

# Analysis of urban change and spatial pattern

By:

**Drs P. Hofstee**

**Department of Land Resource and Urban Sciences,**

**International Institute for Aerospace Survey and Earth Sciences (ITC),**

**P.O. Box 6, 7500 AA Enschede, The Netherlands.**

**Tel: +31 53 4874237, Fax: +31 53 4874399, e-mail: HOFSTEE@ITC.NL**

## Summary

In this exercise urban change and spatial development pattern of the land use in the city of Villavicencio, Colombia, will be analyzed. Needed are the urban land use maps of three years (1960, 1978 and 1991), and raster maps of the low-standard settlements (in 1991), the land values (in 1991), the slopes and the distance to the main roads. Additionally, vector maps of the main roads (in 1960 and 1991) and the rivers are included for orientation purposes.

## Getting started

The data for this case study are stored on the ILWIS 2.1 CD-ROM in the directory d:\appguide\chap20. If you have already installed the data on your hard disk, you should start up ILWIS and change to the subdirectory where the data files for this chapter are stored, c:\ilwis21\data\appguide\chap20,. If you did not install the data for this case study yet, please run the ILWIS installation program (see ILWIS Installation Guide).



- Double-click the ILWIS program icon in the ILWIS program group.
- Change the working drive and the working directory until you are in the directory c:\ilwis21\data\appguide\chap20.

Now you are ready to start the exercises for this case study.

## 20.1 Available data

Needed are the urban land use maps of three years (1960, 1978 and 1991), and raster maps of the low-standard settlements (in 1991), the land values (in 1991), the slopes and the distance to the main roads. Vector maps of the main roads (in 1960 and 1991) and the rivers are included for orientation purposes:

Luse60	Raster map of the urban land uses in 1960.
Luse78	Raster map of the urban land uses in 1978.
Luse91	Raster map of the urban land uses in 1991.
Landuse	Domain and Representation for the Luse60, Luse78 and Luse91 raster maps.
Lowset91	Raster map of the low-standard settlements.
Landv91	Raster map of the land values in 1991.
Mrdistan	Raster map of the distance zones from the main roads (1991).
Slopes	Raster map of the slope classes.
Mroad91	Vector map of the main roads in 1991.
River	Vector map of the rivers.

## 20.2 Background information

### 20.2.1 Geographical characteristics

Villavicencio is located 120 km southeast of Bogotá (Colombia). The average altitude is 500 m above sea level. The importance of Villavicencio is primarily due to its strategic location at the entrance of the Llanos Orientales, a large cattle breeding and agricultural region. Being the capital of the province Meta, the city serves as the center of education, commerce, and industry of the Llanos Orientales. The population in 1964 was 45,000; in 1973, 83,000; and in 1985, 170,000 (Gaceta Municipal, 1990).

With an estimated growth rate of about 6% per annum, the population in 1991 is estimated at 247,000.



Figure 20.1: Villavicencio satellite image. Landsat TM band 5 (Jan.1988) + SPOT Pan (Apr.1990)

The study area was defined on the basis of the aerial photos of 1987 (scale 1:9000) and the topographic map scale 1:10000 (IGAC, 1989). It covers 8100 ha, of which in 1991, 1823 ha was urban, 4547 ha non-urban, 462 ha water body, and 1266 ha no information available (outside coverage of aerial photos).

The Villavicencio study area lies on the eastern lower slopes of the Cordillera Oriental of the Andes mountain range. The urban area is not completely flat, as the western part of the city is sloping up to the hill. Two large rivers cross the area in West↔East direction: the Rio Guatiquía in the north and the Rio Ocoa in the south. A number of small rivers have cut valleys (often steep and narrow) in the area: the caños Parrado, Gramalote, Maizaro, Cuerera, Buque, Tigre, and Grande.

Annual rainfall is around 3000-4000 mm. The rivers may inundate large areas during the rainy season (April-November). In 1985 a large flood destroyed many

houses in the city. Further siltation of the rivers will increase the flood risk. Moreover, the area is suspected of having a liquefaction risk.

Being located in an active geological fault zone, there is also an earthquake risk. Land slides are likewise a risk on some slopes.

The main activities in the Llanos Orientales are agriculture, cattle breeding and on a small scale oil exploration. In the last two decades the city has been subjected to an accelerated process of migration of people looking for employment opportunities and urban facilities and services. This has resulted in the very fast growth of the city.

Villavicencio has mainly agro-based industries. The Meta province is the source of raw materials like rice, maize, soybeans, and cotton. Commercial ranching is also located in this zone and supplies the slaughter houses in Villavicencio and Bogotá with live animals.

Due to rapid urbanization during last two decades, the construction industry has also grown fast and now employs a significant percentage of the population. Economic activities in the municipality of Villavicencio in terms of employment are commercial 25%, construction 21%, agriculture and livestock 20%, industrial 16%, public sector 12%, and education and services 6% (Anuario Estadístico, 1989).

### 20.2.2 Urban Structure and Development

The layout of the city follows the colonial Spanish planning system: a grid pattern structure with the central square (Plaza Mayor) located in the original center. In the current layout of Villavicencio the grid pattern is still predominant in the flat areas, but due to the topography some building blocks (*manzanas*) have irregular shapes. The topography, rivers, main radial roads (to Bogotá, Puerto López, and Acacías) the ring roads, and unplanned residential areas have further shaped the city's development. Presently, a delta shape (with the top in the northwest and the base in the southeast) can be observed.

The center (CBD) is now fully developed and spilling over into other places. The industrial sector is following the main radial roads. The dominant land use is residential. This requires affordable land prices, accessibility, and services. New developments also take place outside the contiguous built-up area, including unplanned areas along the rivers and on steep slopes (with flooding and landslide risks, respectively).

The recent growth pattern of the city is characterized by densification (fill-in) of existing areas, vertical development (particularly commercial and high-income residential land use), and ribbon development along the main roads. The new ring road and the relocated bus terminal affect other developments and land values.

Table 20.1: Main land uses (ha and %) in Villavicencio in 1960, 1978, 1987, and 1991 (ITC, 1991)

Main land use	1960		1978		1987		1991	
	ha	%	ha	%	ha	%	ha	%
Residential	185	58	630	58	980	60	1136	62
Commercial	29	9	38	4	91	5	116	6
Industrial	12	4	62	6	152	9	173	9
institutional	29	9	75	7	125	8	137	8
Recreational	2	0	28	2	78	5	77	4
Transportation	-	0	1	0	7	0	17	1
Vacant	39	12	237	22	169	10	159	9
Under development	25	8	11	1	44	3	8	1
Total urban	321	100	1082	100	1646	100	1823	100
Urban	321	4	1082	13	1646	20	1823	22
Non built-up	1080	13	2053	25	4718	58	4547	56
Water body	462	6	462	6	462	6	462	6
No information	5507	67	4503	56	1274	16	1268	16
Total study area	8100	100	8100	100	8100	100	8100	100

## 20.3 Procedure

The analysis of urban changes and spatial pattern, will be carried out as follows:

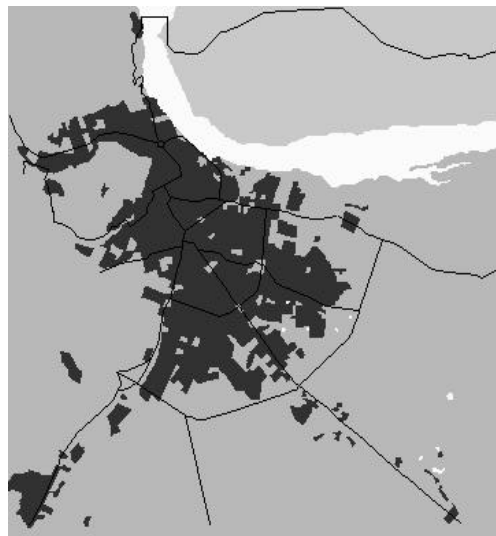
1. Calculate the basic land use data for three years.
2. Quantify the growth rate of the urban area.
3. Analyze the land use changes 1960-1978 and 1978-1991.
4. Visualize the urban growth from 1960 to 1978 to 1991.
5. Analyze the spatial pattern of the urban development from 1978 to 1991 in circular distance zones around the center of the city and in linear distance zones along main roads.
6. Analyze the location of low-standard settlements in relation to the topography (slopes).



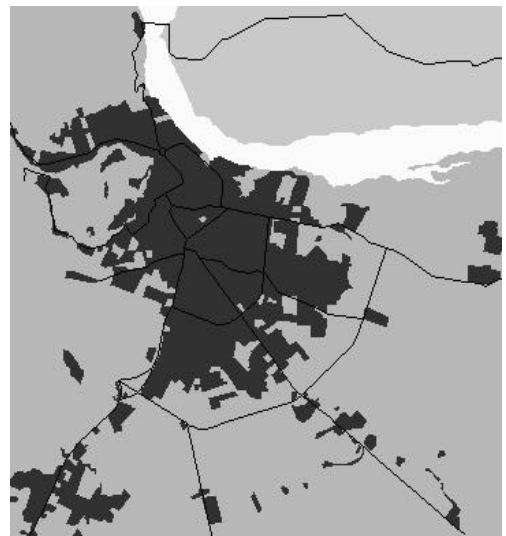
Urban area in 1960



Urban area in 1978



Urban area in 1987



Urban area in 1991

Figure 20.2: Urban area Villavicencio in 1960, 1978, 1987, and 1991

## 20.4 Calculate basic land use data for three years

The three raster maps of the urban land uses (of 1960, 1978 and 1991), contain the following classes (table 20.2):

Table 20.2: Codes and class names used for the domain Landuse

Code	Class	Code	Class
co	Commercial	re	Recreational
de	Demolition	rs	Residential
id	Industrial	ri	River
is	Institutional	tr	Transportation
ni	No information	ud	Under development
nb	Non built-up		



- Calculate the histogram for the map Luse60.
- Create an attribute table Luse60, using the domain Landuse. Open this table, and type the following formula:  

$$\text{Area} := \text{Luse60.His.Area} \downarrow$$
- Calculate the area in hectares of each land use class. Type in the command line:  

$$\text{Areaha} = \text{Area} / 10000 \downarrow$$

Give a precision 0.1.
- The percentages for the different land use classes also can be calculated, using the aggregate sum **AggSum** command. Create a column **Areatot** by typing:  

$$\text{Areatot} = \text{aggsum}(\text{Areaha}) \downarrow$$

Then create a column with the percentages by typing:  

$$\text{Perc} = 100 * \text{Areaha} / \text{Areatot} \downarrow$$
- Repeat the procedure for the years 1978 (map Luse78) and 1991 (map Luse91).

The results will be slightly different from the data shown in table 20.1.

Table 20.3: Main land uses (ha and %) in Villavicencio in 1960, 1978, and 1991

Main land use		1960		1978		1991	
Code	Class	ha	%	ha	%	ha	%
rs	Residential						
co	Commercial						
id	Industrial						
is	Institutional						
re	Recreational						
tr	Transportation						
ud	Under development						
de	Demolition						
	Total urban		100		100		100
	Urban						
nb	Non built-up						
ri	River						
ni	No information						
	Total study area		100		100		100

## 20.5 Quantify the growth rate of the urban area

The data on the areas of the main land use classes in Villavicencio in the years 1960, 1978, and 1991 as stored in the attribute tables, can be used to quantify the land use changes.



- Extract the total urban area in hectares from the table you filled in above.

Calculate the changes between the years (urban expansion) per year in hectares. The % change between 1960 and 1978 is calculated assuming that the urban area in 1960 is 100%; similarly to calculate the change 1978-1991 it is assumed that the urban area in 1978 is 100%.

- Calculate the mean change per year (arithmetic mean) in ha/year and %/year for the two periods.
- Fill in the table urban expansion in ha/year and %/year.

The speed of development, an increase or a decrease, can be established.

In this case the easiest way to calculate the mean is used. Alternatively, the geometric mean, based on the exponential law, could be applied. This is normally done when calculating population growth percentages per year. It could also be



assumed that the growth rate of an urban area follows this exponential growth rate model.

- ☞
- Calculate the mean values of urban change and fill up the following table.

Table 20.4: Urban expansion in ha/year and %/year

Year	Urban area (ha)	Change		Time span (years)	Arithmetic mean change		Period
		(ha)	(%)		(ha/year)	(%/year)	
1960							1960-1978
1978							
1991							1978-1991

## 20.6 Analyze the land use changes 1960-1978 and 1978-1991


The attribute tables provide information on the land use assigned to each pixel in the three years 1960, 1978, and 1991. By extracting the areas in hectare, a quantified overview of the type of change can be made. In this way the type of change can be analyzed for the two change periods.

- ☞
- Cross the raster maps Luse60 and Luse78 and create an output table Luse6078.
  - Calculate the area in hectares of each combination of land use classes. Type in the command line of the cross table:  
 $Area_{ha} = Area / 10000$   
 Give precision 0.1.
  - Repeat the cross operation with the raster maps Luse78 and Luse91 and create an output table Luse7891.
  - Extract the land use changes (non-urban to residential, commercial, etc., and no information to residential, commercial, etc.) in hectares from the cross table.
  - Fill in the table changes from non-urban and no information to urban land uses.

Table 20.5: Changes from non-urban and no information to urban land uses in ha 1960 to 1978 and 1978 to 1991

Period	to → from ↓	Land use class (in ha)							Total new Urban
		Resid	Comm.	Indust.	Instit.	Recr.	Trans.	Constr./ Demol.	
1960	Non-urban								
-	No info								
1978	Total								
1978	Non-urban								
-	No info								
1991	Total								


The information from the cross tables also provides information on particular land use changes, e.g. from residential to commercial. This type of change gives insight into the dynamics of urban land use changes: replacement of one urban land use by another urban land use (succession).



- Extract the land use changes (residential to commercial, residential to under construction plus demolition, non-urban to commercial, non-urban to under construction plus demolition) in hectares from the cross table.
- Fill in the table change from residential and non-urban to commercial and under construction together with demolition areas.

Table 20.6: Changes from residential and non-urban to commercial and under construction + demolition land uses in ha 1960 to 1978 and 1978 to 1991

Period	to → from ↓	New land use class (in ha)		Total
		Commercial	Under construction/demolition	
1960	Residential			
-	Non-urban			
1978	Total			
1978	Residential			
-	Non-urban			
1991	Total			

 There may be changes from residential to non-urban, but as they are very limited in areal extent (and moreover could partially be the result of digitizing inaccuracies: slivers), they are disregarded here.

## 20.7 Visualize the urban growth 1960 to 1978 to 1991

The number of land use changes, as calculated by a map cross operation and stored in a cross table, is very high. For a good visual impression of the main trends of the land use changes it is necessary to group the land uses into a limited number of classes.

In this case the land use maps of the base years 1960, 1978, and 1991 will be reclassified from 11 into 4 classes. Using only 4 classes also makes it possible to use easy to reproduce (black-and-white) maps using graytones or hatching patterns.

The new class urban should contain the land use classes residential, commercial, industrial, institutional, recreational, transportation, under construction and demolition.

The final output map will show the urban growth 1960 to 1978 to 1991.



- Create a new domain Urban, type Class. Add the following classes: Urban, Non urban, River, No info. Do not fill in codes. A representation is automatically created.
- Edit the representation Urban by double clicking on each class:
 

Class	Color
Urban	red
Non urban	green
River	blue
No info	gray
- Create a new table Landuse with class domain Landuse. Add a column Urban, with domain Urban. Assign the name Urban to the classes Residential, Commercial, Industrial, Institutional, Recreational, Transportation, Under development and Demolition, the name Non urban to the class non built-up, the name No info to the class No information, and the name River to the class river.
- With the operation **AttribRas** use the raster map Luse60, the table Landuse, and the attribute Urban. Create and show the attribute map Urban60.
- Repeat the operations with the map Luse78 to create the output map Urban78, and with the map Luse91 to create the output map Urban91.

An alternative approach would be to use **MapCalc** operations to create the new maps Urban60, Urban78, and Urban91. However, this approach is less

efficient when reclassifying so many classes than the attribute table approach. The Mapcalc formula is given below, only as an illustration, not for execution.

```
Urban60=iff(((Luse60="re") or (Luse60="co") or
(Luse60="id") or (Luse60="is") or (Luse60="re") or
(Luse60="tr") or (Luse60="ud") or (Luse60="de")),
"urban", iff(Luse60="nb", "non urban", iff(Luse60="ri",
river, iff(Luse60="ni", "no info", Luse60))))
```



- Display the 3 new maps Urban60, Urban78 and Urban91 simultaneously on the screen. Study the differences.
- Print the maps.
- Create a new map Urbgrew from the maps Urban60, Urban78 and Urban91 to show the growth of the urban area (assume that the urban area is always expanding, there is no land use changing from urban to non-urban).
- Edit the domain Urban by adding the classes Urban60, Urban78, and Urban91.

In the following MapCalc operation the maps of the urban area of the 3 years are overlaid on each other. The order in which the maps are overlaid is critical to arrive at a proper output map.



- Overlay the three maps with the following formula:  
`Urbgrew=iff(Urban60="Urban", "Urban60",  
iff(Urban78="Urban", "Urban78", iff(Urban91=  
"Urban", "Urban91", Urban91)))`

The statement says: if the map Urban60 has a class Urban, then assign the class Urban60 (to the output map Urbgrew), otherwise if the map Urban78 has class Urban then assign the class Urban78 , etc.



- Assign the color red to the urban area in 1960, orange to the new urban area 1978, yellow to the new urban area 1991, green to the non-urban area 1991, blue to the rivers, and gray to the no info area 1991.

- Convert the map Urbgrow to a polygon map with the RasPol command. Choose **Connect 8**. Edit the representation of the polygon map replacing the colors by patterns in the color black.
- Print the map on a non-color printer to study the effects. Change the patterns if necessary to improve the map legibility.

## 20.8 Analyze the spatial pattern of the urban development in distance zones

Several approaches exist to analyze the spatial pattern of development. In this exercise circular distance zones around the center of the city and in linear distance zones along main roads will be used to study the pattern of development.

### 20.8.1 Circular distance zones around the center

The center is considered to be the area with the highest land values, as stored in a map Landv91. The land values were derived from the cadastral database of 1989 and corrected by 16% inflation to approximate the values for 1991. This map is the base map for creating distance zones.

The map Landv91 contains the following land value classes (in Colombian pesos per square meter):

Table 20.7: Codes and class names used for the domain Landval and the map Landv91

Code	class name
c1	1-150
c2	151-1000
c3	1001-3000
c4	3001-5000
c5	5001-15000
c6	> 15000
ri	River
ni	No information on land value



- Display the map Landv91 and check the.
- Create a new map Source with MapCalc using the following formula:

```
Source=iff(Landv91="C6",Landv91,?)↵
```

In words, in the map `Source`, the city center (area with the highest land values, i.e. `C6: > 15000` in map `Landv91`) is displayed, and the rest of the map should get an undefined value.



- Create a distance map `Circdist` with circular distances of 1 km around the city center: Use the map `Source`. The output raster map `Circdist`, will have a domain `Distance`, a range 0-10000 (meters) and precision 1000 (meters).
- Display the map `Circdist`.



- Create an attribute table `Landv91` using the domain `Landval` and add a value column `Lv91` (value range 0-100, precision 1). This column will contains weight values. Edit the values and give the city center (class `>15000`) the value 0, and the lower classes a value 1. The classes `river` and `no information` will get a weight value -1.
- Create an attribute map `Lv91` from the column `Lv91` applied to the map `Landv91`. This map will be used as weight map in the distance calculation.



- Apply the distance calculation with the source map `Source` and the weight map `Lv91`. Do not select the option box `Thiessen map` (not needed here). Call the output map `Circdisw`, with domain `Distance`, value range 0-10000 (meters) and precision 1000 (meters).



- Display the maps `Circdisw` and `Circdist` next to eachother and compare the results and the effect of the weight factor. Inaccessible (or irrelevant) areas are in this case the areas with no information.
- Analyze the land uses in each distance zone for the years 1978 and 1991 by crossing map `Circdisw` with maps `Luse78` and `Luse91`, respectively. Fill in the table below.

Table 20.8: Main land uses in ha in circular distance zones in 1978 and 1991

Main land use	0...1 km		1...2 km		2...3 km		3...4 km		4...5 km	
	1978	1991	1978	1991	1978	1991	1978	1991	1978	1991
Residential										
Commercial										
Industrial										
Institutional										
Recreational										
Transportation										
Under development										
Demolition										
Total urban										
Urban										
Non-built-up										
No information										
Total zone										
% Urban										


**20.8.2 Distance zones around the main roads**

The land use development 1978 to 1991 along both sides of the main roads of Villavicencio will be studied in a linear distance zone 500 m wide.

The raster map `Mrdistan` contains the distance zones along the main roads. It was prepared in a way comparable to map `Circdisw`, but the information came from the main roads and the distances were classified. Map `Mrdistan` contains the following classes (distance values towards the main roads):

Table 20.9: Codes and class names used for the domain `Dist`

code	Class	Code	Class
c1	0 m	c7	2501 - 3000 m
c2	1 - 500 m	c8	3001 - 3500 m
c3	501 - 1000 m	c9	3501 - 4000 m
c4	1001 - 1500 m	ni	No information
c5	1501 - 2000 m	ri	River
c6	2001 - 2500 m		



- Display the classified distance map `Mrdistan` on the screen.
- Create a map `Mrdistan2` in which only 2 pixel values occur:  
 (1) Pixel value = 100, a pixel is located in distance zone 0-500 m along a main road.

(2) Pixel value = 0, a pixel is not located in distance zone 0-500 m along a main road.

To do it, use a MapCalc statement like:


```
Mrdistan2=iff(Mrdistan="C2",100,0)↵
```

- Cross map Mrdistan2 with the land use maps of 1978 and 1991 (Luse78 and Luse91, respectively) and fill in the table below.

Table 20.10: Main land uses within 500 m from the main roads in 1978 and 1991

Main land use in the 0-500 m zone	1978		1991	
	ha	%	ha	%
Residential				
Commercial				
Industrial				
Institutional				
Recreational				
Transportation				
Under construction				
Demolition				
<b>Total urban</b>		100		100
Urban				
Non-urban				
No information				
<b>Total zone</b>		100		100

## 20.9 Analyze the location of low-standard settlements in relation to the topography (slopes)



- Analyze the location of low-standard settlements in relation to the topography (slopes). To do so, display the maps Lowset91 and Slopes next to each other. Get an impression where low standard settlements are located.
- Display the low-standard settlements in relation to the general land



uses in 1991.

The low-standard settlements map `Lowset91` contains the following classes:

Table 20.11: Codes and class names for the map `Lowset91` (domain `Lowset`)

Code	Class name
re	Residential without low standard settlements
lo	Low standard settlements
un	Urban no residential
nb	Non built-up
ri	river
ni	No information

The slope map `Slopes` contains the following values:

Table 20.12: Codes and class names for the map `Slopes` (domain `Slopes`)

Code	Class name
fl	flat (< 7%)
in	inclined (7-15%)
st	steep (> 15%)
ri	river
ni	no information


- 
- Cross the low-standard settlements map `Lowset91` with the slope map `Slopes`.
  - Analyze whether more low-standard settlements are located on steep slopes than other residential areas (use the cross table) and fill in the tables below.

Table 20.13: Location of the low-standard settlements respect to the slope

Type of residential area	Flat (< 7%)		Inclined (7-15%)		Steep slopes (> 15%)		Total area	
	ha	%	ha	%	ha	%	ha	%
Low-standard settlements								
Residential without l-s settlements								
All residential areas		100		100		100		100

Type of residential area	Flat (< 7%)		Inclined (7-15%)		Steep slopes (> 15%)		Total area	
	ha	%	ha	%	ha	%	ha	%
Low-standard settlements								100
Residential without l-s settlements								100
All residential areas								100

## References

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