LAND COVER CHANGES IN THE REGION OF ROSTOCK - CAN REMOTE SENSING AND GIS HELP TO VERIFY AND CONSOLIDATE OFFICIAL CENSUS DATA?

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ABSTRACT:

Remote Sensing and GIS techniques are very helpful and useful tools for decision makers. A particularly important application of remote sensing data is the generation of land use and land cover maps. The analysis of land cover changes in the region of Rostock over the period of 1973-2006 was carried out based on the interpretation of satellite imagery from Landsat MSS (1973), Landsat TM (1989), and Landsat ETM+ (1999) and assisted by detailed CORINE 1990/2000 and ATKIS 1999 information on land use. The satellite imagery has been analysed based on an object-oriented image classification approach as an alternative to pixel based classification. Census data are acquired and published in many countries on a more or less regular basis, for instance annually. Data collected are e.g. the number of inhabitants, the birth, mortality, and migration rates. In some cases more detailed information might be available considering settlement and housing activities and others. These data registers are part of the administration processes in municipalities, counties and states. At all administrative levels development strategies and decisions are often based on this data. The data are however not always analysed with spatial information systems nor visualised with spatial mapping technologies. In this research project we try to link official statistical data with the results of remote sensing data and GIS. The hypotheses for our research are as follows:- Remote sensing data and official statistical data are simply different measures to quantify land use/land cover and land use/land cover changes, especially related to settlement activities.- Official statistical data are very often at a more coarse level, remote sensing data may consolidate the official statistics and may show the real spatial distribution of area sealing caused by settlement activities. - Thus a combination will strongly improve decision making and strategic planning at administrative levels.

1. INTRODUCTION AND MOTIVATION

1.1 Land use and land change

Land use is a key indicator for the evaluation of environmental impacts caused by human activities. The change of land use represents one of the most important factors influencing terrestrial and aquatic ecosystems. Land use and/or land cover changes play a major role in global environmental changes, as they significantly change the boundary relationship between the Earth and the atmosphere. Natural and anthropogenic changes in land use affect many landscape features, and interact in a variety of ways - for example on the global carbon cycle - with the climate system (IPCC, 2000). The resulting changes in climate, carbon cycle, loss of biodiversity, sustainability of agriculture and water cycle may result consequentially in further changes in land cover and land use cause. Research and investigations of land use changes in the past decades have become more and more widespread.

Urban sealing is a major problem worldwide. Continuously increasing settlement activities of human beings result in loss of natural soil resources and impact on the urban ecosystem and the quality of life of mankind. The land consumption for settlement purposes and traffic infrastructure today in Germany, as in other industrialised nations, belong to the most urgent environmental problems. In Germany an average area of around 129 hectares (≈ 175 football pitches) is urbanised daily, a major part of it is sealed. The German parliamentary Enquete-Commission “Protecting the human being and the environment” in 1998 stated that the annual newly used areas should by 2010 be reduced by 10% compared to the level of the years 1993-1995. The goal of max. 30 hectares/year in 2020 should be reached by limiting sealing by a sustainable (economical, ecological and social) settlement development policy.

The use of remote sensing technologies to determine the total sealing and the changes over time is very common. The combination with GIS allows the derivation of the relevant information for the management and strategic planning in municipalities and counties.

1.2 Remote sensing and GIS

Remote Sensing and GIS techniques offer highly sophisticated methods and tools for decision makers. A particularly important application of remote sensing data is the generation of land use and land cover maps. Since the 1970s, remote sensing data are available on a more or less regular basis and at an acceptable quality level. In the last decades, remote sensing has evolved to be a very innovative and powerful methodology for tasks in the field of land use documentation and land change monitoring. Around the world, many working groups on "GIS and remote sensing in the urban environment" are discussing innovative methods and the use of new sensors. Results are periodically presented and discussed e.g. in the workshops of EARSeL organisation on land use/land cover, the International Symposium on Remote Sensing of Urban Areas, the international remote sensing forums of the International Society for Photogrammetry and Remote Sensing (ISPRS) and the International Geoscience and Remote Sensing Symposium (IGARSS).

1.3 Research contributions from Rostock University

Research related to land use and land use changes, urban growth and urban sealing determination has been carried out at the Chair of Geodesy and Geoinformatics at Rostock University for over a decade. This has covered satellite-based approaches using Landsat, SPOT etc. as well as airborne related procedures using the digital airborne camera systems HRSC (High Resolution Stereo Camera) and our own imaging system development PFIFF (Precision Farming-Integriertes flugzeuggestütztes Fernerkundungssystem). Visual interpretation and automatic classification procedures have been used to investigate the land use changes in and around Rostock for the time period 1989 until today. This paper links to these research activities and tries to contribute new aspects related to

• monitoring and documentation of the land use and change detection in the Rostock region from 1973 until now,

• algorithm developments to determine land use and land use changes using remote sensing data and

• integration of GIS data with statistical and socio-economic data registers and reports.

In this research project we try to link official statistical data with the results of remote sensing data and GIS. The hypotheses for our research are as follows:

- Remote sensing data and official statistical data are simply different measures to quantify land use/land cover and land use/cover changes, especially related to settlement activities.

- Official statistical data are very often at a more coarse level, remote sensing data may consolidate the official statistics and may show the real spatial distribution of area sealing caused by settlement activities.

- Thus a combination will strongly improve decision making and strategic planning at administrative levels.

2. THE INVESTIGATION AREA – ROSTOCK AND ITS SURROUNDING

2.1 Urban developments in Rostock and its surrounding

The study area is the region of Rostock, located in the federal state Mecklenburg-Western Pomerania (MWP) in the north eastern part of Germany close to the Baltic Sea. It includes the administrative area of the city of Rostock plus a selection of surrounding communes in the county of Bad Doberan. The study area covers in total 1543 km². At the end of 2006 there were a total of - according to initial indications – about 320.000 inhabitants in the study area.

In the hanseatic city of Rostock, the population grew from 130,000 inhabitants after World War II, about 199,000 residents in 1970 to around 250,000 inhabitants in 1989. The main reasons for this were the creation of the overseas port, the harbour, and the establishment of marine and shipyard industry during the GDR years. Following the reunification, since 1990 in Rostock a 20% decrease in population has occurred.
In the area of the county Bad Doberan the population changed from 1950 with 120.000 until 1989 to less than 100,000. Since then the population in the county surrounding Rostock has increased by nearly 20%.

However, there are significant regional and local differences. Some communities are still growing, others are shrinking. The given figures compare the population densities of the years 1971 with 1990 (Figure 1) and 1990 with 2006 (Figure 2). For each municipality the number of residents is divided by the area size to compute the so-called traditional population density. The population density in the whole of Germany is around 207 inhabitants per square kilometre, whereas in Mecklenburg-Western Pomerania the population density is only 75 inhabitants per square kilometer. Our study area is the most densely populated region in MWP.

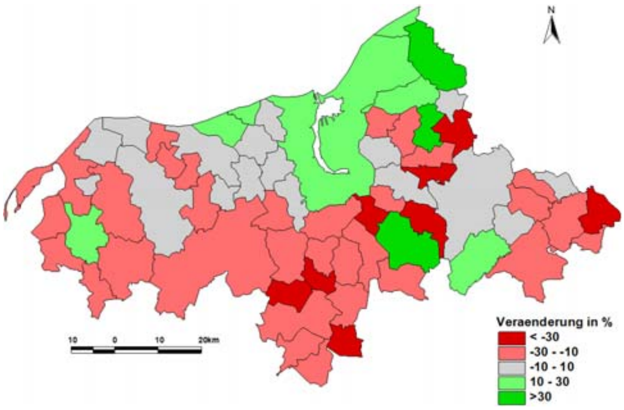


Figure 1. Demographic development (population density changes) between 1970 and 1990 (red = loss, green = increase).

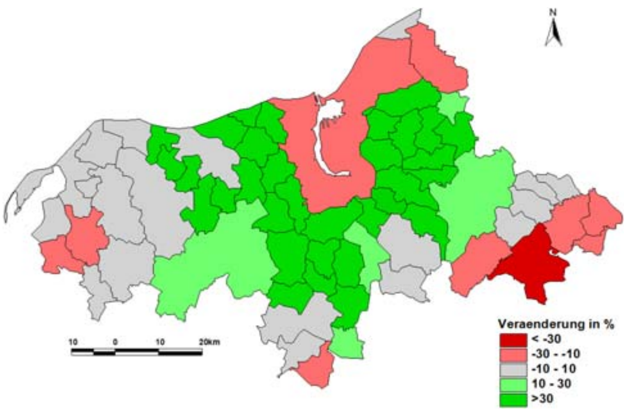


Figure 2. Demographic development (population density changes) between 1990 and 2006 (red = loss, green = increase).

Figures 1 and 2 illustrate the dramatic changes in population density over the last decades. During the former GDR period a concentration in the city of Rostock took place, whereas after the reunification the typical process of suburbanisation happened. Nevertheless the visualisation of these census data does not show the real distribution of settlement activities and the spatial pattern of area sealing in this study area, giving a chance for GIS and remote sensing data to go into more details.

2.2 Preliminary investigations

At the chair of Geodesy and Geoinformatics at Rostock University there is a long tradition in determining and analysing land use and land use changes using imagery captured by remote sensing (e.g. Grenzdörffer, 2005).

In order to analyse the changes in the hanseatic city of Rostock and the surrounding area, Riechelmann et.al. (1997) used Landsat TM images from 1989 and 1995 separately classified. For the efficient documentation of the process of urban sprawl and land use changes Riechelmann et.al. (1997) created satellite maps of Rostock 1989 and 1995 in the scales 1:100.000 and 1:50.000 using image fusion of SPOT data (pan-chromatic 10*10m ground resolution) and Landsat TM data (multi-spectral 30*30m ground resolution). Based on this they evaluated the Landsat TM data using supervised classification with the maximum-likelihood method and derived a map of the land use changes between 1989 and 1995.

Fiebach (2004) developed in her thesis, based on practices and procedures in other cities and optimized to the requirements of the Environmental Agency in Rostock, a cost-effective method to derive the current area sealing in large scales (1:1000 to 1:2500) using HRSC-aerial imagery from 2000/2002. The data of the HRSC high-resolution camera AX recordings were supplemented by data from the Automated Property Map (ALK) and visually interpreted to determine the surface cover. The presentation of the results and the calculation of ecological indicators such as the sealing degree, a modified sealing degree, a soil function number, a habitat area factor and a climatic-ecologic-hygienic value for the quantitative evaluation of the above-mentioned effects is done in a geographic information system. Thus, the hanseatic city of Rostock is in a position to get a reliable and regularly updatable planning for these purposes.

Mai (2008) studied land use patterns and land-use changes in the municipalities of the county of Bad Doberan, based on CORINE 1990 and 2000 data to quantify and derive cartographic visualisations in the light of the concept of eco-efficiency of municipal structures.

Al-Hassideh and Grenzdörffer (2006) started to investigate land cover changes in the region of Rostock over the period of 1973-2006. This study was carried out based on interpretation of remotely sensed satellite imagery from Landsat MSS (1973), Landsat TM (1989), and Landsat ETM+ (1999). A further data set derived from satellite remote sensing is CORINE 1990 and CORINE 2000 covering the area of the states in the European Union. The federal states in Germany are delivering the ATKIS data since 1999, which is derived from topographical maps and orthophotos. ATKIS shows the topographical situation and the land use.

2.3 Existing data

2.3.1 Census data: The National and Federal Statistical Offices are the most important information service providers in Germany. Their job is to keep the necessary statistical information about the condition and development of society, economy, public sector and the environment. This creates an essential foundation for democratic processes and facts for political and private-sector decisions. These census data are acquired and published in many countries on a more or less regular basis, for instance annually. Data collected are for instance the number of inhabitants, the birth, mortality, and migration rates, in some cases more detailed information might be available considering settlement and housing activities and others. These data registers are part of the administration processes in municipalities, counties and states. At all administrative levels development strategies and decisions are often based on these files. These data are sometimes analysed with spatial information systems or visualised with spatial mapping technologies. In our study we integrated statistical data sets from 1970 until 2006: Table 1 shows the population development in this period.

1970	1981	1990	1994	1999	2006
416,397	427,568	343,079	423,480	319,741	319,354

Table 1: Population development in the study area

2.3.2 Satellite data: To study the land use in the investigation area, multispectral satellite data were used. For the study area, there are three small cloud free scenes of Landsat available.

Captured at	Sensor	Path/ row	Spectral resolution	Spatial resolution
29.05.1973	MSS	194/22	4 channels	75m
12.06.1989	TM5	194/22	7 channels	30m
03.08.1999	ETM+	194/22	8 channels	30m (15m)

Table 2: Main characteristic of the Landsat scenes used

2.3.3 CORINE: CORINE (CoORdination of Information on the European Environment, de.wikipedia.org/wiki/Corine) is one of the European Community founded programmes. The aim was to establish a uniform and in the EU comparable data record of the land cover and land use with an application priority to environmental problems. The basis of the mapping of CLC 1990 (Corine Land Cover) are the images of the satellite Landsat TM5. The updating for CLC 2000 used the ortho-rectified Landsat-7 ETM+ satellite data created in the project-2000 image. Corine Land Cover 2000 resulted in a pan-European harmonised update of the land use data.

In CORINE Land Cover the nomenclature covered three hierarchical levels: level 1 includes five very generic coverage themes (built-up areas, agriculture areas, forests, wetlands, water bodies), the second level is grouped in 15 groups, and the third level is divided in 44 species. The most common uses of CLC data are environmental, agricultural, land-use planning (16%, 15%), followed by general mapping (11%), with more than 50 applications. The following figure shows the result of the CORINE 2000 data for the study area.

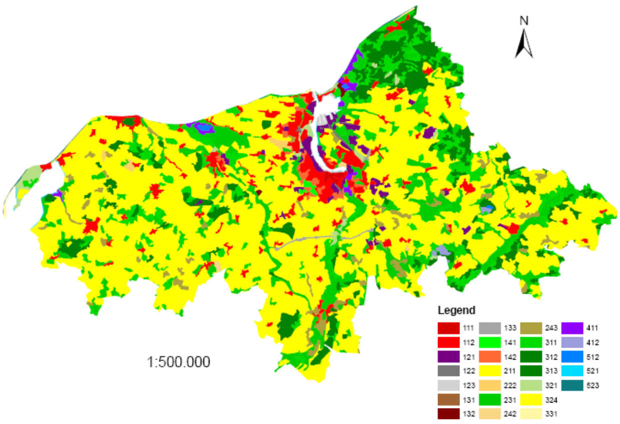


Figure 3. CORINE 2000 results for the investigation area.

2.3.4 ATKIS: ATKIS (in Mecklenburg-Western Pomerania finished in 1999, www.atkis.de), is a registered trademark of the German national survey and stands for Amtliches Kartographisch-Topographisches Informationssystem (Official Topographic Cartographic Information System). It is a uniform system nationwide offering topographical information in digital form (Bill, 1999). The ATKIS data collection is legally mandated and should be up-to-date. ATKIS is regarded as the basis for the landscape description of the German national survey. ATKIS provides an object-oriented approach, and signature-catalogue descriptions of the earth's surface in the form of the following digital models:

- Digital landscape models (DLM)
- Digital terrain models (DTM)
- Digital topographic maps (DTK, DTK-V)
- Digital orthophotos (DOP)

The first realisation level of the base-DLM (scale 1:10.000 to 1:25.000 approximately) included about 65 of 170 object types. In 1999 a second implementation stage with an update and an extension by about 55 object types took place. From 2004 the third expansion stage of ATKIS-base DLM began with further 15 object types, and a summarisation with new attributes and attribute values. For this investigation ATKIS provides geodata objects from feature classes such as settlement areas, transportation, vegetation, water and special territories. In addition a DEM (Digital Elevation Model) with 25 m resolution is available.

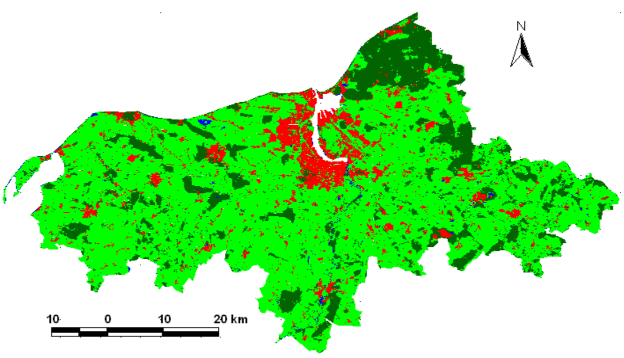


Figure 4. Reclassified ATKIS data for the investigation area.

3. METHODICAL APPROACH FOR THE REMOTE SENSING DATA

The remotely sensed satellite imagery has been analysed based on an object-oriented image classification approach as an alternative to pixel based classification. The following methods were investigated and a workflow was designed.

The remotely sensed data generally requires radiometric calibration, atmospheric correction and geometric correction of undesirable sensor characteristics and other disturbing effects before reliable data analysis can be performed. When using Landsat satellite imagery to map land use and land cover or monitor land cover changes, it is desirable to remove these effects by implementing a method which can produce a radiometrically consistent time series of images. In this study, image based COST algorithms for radiometric calibration and atmospheric correction were applied. This method is very important for multi-temporal analysis, a method using theoretical spectral radiance and image acquisition date was used to convert TM DN values to at-satellite radiance. The COST-based model was then employed to convert at-satellite radiance to surface reflectance in the study area.

The spectral enhancement in this study was performed by selection of colour-composites based on the calculation of the optimum index factor (OIF). The OIF is based on total variance within bands and a correlation coefficient between bands, a statistical approach to rank all possible three band combinations. Three band combinations with high total variance within bands and low correlation coefficient between bands will have high OIF-values indicating bands that contain more spectral information of the object (e.g. high standard deviation) with little "duplication" (e.g. low correlation between the bands). By using the OIF method, three band colour-composites can be evaluated on their effectiveness for display.

Image fusion is a concept of combining lower resolution multispectral image with higher resolution panchromatic data to increase the spatial resolution of multispectral imagery. Here, the high-resolution Landsat ETM+ panchromatic channel (14.25m ground resolution) was used to enhance the three multispectral channels (1,4,7) (28.5m resolution).

The data analysis was carried out with the software eCognition from Definiens AG. The three images were classified based on the standard nearest-neighbour method in five classes (urban, agricultural, coast, forest, and water). For accuracy assessment of the classification results, a TTA mask with independent samples was built in ArcGIS. An accuracy assessment was performed on the classification results. A confusion matrix of the TTA sites with the classification was produced. The overall classification accuracy is 95.9% for 1973, 98.95% for 1989, and 98.45% for 1999.

Multi-temporal analysis is a process to detect the changes which occurred on an area. Temporal analysis has been undertaken by considering differences between 1973, 1989, and 1999. Using GIS-intersection analysis, the changes can then be detected and quantified.

4. RESULTS

Change detection is the most common approach (post classification comparison) to detect the land use changes in terms of thematic classes. An advantage of the approach is that it provides "from-to" change information. In this section we want to present some of our results combining the official statistical data (e.g. population density and others) with the area sealing derived from land cover mapping by remote sensing and GIS. With statistical means we are able compute correlation and regression measures and analyse the spatial patterns in the municipalities to prove our hypotheses.

4.1 Change detection

Figure 5 shows the development of building spaces in the city of Rostock and the town of Bad Doberan between 1973 and 1999 to indicate urban changes derived from the satellite imagery. The dark blue colours indicate the newly established settlement areas, an information which is not available in such detail in the census data.

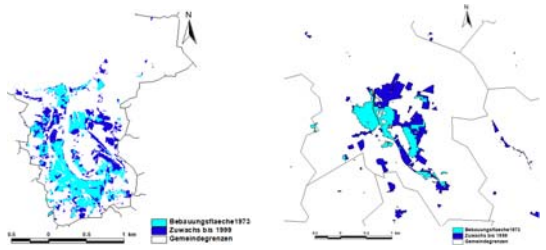


Figure 5: Development of building space in the City of Rostock (left) and the City of Bad Doberan (right)

4.2 Correlation analysis of the various data sets

For our research we use the percentage shares of the settlement area to the total area of the communities, namely from the databases CORINE, ATKIS and satellite data, and compared this with the official census data of our communes. Figure 6 illustrates this for 30 communes using the data from 1999. Portrayed is the linear correlation between the official statistics and the three other data sources for these communes. It results in high values of the linear certainty measure R^2 for all three comparisons. However, the values from CORINE are a factor of about 1.6 higher than those given from the official statistics. The reason for this is, that CORINE record is a result in the scale of 1: 100.000, i.e. details smaller than 25 hectares are not captured.

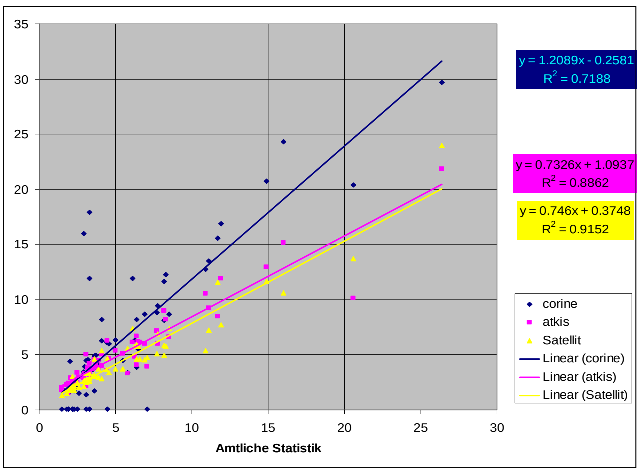


Figure 6: Correlation analysis between the official census data and CORINE (blue), ATKIS (purple), and remote sensing data (yellow)

Figure 7 shows a detailed comparison of CORINE and ATKIS related to settlement areas. One can easily recognise on the left side (ATKIS) the additional settlement areas in red.

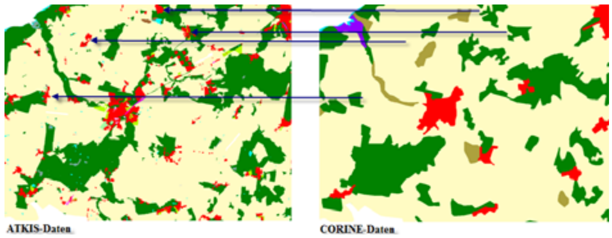


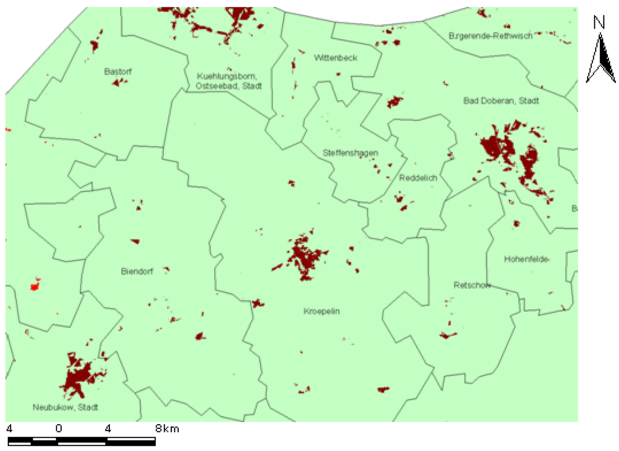
Figure 7: Unrecognised settlement areas comparing CORINE data (right) to ATKIS (left).

The ATKIS data show a better linear correlation ($R^2 = 0.8862$). Nevertheless, ATKIS results in a lower number of settlement areas. Only about 90 percent of the settlement areas are recognised.

The comparison with the remote sensing data provides the strongest linear relationship ($R^2 = 0.9152$). However, the percentage of settlement areas in the satellite data is about 23 percent over those from the official statistics.

4.3 Detailed investigations on land use measures

4.3.1 Population density: Satellite images are useful instruments to calculate the real population density distribution. The next figure determines the actual population density of urban areas in our region of interest. It shows that the population density in the larger cities decreased whereas a lot of smaller municipalities in the surrounding increased their population density. Most obvious is the decline of population density relative to the real estate area, resulting from a strong settlement expansion at a moderate population growth.



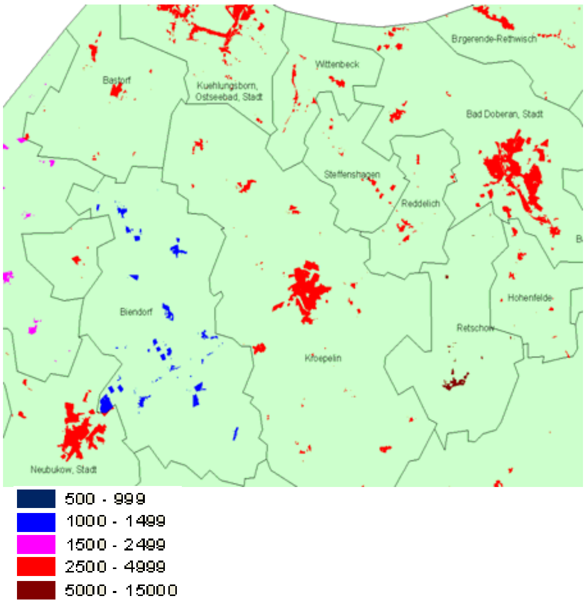


Figure 8: Comparing the actual population density (Inhabitants/ km²), (above: 1989, below: 1999)

4.3.2 Development of the housing stock

Looking to the published statistical reports for the period 31.12.1991 to 31.12.2005 the situation on completed apartments in residential buildings for the town and city districts of our study site is as follows (Figure 9):

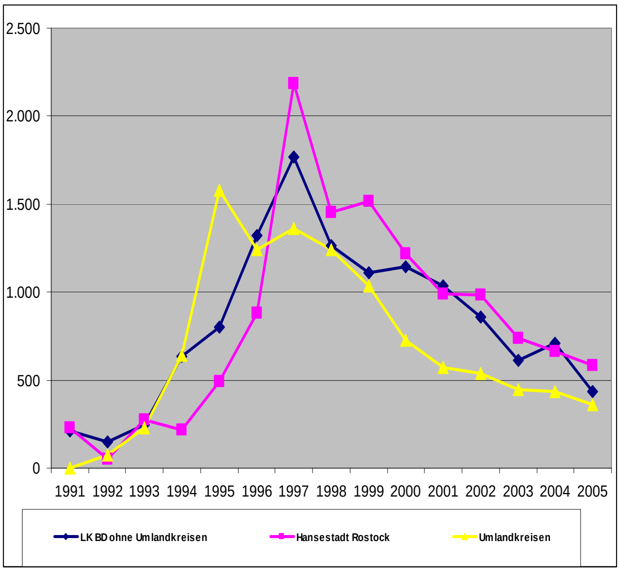


Figure 9: Housing (completed apartments) (development and cooperation within urban areas, 2006)

Between 1991 and 2005 a total of 47,549 homes were completed. After German reunification, the city of Rostock (purple colour) and the county of Bad Doberan had the highest growth of housing stock around 1997, whereas all communes close to Rostock (yellow colour) grew between 1993 and 1995. The steady decline in housing construction since 1997 illustrates the situation of the construction branch in the eastern part of Germany.

4.3.3 Living space per inhabitant and apartment: The next figures show the changes in living space within the last 15 years derived from the statistical records. One can easily recognize that in general the square meters living space per inhabitant (Figure 10) and per apartment (Figure 11) increased dramatically leading to a larger degree of area sealing. Especially in the suburban region (SUR) around Rostock the size increased, whereas the size of the apartments in Rostock (HRO) remained more or less stable.

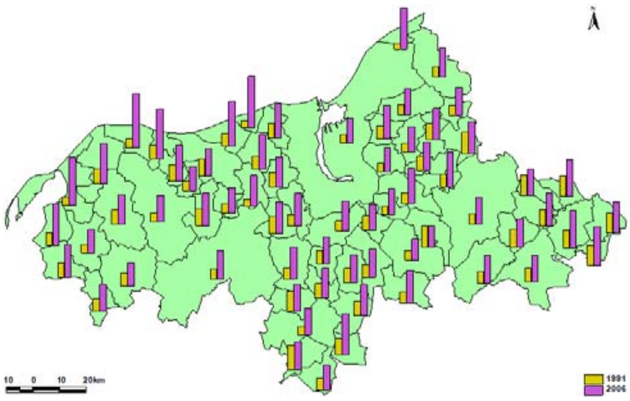


Figure 10: Living space per inhabitant (1991, 2006)

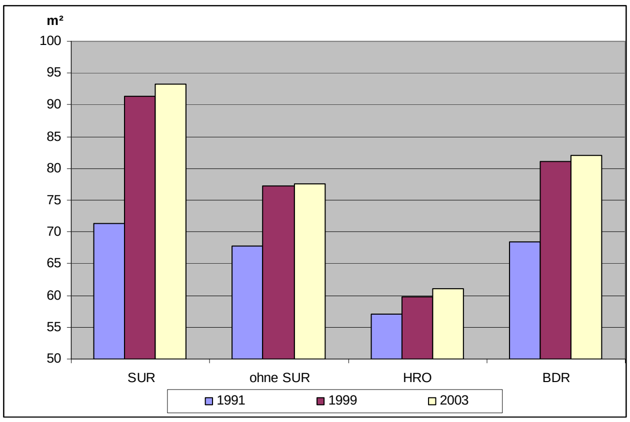


Figure 11: Living space per apartment

5. SUMMARY AND CONCLUSION

During the investigation period, for the primary types of land cover, distinct changes have occurred: urban areas increased by 50 % between 1973 and 1999 (~ + 3.000 ha), agricultural land decreased over the same time (~- 3.600 ha). Forested areas increased in the time frame 1973 – 1989, and have remained constant since then. Water bodies remained approximately the same during the whole time period. The strong increase of the urban land use/impervious area is due to two different processes. In the years between 1973 and 1989 the city of Rostock underwent a rapid growth in population and industrial areas. In the years 1989 to 1999, after German reunification, suburbanisation in the vicinity of the city of Rostock is the main driving force for construction of new houses and commercial areas.

Remote sensing methods proved to be very useful to monitor the land use developments of large cities and their surroundings at different scales, both with automatic and visual procedures. Feature-based procedures are needed for a successful classification with high resolution imagery, including GIS-data if available. Updating of these data is becoming more important, especially for strategic planning activities.

This research has proven the hypotheses stated in the introduction. There is a good correlation between census data and remotely sensed image analysis. However, remote sensing data are able to show the spatial patterns of settlement activities and area sealing in a much more detailed way.

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