
MONITORING URBAN DYNAMICS FOR BRATISLAVA IN 1949 - 1997

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ABSTRACT

The main goals of Bratislava Project are analyses and monitoring of urban changes. The use of digital photogrammetry, remote sensing and GIS methods in such type of projects was verified. This project belongs to the MURBANDY (Monitoring Urban Dynamics) project, which was originally started as part of the CEO (The Centre for Earth Observation) programme in 1998. It is aimed to demonstrate that satellite data can be effectively used for urban monitoring and planning.

1 INTERNATIONAL INITIATIVE AS PROJECT BACKGROUND

1.1 What is the CEO?

The Centre for Earth Observation (CEO) is a European initiative to encourage the wider use of information generated by satellites, which are observing the planet Earth. The CEO seeks to attract a wide range of participants in Europe, from local government authorities and the Services of the European Commission to scientific researchers and commercial companies; bringing together those who could benefit from the use of EO data and those who provide it. The CEO is founded by the European Commission, firstly as a joint DG JRC/DG XII program under the 4th Framework Program, and after that as one of the main projects of the JRC's Space Application Institute in the 5th Framework Program.

The Centre for Earth Observation Program was started to show potential customers how to use and exploit Earth observation data and to promote European activity in this important global market. Funded and managed by the European Commission, the CEO Program has been one of the biggest European undertakings since the launch of the first remote sensing satellite to transform the science of the Earth observation into an operational tool for daily use.

Most of the CEO staff is located at the European Centre in Ispra in Northern Italy. The second office is in Brussels in the Space Unit of the Directorate General of DG XII.

1.2 MURBANDY project

The MURBANDY (Monitoring Urban Dynamics) project was originally started as part of the CEO Program in 1998. It aimed to demonstrate that satellite data could be effectively used for urban monitoring and planning by the EC. Results from MURBANDY have been included in the European Spatial Development Perspective (ESDP) policy document that was approved by the Council of Ministers in May 1999. The derived data-sets for the cities of Dublin and Milan were used as examples of urban sprawl.

The main object of MURBANDY project was to measure land uses of artificial fabric of Bratislava and its immediate suburban area and to detect changes of land use within last 48 years. The derived products were „reference“ and „historical“ land use databases for urban and suburban areas. The development and verification of methodology for the enlarged CORINE land cover layer production belonged also to this project.

2 DATA SOURCES AND DATA PROCESSING

2.1 MURBANDY legend for Bratislava

The legend for MURBANDY project was defined in the CEO in Italy. It comes from former CORINE project.

Level 1	Level 2	Level 3	Level 4	
1. Artificial surfaces	1.1 Urban fabric	1.1.1 Residential continuous urban fabric	1.1.1.1 Residential continuous dense urban fabric	
			1.1.1.2 Residential continuous medium dense urban fabric	
		1.1.2 Residential discontinuous urban fabric	1.1.2.1 Residential discontinuous urban fabric	
			1.1.2.2 Residential discontinuous sparse urban fabric	
	1.2 Industrial, commercial and transport units	1.2.1 Industrial, commercial, public and private units		1.2.1.1 Industrial areas
				1.2.1.2 Commercial areas
				1.2.1.3 Public and private services
		1.2.2 Road and rail networks and associated land	1.2.2.1 Toll-ways	
			1.2.2.2 Other roads	
			1.2.2.3 Railways	
	1.3 Mine, dump and construction sites	1.3.1 Mineral extraction sites		
1.4 Artificial non-agricultural vegetated areas	1.4.1 Green urban areas			
2. Agricultural areas	2.1 Arable land	2.1.1 Non-irrigated arable land		
	2.2 Permanent crops	2.2.1 Vineyards		
		2.2.2 Fruit trees and berry plantations		
	2.3 Pastures	2.3.1 Pastures		
	2.4 Heterogeneous agricultural areas	2.4.2 Complex cultivation patterns		
3. Forests and semi-natural areas	3.1 Forests	3.1.1 Broad-leaved forest		
	3.2 Shrub and/or herbaceous vegetation associations	3.2.1 Natural grassland		
	3.3 Open spaces with little or no vegetation	3.3.1 Beaches, dunes, and sand plains		
4. Wetlands	4.1 Inland wetlands	4.1.1 Inland marshes		
		4.1.2 Peatbogs		
5. Water bodies	5.1 Inland waters	5.1.1 Water courses	5.1.1.1 Canals	
			5.1.1.2 Rivers	
		5.1.2 Water bodies		

Table 1. MURBANDY legend classes used for Bratislava

2.2 City Study Area and Buffer Zone

The project study area was defined in two parts - Centre Zone (City) and Buffer Zone. The Centre Zone interferes in the continuous built up areas of Bratislava City. The Buffer Zone was chosen according to Bratislava District. The state

border of The Slovak Republic, Austria and Hungary bound west and south parts of the Buffer zone. This border leads also in the middle of Morava and Danube rivers. The Buffer Zone was enlarged also to the Austrian and Hungarian parts of these rivers by using some small strip on the banks so not to cut Morava and Danube rivers in the middle.

2.3 Data Sources

2.3.1 Used Maps and Their Processing

For the geodetic basement creation were chosen so-called „The Basic Maps of The Czechoslovak Socialist Republic (CSSR)“ (topographical maps) in 1:10.000 scale from the state department in JTSK co-ordinate system and in Krovak's double conform cone projection. The altitude system was the Baltic system after adjustment. These maps were also called the maps for national economy of CSSR. Some maps have been available in colours, other ones have been produced by contact copy from the transparent originals. These maps have been updated last time between 1974 and 1986.

All maps had been scanned with resolution of 400 dpi in 24-bit colours as JPEG-Format. The very bright colours of maps have been bettered by using imaging software on PC. The Format was changed to tiff and colour deep was reduced. Such data were prepared for transformation into JTSK co-ordinate system. All maps had crosses and frame lines in the places of whole co-ordinates in JTSK system.

The corners of the maps had no co-ordinates. Several tests of different algorithm (Equal, Affin, Kolin, Polynomial) delivered not good results on the corners and in the centre of the maps. The Affin-Transformation had been the best and brought the best result for the corners. The transformation was done in two steps. The first transformation was done by 4 co-ordinated points, which were placed the nearest of the corners by Affin-algorithm. The second transformation by using Special-transformation algorithm (TIN-Affin) was used by catching and weighting all available co-ordinated points. It was usual about 45 points and error was then below 1 m for the chosen points. This way was necessary to get good base for work on satellite image and for orientation of aerial pictures. All steps were done in TopoL-GIS software, which is developed by TopoL-Software Ltd. in Prague/CZ. TopoL is Geographic Information System software for use in various fields. It enables the creation, maintenance, presentation and analyses of geographical data. TopoL can satisfy many needs for GIS and remote sensing image analyses (image processing, spectral analyses, image classification). TopoL can process vector and raster data equally well and provide wide scale of vector data overlays, database analyses as well as image processing and classification. Digitising capabilities of TopoL are easy to use and the system is able to solve topologic relations in real-time while data are digitised. TopoL can import and export data in many industry-standard formats as well as ArcView Shape File and ArcInfo Generated. TopoL is running on standard PC computers in Windows environment.

2.3.2 Reference imagery

The reference land use database was derived from „reference imagery“. The reference imagery was IRS/C panchromatic imagery at 5,8 meter resolution, which was purchased and delivered by JRC. The format was *.img and as well description was delivered on the CD. Bratislava is on the right-bottom quarter of this picture. In that case view was not straight and transformation to geodetic co-ordinate system (geo-referencation) should be done carefully. The geo-referencation of satellite-image was done in TopoL-GIS by identical points between maps and image. The work was done in two steps. The first geo-referencation by 10 points delivered result with a maximum-departure of 30m. However the worst points had been deleted out of calculation and then we achieved better results. In the second step about 120 points were chosen on the map and satellite image, mainly corners of big houses were used. In the suburban and rural area it was the problem to find suitable points, in that case the density was higher in the city. Algorithm of special transformation was used but before departures have been checked in calculation table. Points have not been used when the departure was bigger than 15m. Finally more than 90 points have been taken in geo-referencation processing.

The final result fits well to the maps however some parts in maps did not fit totally. These problems have been checked by GPS-Field-measurement with Trimus DGPS-System. This System allows an accuracy of better 3m by using the German long wave signal. The system is produced by GGS in Speyer /D. The mistakes were identified on the maps.

2.3.3 Used Historical Imagery

Aerial photos for historical years were chosen from the Military Topographical Institute in Banská Bystrica. Historical aerial photos are only available from military archives. We found suitable pictures for:

year	approximately scale	number of pictures	size
1949	1 : 33.000	25	19 x 19 cm
1969	1 : 38.000	24	18 x 18 cm
1985	1 : 27.000	30	23 x 23 cm

The problem of photos from all years has been, that flight-direction was according to border along 3 different direction of axes sometimes with different cameras and flight-altitude in one year. The Military Topographical Institute scanned

the pictures to enable deleting areas of military protection out of aerial photos. Scanning was done by 1200 dpi. The certification of European commission in Ispra with link of kind of use of this data was a good help to get the photos. The deliverable of this data had been difficult and needed long time. Data on CD-ROM had to be officially ordered from some Slovak company.

2.3.3.1 Processing of Aerial Photographs

With the software PhoTopoL operations of the digital photogrammetry are possible. The scanned photos had to be prepared by internal and external orientation.

For internal orientation the co-ordinates of camera fiducial marks are used. The calibration protocols, which were delivered together with the photos, have been mostly wrong. Suitable protocols were found in literature in the Department of Geodesy of Technical University in Brno. Other co-ordinates have been measured from hard copies or by recalculation of image co-ordinates by using resolution of the scanned pictures.

External orientation was done by use of identical points on photo and map. At each picture between 12 and 20 points were picked up and calculation was done by using bundle-adjustment method. The pictures were prepared for orthorectification.

Before the orthorectification of the aerial photos could be done, a digital terrain model had to be created. Because no existing model had been available for adequate price or the quality was too bad, the model was created by us through vectorisation of contour lines with the software Atlas DMT. The geo-referenced maps out of TopoL-GIS were used in the software module NetEditor, which enables placement of points with interactive recalculation of model with its contour lines. The created model became very complex and had finally 279.545 points. Other operations out of this model, like profile drawing, slope-calculation, volume-validation, 3D-views and other things are possible in AtlasDMT. The model can be directly used from TopoL by DDE-connection.

The new created orthophotos were simplified to 2m pixel-size. The resolution is good enough for identify the changes and each photo has less than 20 Mbytes. For comparing, original photo had about 120 Mbytes.

2.4 Digitalisation and Interpretation of Prepared Data

Vectorisation and interpretation was done together. At first line-features were mapped out of satellite image and maps. Many information from analogue city-plan have been integrated. Topological structure was used and different land-use classes have been documented in a database. The vectorisation was done on screen in two windows, in one on basement of the satellite-image, in the other one on the maps. Result of mapping was seen interactive in both windows. In the other window the original aerial photo was displayed. Some shadows, which made identification and orientation difficult, were very often found in the satellite image. Behind of high buildings streets were very difficult to locate. Especially in panel house areas, where buildings sometimes guide roads several hundred meters, this effect took place. Some of them have dark roofs, which are made of new bitumen-seal. In that case end of building on shadow-side was not identifiable. The same effect was found in the areas of water-bodies in the mead-forest area. Shadow and water had usually the same grey scale. Some roads are guided from trees on one side. In such cases it is difficult to identify, on which side is road and on which is shadow. Big constructions were usually very good for identification on satellite-image, with small buildings it was much more difficult. There have been also problems in the central old part of Bratislava, where old houses with 3 or more floors stand close together. Other problematic field is the area of cottages (or small houses) under forest. When trees are high, the cottages are nearly not visible. Only when there is also use of gardens or an agglomeration with higher density, you can identify it in satellite image. Mostly aerial photos and maps were used to interpret the land-use of the area. Some official buildings like schools, hospitals and so on, are signed in maps with some symbols or cartographic signs (logogram). Special books with description of symbols and logograms have been used for map interpretation. Additional to this, field checks have been used for validation of interpretation. Photographs have been taken for the use in documentation. Areas were mapped as homogeneous parts with one polygon. Setting the label point and filling the database according to MURBANDY legend created the area. Sometimes there have been several kinds of use in areas and it was not possible to divide it in the horizontal direction. In that case the main area use of all floors or the importance of the area was taken into account. Because of this the residential structure seem to be over-represented.

3 RESULTS

3.1 The Simplified Statistics

	1949	1969	1985	1997
Urban Fabric	2.387	3.833	5.174	5.539
Agricultural land	25.722	21.602	19.484	18.335
Industrial, commercial, transport & service	1.067	3.389	5.103	5.842
Forest & seminatural areas	14.927	14.789	13.638	12.421
Artificial non-agricultural vegetated area	159	498	630	699
Wetlands & water bodies	1.541	1.590	1.780	3.178

Table 2. Development for major land-use groups from 1949 up to 1997 in hectares

The size of residential area grew from 1949 more than 130% from 2.387 ha up to 5.539 ha in the year 1997. In the same time the size of economical area grew more than 5 times, that means a rate of 440%. Agricultural area shows a loss of 7387 ha, that is a rate of 40%. The artificial structure had profit of this loss. Forest lost 2506 ha, that is a rate of 20%. Especially in the region of the dam-project mead-forest-areas have been lost. In that case the water area grew from 1.541 ha up to 3.178, that is more than twice. The urban green areas grew strong on small level. Especially the class 1.4.2 (sport and leisure facility) grew parallel to the increase of urban fabric.

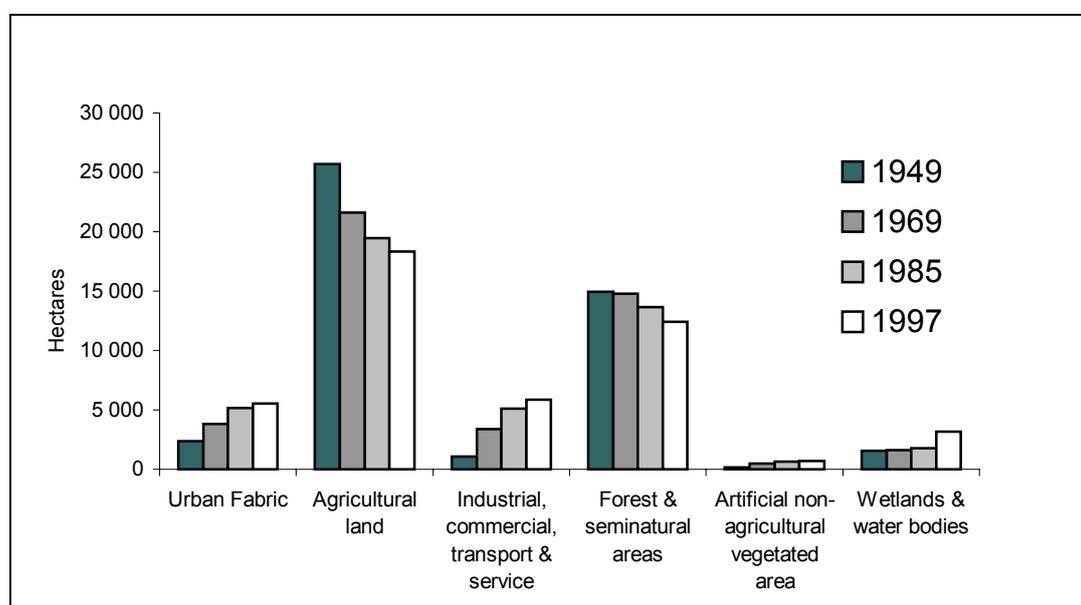


Chart 1. Graphic development for major land-use groups from 1949 up to 1997

3.2 Increase in Artificial Surfaces

The artificial areas grew since 1949 up to 1985 very strong with nearly linear rate of 190 ha per year. The biggest development between 1949 and 1969 happened east of the centre of Bratislava. In the south east of the centre the petrochemical company of Slovnaft was founded and built up. A big number of areas with panel-houses were built up since 1969 and also Slovnaft was again enlarged. After 1985 the last big area of panel-houses with a big number of flats for more than 120.000 people was finished in „Petrzalka“ and the growth rate was taken down at least to 70 ha per year. The strongest increase was in that case finished at 1985, after this the concentration of the existing urban residential and economical fabric was more in focus. Since 1985 the biggest increase can be detected in „Karlova Ves, Devínska Nová Ves“, in the enlarging of the airport, in the built up of new toll-ways and of course in the dam project on the Danube-river on the south of Bratislava. With the end of the socialistic system and the foundation of The Slovak Republic with Bratislava as its capital, a new development was initiated within a new motivation for built up artificial fabrics, but also to reconstruct existing city structure to support better quality of work, life and business.

3.3 Increase in Residential Surfaces

In the following analyses the residential areas of the classes 1.1.1.1, 1.1.1 2, 1.1.2.1, 1.1.2.2 have been included together with some demographic data and some simple previous modelling. From 1949 up to 1969 on all places residential area was created around the existing old structure of 1949. The strongest development was done at the east part of the centre in „Ruzinov“. Strong increase also appeared in the villages „Podunajské Biskupice“ and „Ivanka pri Dunaji“. After 1969 the biggest increase can be found in „Dubravka“ and „Petrzalka“, where big blocks of flats have been built up. There was concentrated some very big increase. After 1985 the centre of residential increase can be found in „Karlova Ves“, where also blocks of flats (panel houses) have been built up.

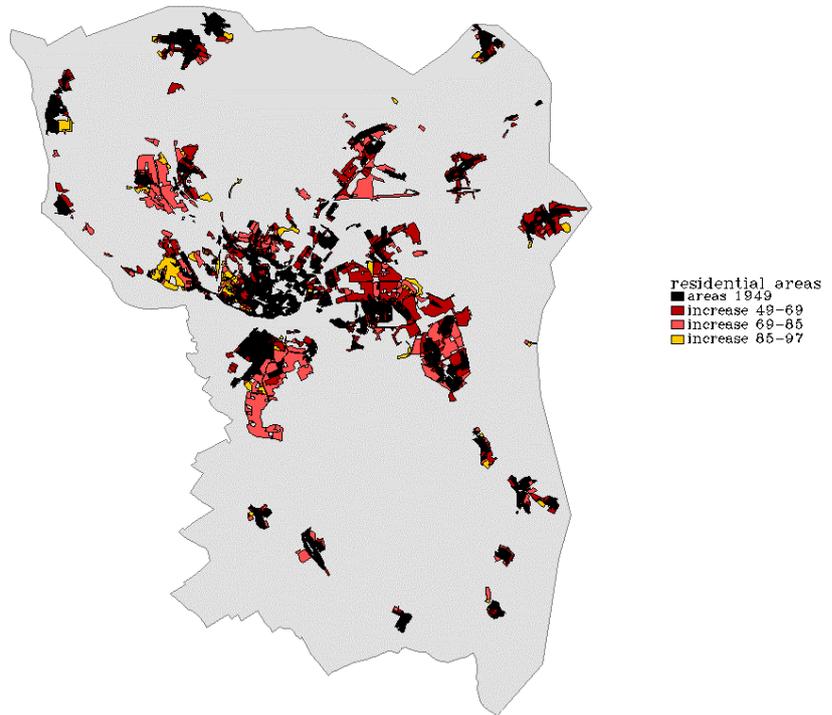


Figure 1. Increase in Residential Surfaces

3.4 Increase in Business Surfaces

In this chapter the increase of the classes 1.2.1.1, 1.2.1.2, 1.2.1.3, 1.2.2.1, 1.2.2.2, 1.2.2.3, 1.2.3, and 1.2.4 is discussed and analysed together. The main trend goes parallel to the increase of residential area like it was discussed above. The biggest development was done after 1949; the last time lag however showed only small increase of such area. Main regions of increase are on the north east and south-east of the centre. One big area was lost after 1949; it is the old airport visible in black far on the north east of the centre and on the north of the new airport. The new airport was built up after 1949 and the old airport changed to 1.4.2 because it became a sporting airport. On the new airport the built-up phases can be seen. The foundation and grow of the petro-chemical factory „Slovnaft“ is shown in the south of the centre near Danube. The biggest change in all analysed classes has been done by 1.2.1.1 industrial area. All other areas went parallel but on smaller level.

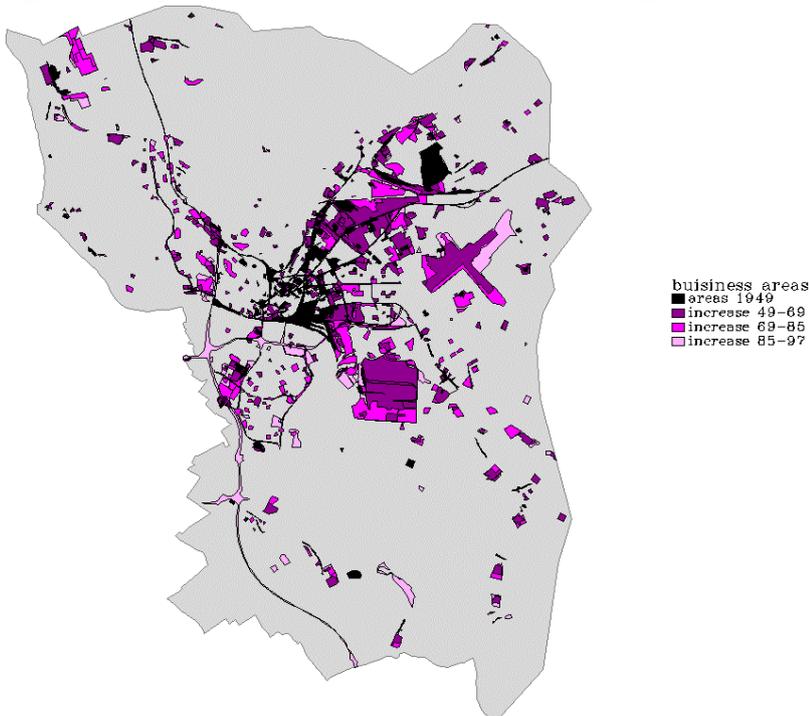


Figure 2. Increase in Business Surfaces

3.5 Loss of Agricultural Surfaces

The increase of artificial surface was discussed in the previous chapters. The increase in these groups needs some resources from other classes. The agrarian structure was the main source for the artificial increase. The increase of residential and business area forces the loss of fields. The biggest changes took place around the centre and the development axes of artificial increase. The correlation is significant.

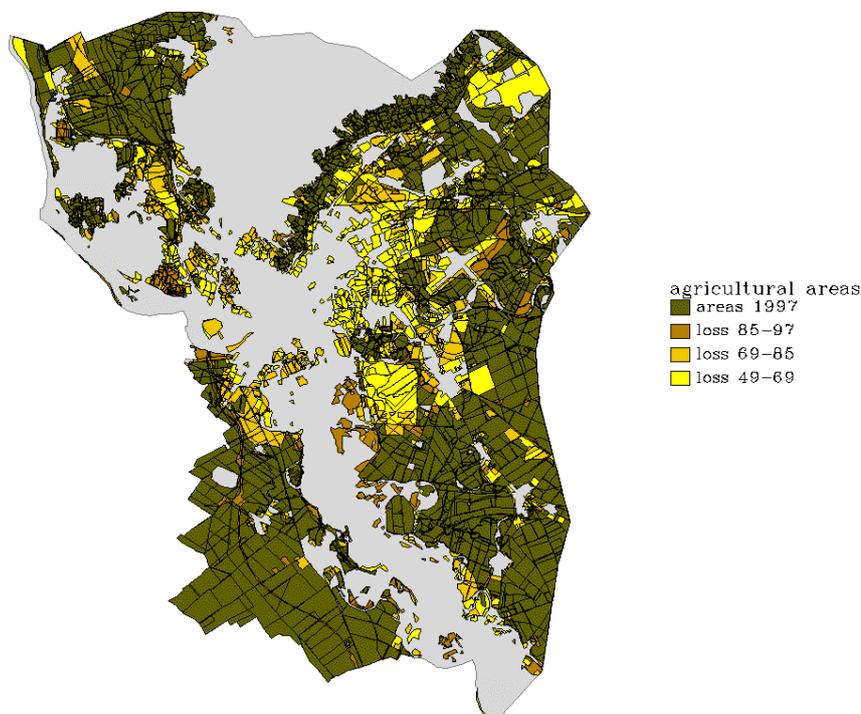


Figure 3. Loss of Agricultural Surfaces

3.6 Changes in Transport Network

The changes in line-features seem very small on the first view. The class of other roads (1.2.2.2) is dominant with some big increase after 1949 and then some loss again. There was some loss of roads during changing structure of field and field units in the agricultural area. In that case there was some kind of „road-shift“ from the surrounding to the artificial built-up areas. In that case in the statistic it looks more linear. The increase of railway-lines became after 1969 very small and was mostly depended on the industrial grow. Definitely some normal railway lines have been lost for example the railway-line (tram) to Vienna, which went through Petržalka. Big increase on small level exists since 1985 for toll-ways.

3.7 Changes of the Past and Trends for the Future

The changes of agrarian landscape to artificial fabric were shown. The increase of residential area had the biggest value between 1949 and 1985. Also the industrial area grew very strong and demonstrates the big importance of Bratislava for chemistry. The trend analysis showed that the increase-rate went down since 1985 especially for residential fabric. In the demographic studies was shown that it had no influence on the increase of inhabitants. The concentration on the existing areas supported this development.

The increase of artificial surface was compensated by the loss of fields. The loss in forest areas was based on the dam building at Danube river. The loss of mead-forest areas around the old arms of Danube river has an increase of water-areas on the other side. A further increase of water areas can not be expected. The forest areas also will keep its size.

The further development of Bratislava can be expected in residential and business fields. New industrial areas just growing in the north west of the city, where „Volkswagen“ builds up a new buildings of their factory. Also along the new highway, there can be expected the settlements of commercial and industrial companies. All need of area will be compensated by agrarian fields. Forest areas are not very much suitable for changes, because they are either placed in the mountains or along the Danube.

With the roll as capital of Slovak Republic, the change of existing structure to public service and also further concentration of residential area may take place in the central part of Bratislava. The increase of industrial areas will slow down; the increase of public-service areas will grow.

4 CONCLUSIONS

This Project demonstrated that methods of remote sensing and photogrammetry in GIS environment by using satellite and aerial photos are irreplaceable for multitemporal analyses. In the following stage it is suitable to enlarge such study about environmental problematic, urban planning, development of tourism and to connect cities along corridors. MURBANDY continues into the 5th Framework Programme as MOLAND – Monitoring Land Use and Land Cover Dynamics.

ACKNOWLEDGEMENTS

We thank the JRC for supporting and financing this project. The co-ordination of this kind of work for several European cities enables a very good comparability of them. To develop forecast activities will be one of the next objectives.

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