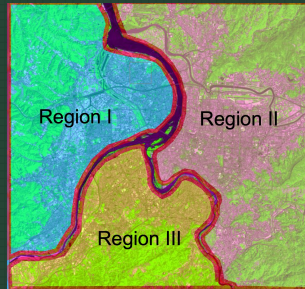
Land Cover vs Land Use

- Land cover can be determined by analyzing satellite and aerial imagery.
- Land use cannot be determined from satellite imagery.
- Land cover maps provide information to enable interpreting current landscape.

This research focused on study of land cover types in Taipei using GIS & RS.

To highlight dynamics in the land cover types, multi-temporal RS images for several different years were taken and compared. With this information, past situation was evaluated and insight into the effects of urban sprawl in Taipei area are made.

Taipei: Urban Area



Population

A Taipei population living within an area of 271.8 km^2 , density of $9566 \text{ persons/km}^2$, which is higher than for most of Asia's other major cities (Tsou & Cheng, 2013).

Function

Located on the north of the Taiwan Island, Taipei is the country's core urban **political and economic center** with population reaching over 2.6 M and continuing to expand within the metropolitan region.

Taipei: Urbanization

Concentrated **population density** and **environmental pressure** within the **limited geographic space and resources** => metropolis as Taipei deal with specific urban environmental problems.

Examples

Consequences of urbanization

1. transformation in **structure of natural landscapes**
2. simplification of species, changes in landscape composition
3. disconnected and disrupted components within the hydrological systems, fragmentation of natural habitats
4. changes in **land cover types**: forests, river deltas, meadows, native grasslands, wetlands => human-modified agricultural or **built-up areas**
5. new areas consist of large amounts of **impervious surfaces**, covered by concrete blocks, asphalt pavement, bricks, buildings
6. significantly altered **aboveground net primary productivity**
7. changes in **soil respiration rates**, compared to natural ecosystems (Kaye et al., 2005)
8. **air pollution** and decreased **water quality** (Huang et al., 2001)

Regional Differences: Urban Space

Limitation of Land Resources

Uncontrolled urbanization =>

Gradual limitation of the land and water resources =>

Insufficient infrastructure within the city =>

Development of densely concentrated mixed land use types.

Land Use Types

About 45% of the Taipei city is categorized as restricted with regard to availability and usage due to its topography (Tsou and Cheng, 2013).

Only 14% (46.30 km²) is available for further development (residential and commercial).

Land Cover Types

Urban landscapes are composed of areas of various shape and size, water bodies, human built-up quarters and hilly mountainous areas

Examples

Urbanization Nowadays, new Taipei city face consists of built-up new apartments, buildings, office centers and residential areas, re-structured districts.

This process is reinforced by the average structure age of the buildings and modernization (Lin and Jhen, 2009).



Urban Ecosystems: Functions

Complex Structure

Urban ecosystems have highly complex composing structure and functioning.
Urban landscapes have the highest level of ecosystems hierarchy.

Energy

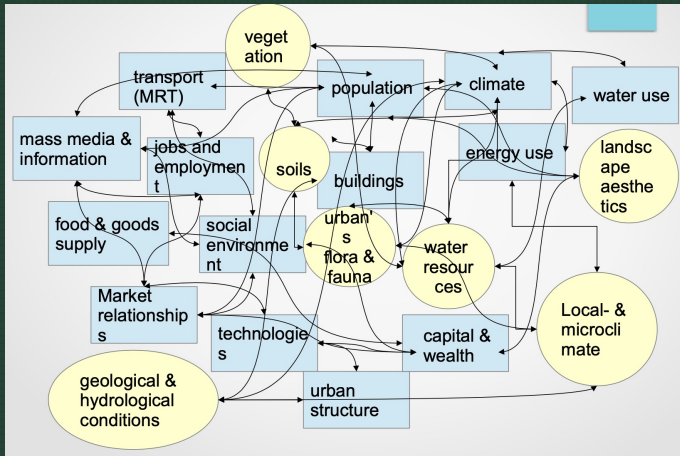
Energy flows and density reach the most intensity in the cities comparing to natural and semi-natural ecosystems

Examples

Typical functions of urban ecosystems: Cultural, supporting, regulating services => core criteria for measurement of the environmental quality of the urban areas (Flores et al., 1998). Complexity of these functions consists in various aspects of urban landscapes (Bonaiuto et al., 2003):

- spatial (architecture and planning space)
- organization and access to green spaces within the city)
- human (i.e. people and social interrelations)
- functional (recreational, commercial, transport services and welfare)
- contextual aspects (life style and environmental health)

Urban structure: a simplified flowchart



Urbanization: Trends

Population

In the past decades, the process of urbanization became more and more notable in the world. About half of the world's population will reside in urban areas and cities by 2000 (Huang et al., 1998).

Importance

World's global cities (e.g. New York, London, Tokyo, Taipei, Paris, Seoul, Moscow, Hong Kong, Singapore, etc.) are the key engines of the human development and global cooperation. The importance of capitals: economies drivers; play key role in national and regional economies of countries (Scott, 2000; Hsu, 2005; Sassen, 2001).

Examples

Functions of capitals in the modern World

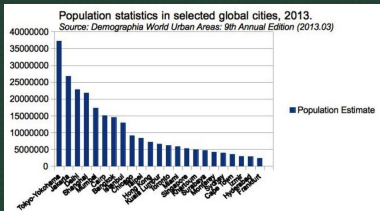
- (a) control resources and information
- (b) attract major material and economic forces
- (c) trigger human activities
- (d) attract financial investments for further development
- (e) involve informational knowledge centers and strategies

Urbanization: Consequences

Global cities, such as Taipei, have to face specific environmental problems, due to the concentrated human density and environmental pressure within the limited geographic space and resources. Consequences of urbanization:

- * transformation in structure of natural landscapes: e.g. simplification of species, changes in landscape composition, disconnected and disrupted components within the hydrological systems, fragmentation of natural habitats
- * changes in land cover types: e.g., from forests, river deltas, meadows, native grasslands, wetlands, or agricultural areas, towards anthropogenic affected built-up areas which consist of large amounts of impervious surfaces, covered by concrete blocks, asphalt pavement, bricks, buildings
- * significantly altered aboveground net primary productivity
- * serious changes in soil respiration rates, compared to natural ecosystems (Kaye et al., 2005)
- * air pollution and decreased water quality (Huang et al., 2001)

Taipei: comparison with other major cities



Taipei Population

Taipei metropolitan area population =
2,618,772 people
including Taipei, New Taipei and Keelung =
6,900,273 people

Taiwan Population

Taiwan population (for the whole country)
according to the last two censuses:

- year 1990: 20,393,628;
- year 2000: 22,226,879.;
- year 2012: 23,315,822.

Source: Number of Villages, Neighborhoods,
Households and Resident Population.
MOI Statistical Information Service.
Retrieved: 2 January 2013.

Environment

Industrialization

Human-driven effects on the environment and landscapes of Taipei agglomeration consist in **high industrialization and urbanization**. The spatiotemporal pattern of landscape diversity changed within Taipei metropolitan region between 1971 and 2005.

Urbanization

Rapid urbanization affects **interrelations between natural and urban ecosystems**, changes their **structure, size and shape**, which gradually became a serious environmental problem. Thus, in Taipei, natural, typical land cover types are being gradually transformed into human-affected artificial surfaces (Hung et al., 2010).

Examples

Increase of built-up areas: Analysis of the landscape biogeographic characteristics of the urban forests shows that species diversity, composition and richness, spatial variability is done by Jim and Chen, 2008. According to their findings, the Taipei's urban the built-up areas with space limitations have the **lowest biodiversity level**, while parks accommodate the **highest biodiversity level**, as represented by native species.

Techniques

ENVI GIS

The research was performed using ENVI GIS software using Landsat TM images for years 1990 and 2005.

K-means Algorithm

The landscapes in the study area at two multi-temporal Landsat TM images were classified using "K-means" algorithm. Different land use types were identified and classified. The area covered by each land cover class is compared for years 1990 and 2005 and dynamics analyzed.

Land Cover Types

Changes in the selected land cover types were analyzed and human impacts on the natural landscapes detected. Classified land cover types were compared at both maps of land cover types for the years 1990 and 2005.

Data

The screenshot displays the Global Land Cover Facility Earth Science Data Interface. The interface includes a navigation menu with options like Home, Map Search, Product Search, Path/Row Search, and Workspace. A sidebar on the left lists various data categories such as Landsat Imagery (ETM+, TM, MSS, ALL), Other Imagery (ASTER), Elevation Data (SRTM, WRS2, SRTM_GTOPO30, SRTM_GTOPO30 Mosaic), and MODIS Products (25-Day Composites, 26-Day Vegetation Index, VCF, Regional, VCF_LMD Tiles). The main area features a map of Taipei, Taiwan, with a red rectangular selection box. Below the map, there is a message: "No images in selection" and a text input field for "Enter dates as mm/dd/yyyy or yyyy-mm-dd". To the right of the map, there is a thumbnail of a satellite image and a table of data for the selected area.

Path/Row	Date	Product	Resolution	Band	Source	Download
224-424	2005-10-18	ETM+	30m	TM	USGS	Download
224-425	2006-03-11	ETM+	30m	TM	USGS	Download
227-788	1972-11-01	MSS	30m	TM	USGS	Download
227-789	1972-11-01	MSS	30m	TM	USGS	Download
227-811	1979-01-07	MSS	30m	TM	USGS	Download
227-812	1974-03-13	MSS	30m	TM	USGS	Download
233-128	2005-08-17	TM	30m	TM	USGS	Download
233-129	2004-07-12	TM	30m	TM	USGS	Download
233-144	2004-12-10	TM	30m	TM	USGS	Download
234-636	1990-07-22	TM	30m	TM	USGS	Download
234-644	1990-07-21	TM	30m	TM	USGS	Download

Source

Data: two Landsat TM imagery taken from the USGS website.

Temporal comparison

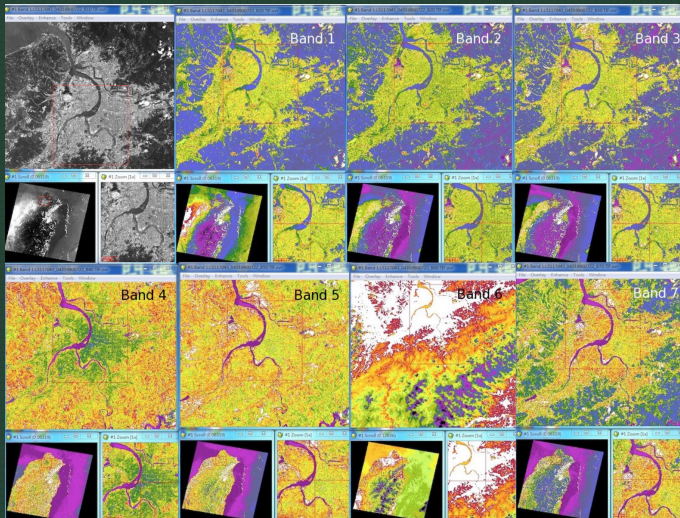
Study period: imagery for summer periods of 1999-2005

Examples

Spatial Comparison Selected territory focused on **3 different areas**: comparison of three districts of southern area of Taipei, Taiwan, along the Tamsui river

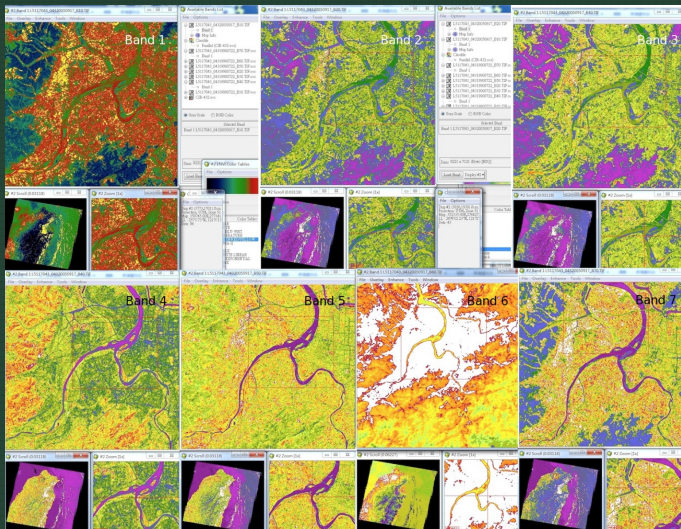
Landsat TM 1990

Landsat TM image (1990). Bands 1-7 (fragment). Color composites (ENVI)



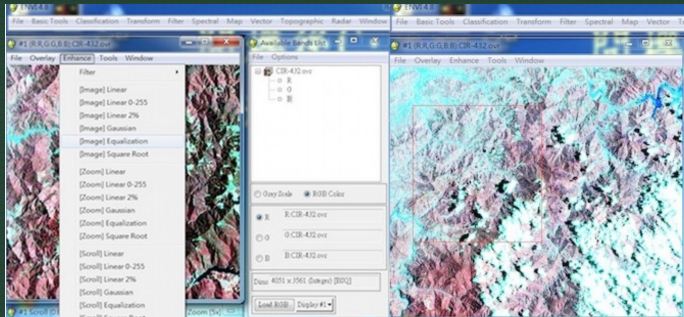
Landsat TM 2005

Landsat TM image (2005). Bands 1-7 (fragment). Color composites (ENVI)

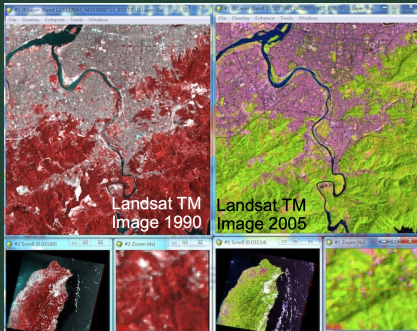


Preliminary Data Processing

- Preliminary data processing: image contrast stretching.
- By default, ENVI displays images with a 2% linear contrast stretch.
- Histogram equalization contrast stretch was applied to the images in order to enhance the visual quality (better contrast)



Methods



Methods used in the current work include following steps:

- Data capture
- Color composition from 3 bands
- Defining Region of Interest (ROI)
- Selecting 3 areas within the city
- Image classification
- Combining classes
- Re-classification
- Post-processing
- Spatial analysis
- Defining 3 different areas of Taipei city

K-means Algorithm

K-means algorithm procedure has 3 steps:

- Choosing the initial **centroids** for defined number of land classes
- **Assignment** of each pixel to the nearest centroid which represent certain land cover class
- Creating new centroids by taking the mean value of all pixels assigned to each previous land cover **class** (i.e. centroid).

Looping between the other steps 2 and 3:

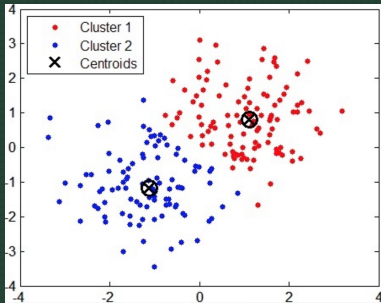
The difference between the old and the new centroids is '**inertia**'.

The algorithm repeats (loops) steps until the 'inertia' is less than a **threshold**.

It **smoothes iteratively** the allocation of pixels until the centroids do not move significantly.

K-Means Clustering

K-Means classification: general idea.



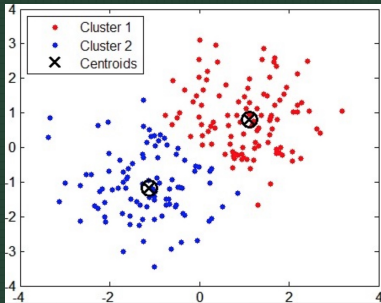
- K-means is a flat clustering algorithm which is often used in classification techniques.

K-Means: a mathematical approach:

$$J(X, C) = \sum_{i=0}^n \frac{\min_{\mu_j \in C} (\|x_j - \mu_i\|^2)}$$

K-Means Clustering

K-Means classification: general idea.



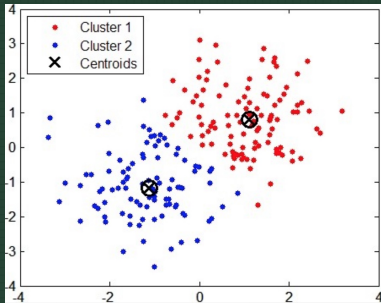
- K-means is a flat clustering algorithm which is often used in classification techniques.
- The objective of K-means: to minimize the average squared Euclidean distance between the cluster centers (the means).

K-Means: a mathematical approach:

$$J(X, C) = \sum_{i=0}^n \frac{\min_{\mu_j \in C} (\|x_j - \mu_i\|^2)}$$

K-Means Clustering

K-Means classification: general idea.



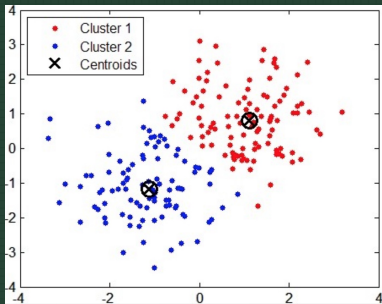
- K-means is a flat clustering algorithm which is often used in classification techniques.
- The objective of K-means: to minimize the average squared Euclidean distance between the cluster centers (the means).
- K-means analysis allocates pixels into various clusters by defining the mathematical centroids of all clusters - groups of pixel with similar values of spectral reflectance, or digital number (DNs)

K-Means: a mathematical approach:

$$J(X, C) = \sum_{i=0}^n \frac{\min_{\mu_j \in C} (\|x_j - \mu_i\|^2)}$$

K-Means Clustering

K-Means classification: general idea.



K-Means: a mathematical approach:

$$J(X, C) = \sum_{i=0}^n \frac{\min_{\mu_j \in C} (\|x_j - \mu_i\|^2)}$$

- K-means is a flat clustering algorithm which is often used in classification techniques.
- The objective of K-means: to minimize the average squared Euclidean distance between the cluster centers (the means).
- K-means analysis allocates pixels into various clusters by defining the mathematical centroids of all clusters - groups of pixel with similar values of spectral reflectance, or digital number (DNs)
- K-means separates raster pixels in n clusters (groups of equal variance) by minimizing the 'inertia' criterion.

K-means Classification by Means of ENVI GIS

The screenshot displays three overlapping dialog boxes in the ENVI GIS interface:

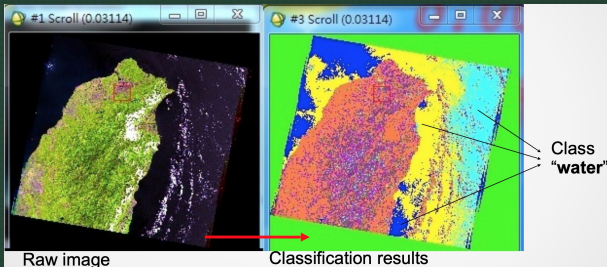
- Classification Input File:** Shows the selected input file '2005-543' and its metadata, including dimensions (8221 x 7121 x 3) and file size (176,625,320 bytes).
- Select Spatial Subset:** Shows the file '2005-543' with dimensions '8221 (Byte)'. The 'Samples' field is set to '1 To 8221 NS 8221' and 'Lines' to '1 To 7121 NL 7121'. It also displays 'Full Size: 58,541,741 bytes' and 'Subset Size: 58,541,741 bytes'. The 'Subset Using' options are 'Image', 'Map', 'File', 'ROBEVF', and 'Scroll'. The 'Subset by Image' dropdown is set to 'Display #1'. Buttons for 'Reset', 'Previous', 'Open', 'OK', and 'Cancel' are visible.
- K-Means Parameters:** Shows 'Number of Classes' set to 10, 'Change Threshold % (0-100)' set to 5.00, and 'Maximum Iterations' set to 3. It also includes fields for 'Maximum Steiny From Mean' and 'Maximum Distance Error'. The 'Output Result to' radio buttons are set to 'File', with an 'Enter Output Filename' field containing '190-07-22A_SUPERVISED-CLASSK-means-1990'. Buttons for 'OK', 'Queue', 'Cancel', and 'Help' are at the bottom.

Red arrows indicate the flow of information: from the 'Classification Input File' to the 'Select Spatial Subset' dialog, and from the 'Select Spatial Subset' dialog to the 'K-Means Parameters' dialog.

Land Cover Types

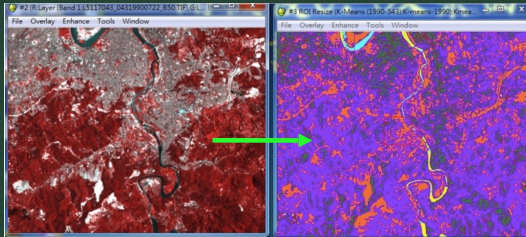
Classification of the land cover types in the city:

- Forests
- Urban areas – 2 (roads)
- Grasslands
- Open fields (little or no vegetation)
- Water areas
- Urban vegetation – 1 (bushes)
- Cultivated lands
- Agricultural facilities
- Urban vegetation –2 (parks and squares)
- Urban areas -2 (built-up surfaces)

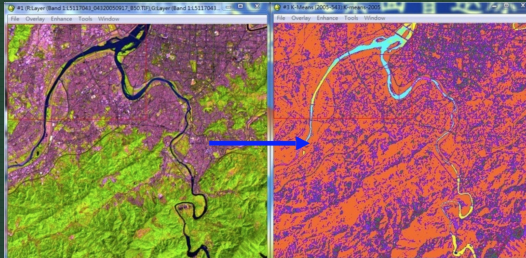


ENVI GIS Classification by K-means Method

1990 Landsat TM scene classification (fragment). Random color visualization



2005 Landsat TM scene classification (fragment). Random color visualization



Combining Classes

The screenshot displays the ENVI 4.8 interface with the 'Classification' menu open. The 'Combine Classes' option is highlighted. The 'Combine Classes Parameters' dialog is open, showing the following details:

- Select Input Class:** Water-river, Class 6, Class 7, Class 8, Class 9
- Select Output Class:** Class 1, Class 2, Water-deep, Water-shallow, Water-river
- Input Class:** (Empty)
- Output Class:** Water-river
- Add Combination:** (Button)
- Combined Classes:** Water-deep -> Water-river, Water-shallow -> Water-river
- Buttons:** OK, Cancel

The 'Combine Classes Output' dialog is also open, showing the following details:

- Remove Empty Classes ?** Yes
- Output Result to:** File (selected), Memory
- Enter Output Filename:** Choose
- Filename:** 190-07-22A_SUPERVISED-CLASSK-means-2005
- Buttons:** OK, Open, Cancel

Creating Region Of Interest (ROI)

The screenshot illustrates the workflow for creating a Region of Interest (ROI) in ArcGIS. The main window displays a satellite image of Taipei with a red square ROI. The 'Available Bands List' window shows the selected bands (R, G, B) and the ROI tool settings. The 'Enter ROI Filenames' window shows the saved ROI file 'ROI-Taipei.roi'. The 'Save ROIs to File' dialog shows the selection of the ROI and the output filename 'D:\Landsat-1990-07-22\ROI-Taipei.roi'. The '#1 ROI Tool' menu is open, showing options like 'Export ROIs to EVF...', 'Export ROIs to Shapefile...', and 'Export ROIs to n-D Visualizer...'. The 'Select Input File to Subset via ROI' dialog shows the selected input file 'L5117043_04319900722_B70.TIF.ovr'.

ROI Name	Color	Pixels
ROI-Taipei	Red	101,582

File Name	Date	Type
23April	2013/4/23 下午 0...	標籤資料夾
cir-432	2013/4/22 上午 1...	標籤資料夾
cir-432c1	2013/4/22 上午 1...	標籤資料夾
cir-432c2	2013/4/22 上午 1...	標籤資料夾
cir-432c3	2013/4/22 上午 1...	標籤資料夾
info	2013/4/22 上午 1...	標籤資料夾
ROI.roi	2013/4/23 上午 1...	ROI 檔案
ROI-Taipei.roi	2013/4/24 上午 0...	ROI 檔案

Save ROIs to File

Select Regions to Save:
Region #1 (4051x3561) (Red) 101,582 points

Number of items selected: 1

Select All Items Clear All Items

Enter Output Filename [roi] Choose

D:\Landsat-1990-07-22\ROI-Taipei.roi

OK Cancel

#1 ROI Tool

Save ROIs...
Restore ROIs...
Subset Data via ROIs
Export ROIs to EVF...
Export ROIs to Shapefile...
Export ROIs to n-D Visualizer...
Output ROIs to ASCII...
Cancel

Select Input File to Subset via ROI

Select Input File: L5117043_04319900722_B70.TIF.ovr

File Information:
File D:\Landsat-1990-07-22\CIR-432.ovr
Date: 4051 x 3561 x 3 [BGR]
Size [Data] 25,002,000 bytes
File Type: TIFF
Source Type: Unknown
Byte Order: Host (Little)
Projection: None
Width/Height: None
Upper Left Corner: L1
Description: TIFF File Imported with EVF1 [Wed Apr 24 09:28:13 2013]

Spectral Subset 3/9 Bands

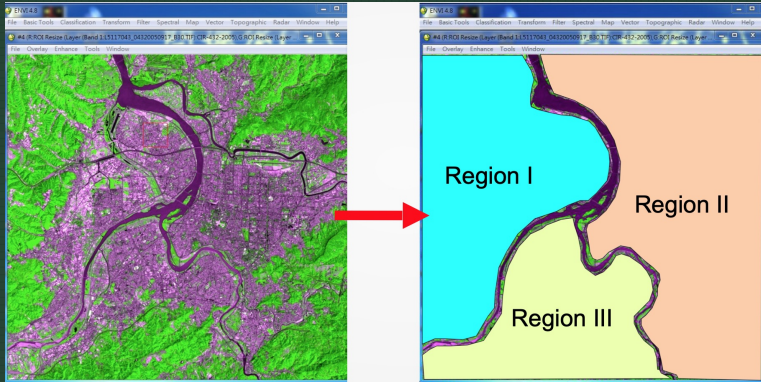
OK Cancel Previous Open

Subset Data via ROI

The image displays a multi-step workflow in ArcGIS 10.1 for creating a spatial subset from an ROI:

- Initial State:** The main workspace shows a classified map of Taipei with various urban and green spaces. The 'Available Bands List' on the right lists several input files, including 'CIB-432.ovr' and 'L5117943_0420000917_840.TIF'.
- Select Input File:** A dialog box titled 'Select Input File to Subset via ROI' is open, allowing the user to choose specific input files from the list.
- Select ROI:** A 'Spatial Subset via ROI Parameters' dialog box is shown. It lists three 'Region #'s, each containing 101,582 points. The 'Mask pixels outside of ROI?' checkbox is checked.
- File Explorer:** A Windows Explorer window shows the file system structure, highlighting the 'ROI-Taipei.roi' file in the 'Data (D:)' drive.
- Final Output:** The bottom row of screenshots shows the resulting 'Subset' maps, including a zoomed-in view of the ROI area, and the updated 'Available Bands List' showing the newly created 'ROI Subset' files.

Regional Division of Taipei City



Statistics of Change Detection: Process

The screenshot displays the QGIS 2.14.0 interface with several windows open, illustrating the steps of a change detection process:

- 1. Processing Toolbox:** The 'Statistics of Change Detection' tool is selected in the toolbox.
- 2. Available Bands List:** Shows the selected input layers: 'Kmeans2005-ROU', 'BOU Rotate (K-Means (2005-543)) K-means (2005)', 'K-means-2005', and 'K-Means (2005-543)'. A '2.' is placed over this window.
- 3. Select Initial State Image:** The 'Initial State Image' dialog shows the selection of 'K-means-1990' as the initial state image. A '3.' is placed over this window.
- 4. Select Final State Image:** The 'Final State Image' dialog shows the selection of 'K-means-2005-ROU' as the final state image. A '4.' is placed over this window.
- 5. Define Equivalent Classes:** The 'Define Equivalent Classes' dialog shows the selection of 'Initial State Class' and 'Final State Class' as 'Class 1'. A '5.' is placed over this window.
- 6. Define Pixel Sizes for Area Statistics:** The 'Define Pixel Sizes for Area Statistics' dialog shows the selection of 'Pixel Size' as '30.00' meters. A '6.' is placed over this window.
- 7. Change Detection Statistics Output:** The 'Change Detection Statistics Output' dialog shows the selection of 'Report Type' as 'Pixel' and 'Output Classification Mask Image?' as 'Yes'. A '7.' is placed over this window.

Process workflow:

- Change detection statistics
- Setting options of process
- Choice of 'Initial Stage' image
- Choice of 'Final Stage' Image
- Defining equivalent classes
- Defining pixel size for area statistics
- Defining statistics output

Post-Classification Data Processing

ENVI 4.8

File Basic Tools Classification Transform Filter Spectral Map Vector Topographic Radar

150.TIF,G:Layer (Band 1:L51177043...)

Statistics

- Spatial Statistics
 - Compute Global Spatial Statistics
 - Compute Local Spatial Statistics
- Change Detection
- Measurement Tool
- Band Math
- Spectral Math
- Segmentation Image
- Region Of Interest
- Mosaicking
- Masking
- Preprocessing

Local Spatial Statistics Input File

Select Input File:

- 1990-local-statgets_out_gi
- 1990-local-statgeary_c
- 1990-local-stmoran_1
- 1990-07-22A
- 2005-543-ROI
- 1990-543-ROI
- Kmeans1990-ROI
- 2005-543
- 1990-543

File Information:

File: D:\landstat-1990-07-22A_SUPERVISED-CLA
 Dims: 703 x 670 x 1 [BSQ]
 Size: [Byte] 471,010 bytes
 File Type: ENVI Classification
 Sensor Type: Unknown
 Byte Order: Host (Intel)
 Projection: UTM, Zone 51 North
 Focal : 30 Meters
 Datum : WGS-84
 Wavelength: None
 Upper Left Corner: 3332,1409
 Description: File Resize Result, x
 resize factor: 1.000000, y resize
 factor: 1.000000, [Thu Apr 25
 13:00:18 2013]

Local Spatial Statistics Parameters

Neighborhood Rule: Rook's Case

Calculate Statistics at Multiple Ranges

Select Maximum Lag (Pows): 2

Include Intermediate Lags

Output Local Moran's I (Clustering)

Output Local Gets-Out G_i (Hot Spots)

Output Local Geary's C (Variability)

Output Result to File Memory

Enter Output Root Name:

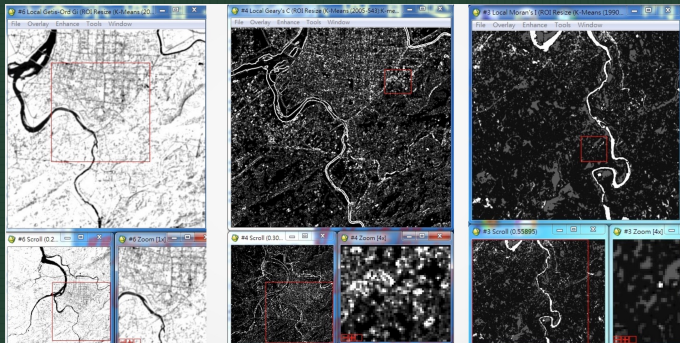
190-07-22A_SUPERVISED-CLASS1990-local-sta

OK Cancel Help

points (62.357%) (23,303,908 0000 Meters
 points (15.589%) (23,326,200 0000 Meters

Unclassified					
n	Max	Mean	Stdev		
0	0	0.000000	0.000000		
EM	Npts	Total	Percent	Acc	Pct
0	0	0	-NaN	-NaN	-NaN
1	0	0	-NaN	-NaN	-NaN
2	0	0	-NaN	-NaN	-NaN
3	0	0	-NaN	-NaN	-NaN
4	0	0	-NaN	-NaN	-NaN
5	0	0	-NaN	-NaN	-NaN
6	0	0	-NaN	-NaN	-NaN

Statistical Processing

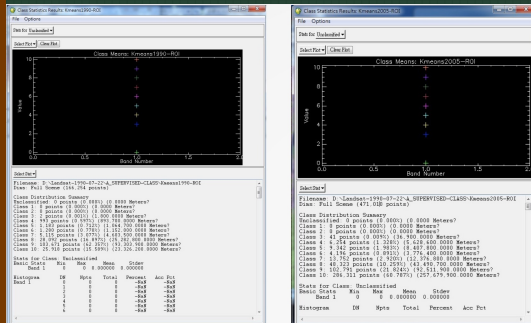


- Left: **Getis Ord G statistics** - measures concentration of the emergency values (highest or lowest) for the land cover classes
- Center: **Geary statistics** - measures spatial dependence and autocorrelation of pixels.
- Right: **Moran statistics** - measures spatial features similarity values based on pixels location and values

Computed Areas of the Land Cover Types

Results: ROI has changes in land cover classes:

1. class "urban areas" increased from 16.9% in 1990 to 21.8% in 2005
2. class "urban vegetation" decreased from 3.1% in 1990 to 2.9% in 2005
3. class "forests" decreased from 62.4% in 1990 to 60.8% in 2005
4. class "grasslands" decreased from 15.6% in 1990 to 10.3% in 2005

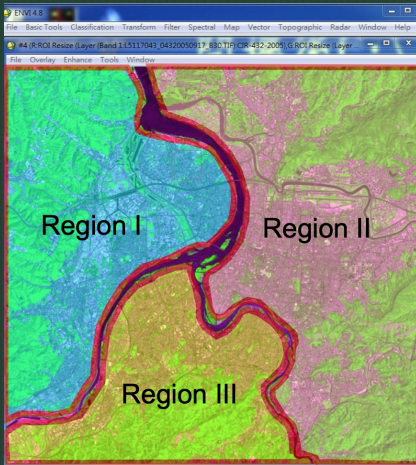


Results: Regions I, II and III

Three regions of Taipei have differences in the land cover types:

	1990, %	2005, %
Region I: "urban areas"	17,1	21,9
Region I: "urban vegetation"	5,7	4,1
Region I: "forests"	19,8	18,6
Region I: "grasslands"	21,4	18,3
Region II: "urban areas"	79,3	83,2
Region II: "urban vegetation"	4,3	5,2
Region II: "forests"	32,7	31,8
Region II: "grasslands"	15,9	14,7
Region III: "urban areas"	24,3	38,2
Region III: "urban vegetation"	3,7	4,3
Region III: "forests"	42,4	41,8
Region III: "grasslands"	13,8	12,1

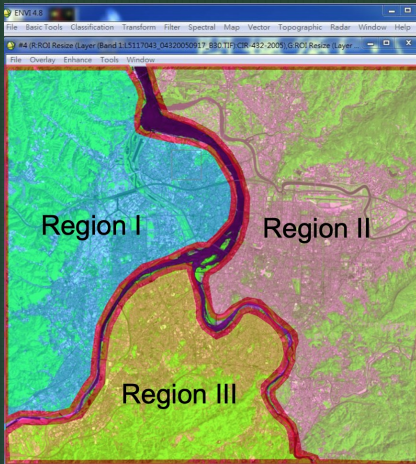
Conclusions



Comparison of regions I, II and III:

- Region I: located on the left bank of Tamsui river, agricultural area. It has significant changes in the land cover types since 1990s.

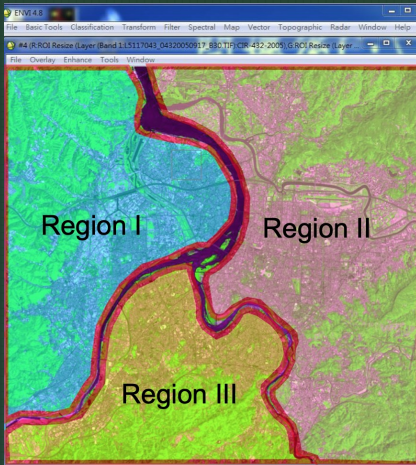
Conclusions



Comparison of regions I, II and III:

- Region I: located on the left bank of Tamsui river, agricultural area. It has significant changes in the land cover types since 1990s.
- Region II is the core, old city area is the most stable region. It has the least changes: this area is already industrialized for a long time.

Conclusions



Comparison of regions I, II and III:

- Region I: located on the left bank of Tamsui river, agricultural area. It has significant changes in the land cover types since 1990s.
- Region II is the core, old city area is the most stable region. It has the least changes: this area is already industrialized for a long time.
- Region III is an area located southwards from the core city. It has undergone notable changes caused by intensive relocation of the population to the Taipei area after 1980s. This is regions is dynamically developing since 1990s.

Discussion

- Spatial analysis performed by ENVI GIS enabled to process satellite images for urban studies.
- Spatio-temporal analysis was applied to Landsat TM images taken at 1990 and 2005:
- Built-in functions of the mathematical K-means algorithm enabled to classify Landsat TM images and to derive information on land cover types.
- Image classification was used to analyze land cover changes in Taipei which includes built-up areas and natural green areas.
- Results of image processing and spatial analysis show changes in structure, shape and configuration of urban landscapes in Taipei since 1990
- Areas occupied by human activities increased, while natural landscapes undergone modifications.
- Changes in urban landscapes of Taipei are caused by the increased relocation of population, urbanization and occupied lands for urban needs.

Thank you for attention !

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