MULTI-DATA APPROACH (MDA) FOR ENHANCED LAND USE / LAND COVER MAPPING

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ABSTRACT:

For spatial decision support and regional (agro-)ecosystem modeling, land use data are of central importance and have to be available in a spatial data infrastructure for regional modeling. Usually, land use data are available, but they lack the desired information detail for many purposes. For example, in official land use maps, agricultural land use is generally differentiated between arable land, grassland, orchards and some special land use classes like paddy fields. For detailed agro-ecosystem modeling, this information resolution is rather poor. Here, disaggregated land use data which provide information about the major crops and crop rotations as well as management data like date of sowing, fertilization, irrigation, harvest etc. are needed. The analysis of multispectral, hyperspectral and/or radar data from satellite or airborne sensors is a standard method to retrieve such kind of information with remote sensing methodologies. By using a Multi-Data Approach (MDA), the retrieved information from multitemporal and multisensoral remote sensing analysis can be integrated into official land use data to enhance both the information level (e. g. crop rotations) of existing land use data and the quality of the land use classification. The workflow of the MDA to generate enhanced land use and land cover data consists basically of two components: (i) the methods and data of the remote sensing analysis and (ii) the methods and data of the GIS analysis.

1 INTRODUCTION

For spatial decision support and regional (agro-)ecosystem modeling, land use data are of central importance and have to be available in a spatial data infrastructure (SDI) for regional modeling (Bareth and Yu 2007, Bareth 2001). The SDI should be organized in a Spatial Environmental Information System (SEIS) which comprises geobase, soil, weather/climate, hydrology, fauna/flora, management, and of course land use data (Bareth 2008).The latter should be organized in a Land Use Information System (LUIS) according to international data standards providing general metadata including information about data quality. Usually, land use data are available, but they lack the desired information detail for many purposes. For example, in official land use maps, agricultural land use is generally differentiated between arable land, grassland, orchards and some special land use classes like paddy fields. For detailed regional agro-ecosystem modeling, this information resolution is rather poor. Here, disaggregated land use data which provide information about the major crops and crop rotations as well as management data like date of sowing, fertilization, irrigation, harvest etc. are needed. In this context, Kersebaum et al. (2007) define the major problem in regional application of (agro-) ecosystem models: ”Applications of agro-ecosystem models on a field or regional scale are mostly characterized by a high uncertainty of input data, especially regarding soil and management data”. The generation of management data in a spatial context on regional scale, the set-up of an Agricultural Management Information system (AMIS), is possible on the base of disagregated land use data (Bareth 2003, Rohierse and Bareth 2004).

The analysis of multispectral, hyperspectral and/or radar data from satellite or airborne sensors is a standard method to retrieve land use/land cover information with remote sensing methodologies. By using a Multi-Data Approach (MDA), the retrieved information from multitemporal and multisensoral remote sensing analysis is integrated into official land use data to enhance both the information level (e. g. crop rotations) of existing land use data and the quality of the land use classification (Butenuth et al. 2007).

In this contribution, we introduce (i) the workflow of the MDA to implement a LUIS, (ii) the results of case studies from Germany and China were the MDA has been successfully applied for regional modelling on various scales of matter fluxes from agroecosystems, and (iii) the LUIS-based regionalization of management data to implement an AMIS.

2 MULTIDATA APPROACH (MDA)

The MDA is based on the approach of integrating remote sensing classification data into official land use data (Bareth 2001). The workflow of the MDA to generate enhanced land use and land cover data consists basically of two components: (i) the methods and data of the remote sensing analysis (remote sensing part) and (ii) the methods and data of the GIS analysis (GIS part). In Fig.1, the workflow of the MDA is shown. The task of the remote sensing part is to classify multitemporal (and multisensoral) satellite imagery and to provide classification assessment in terms of data quality. By considering multitemporal stallite imagery, the identification of crop rotations and therefore of crop management in a spatial and temporal context is of key importance. The results are imported into a GIS environment. Here, the classified data are overlayed with additional relevant data from third sources. These are usually official topographic or land use data. Depending on the task and quality of the available data, selected feature layers are overlayed with the imported classification data. Here, the idea is to use high quality topographic spatial information e.g. about residental area. In the latter case, all other land use classes of the remote sensing analysis will be not considered.

Besides official land use data which are available in topographic information systems like the German official topographic-cartographical information system called ATKIS (www.atkis.de) or the official land use database of China, numerous land use information are stored in various spatial databases, like spatial biotope/biodiversity databases (e.g. in Germany), spatial databases of national parks or research projects, water protection areas etc., and can be used for such an approach as an important spatial knowledge source about management. In Germany for example, the amount of N-input applied by mineral fertilizer in water protection, nature conservation, or bitope areas are limited and controlled. These source contains also high quality land cover information which can be considered in the final land use data.

Additionally, land use data from official statistics like agricultural or land use data have to be integrated into such a LUIS. Information like arable land per administrative unit, total sown area etc. can be retrieved from these sources and can be used to crosscheck remote sensing analysis. And for the simulation of land use and land cover change (LUCC) scenarios, the results of land-cover change models have to be incorporated. Another method to provide land use change scenarios for forest and/or agricultural ecosystems is the socio-economic modeling of regional farm/management units considering environmental or political restrictions (Bareth and Angenedt 2003). The output of such models are optimized land use scenarios according to the model restrictions which does not represent a current situation. Methods and models how to create land use maps from these results have to be considered as well.

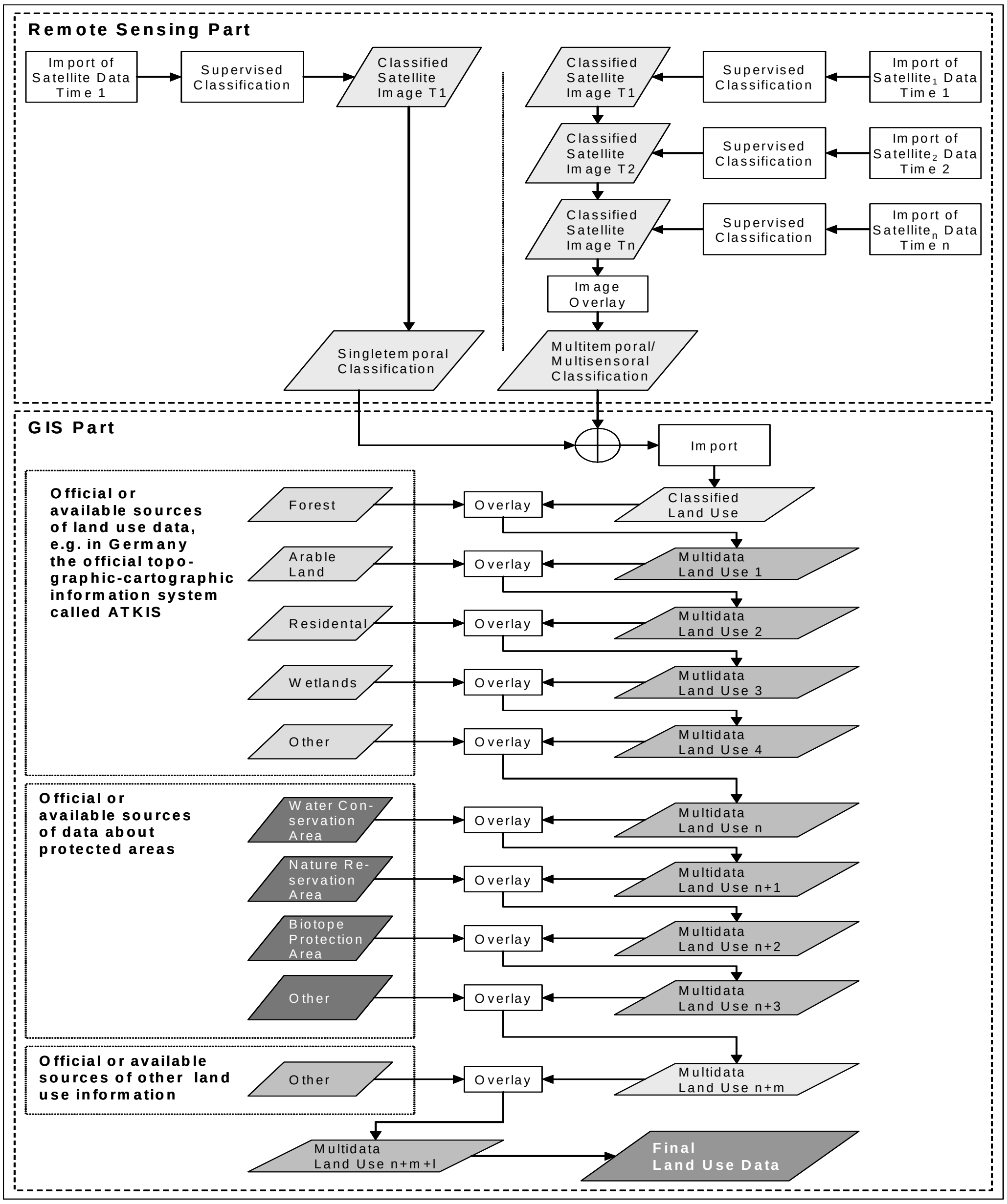

Figure 1. Workflow of the Multidata Aproach (MDA)

3 RESULTS

The introduced MDA was already applied with different sets of data sources for enhanced land use / land cover mapping by Bareth (2001), Rohierse and Bareth (2004), Bareth and Yu (2007), and Waldhoff and Bareth (2008). The case studies were carried out for different German regions and for the North China Plain.

3.1 Arable land region "Kraichgau"

The Kraichgau is located in the North-West of Baden-Württemberg which is the South-Western state of Germany. To the South-West of the Kraichgau, the Black Forest and to the North the Odenwald are bordering. To the west the Rhine River and to the North-East the Neckar River are framing the study area (Rohierse 2003). The study region covers an area of approx. 850 km^2.The Kraichgau is an intensively used agricultural region and the land use is dominated by arable land. Loess is the dominant substrate for soil development and elevation ranges between 100 m and 400 m. Average temperature is around 9 °C and annual precipitation ranges between 720 and 830 mm. Heavy rainfall occurs typically in summer (Rohierse 2003).

The database for the MDA in this case study consists of multitemporal IRS 1C/D remote sensing data, the official German topographic-cartographic information system (ATKIS), the digital biotope vector database, and water and nature reserve vector data. All geodata were compiled in a scale of 1:25.000.
The date of the remote sensing data acquisition were for the year 2000 April 8th and August 11th. For the year 2001, the IRS data were purchased for May 2nd and July 5th. Spatial resolution of the panchromatic channel is 5.8 m and 23.5 of the multispectral bands. For the analyses of the images, the NIR, red, and green bands were used. On the base of extensive GPS field surveys, a supervised maximum-likelihood classification was carried out resulting in following land use classes: winter cereal, summer cereal, maize, sugar beet, pasture, klee und zwischenfrucht, and fallow. .

Follwing the MDA, this multitemporal remote sensing land use was overlayed with the above mentioned geo data to mask out everything besides agricultural land use. The latter was incorporated by the remote sensing analyses results. The overall accuracy of the classifications were for the year 2000 81 % and for the year 2001 87 % (Rohierse and Bareth 2004). In Fig.2, the MDA land use map is shown. The value of the MDA approach is clearly visible by recognizing spatially disaggregated land use information. All land use classes on the right side of the legend usually are represented by one or two land use classes in the official data source ATKIS.

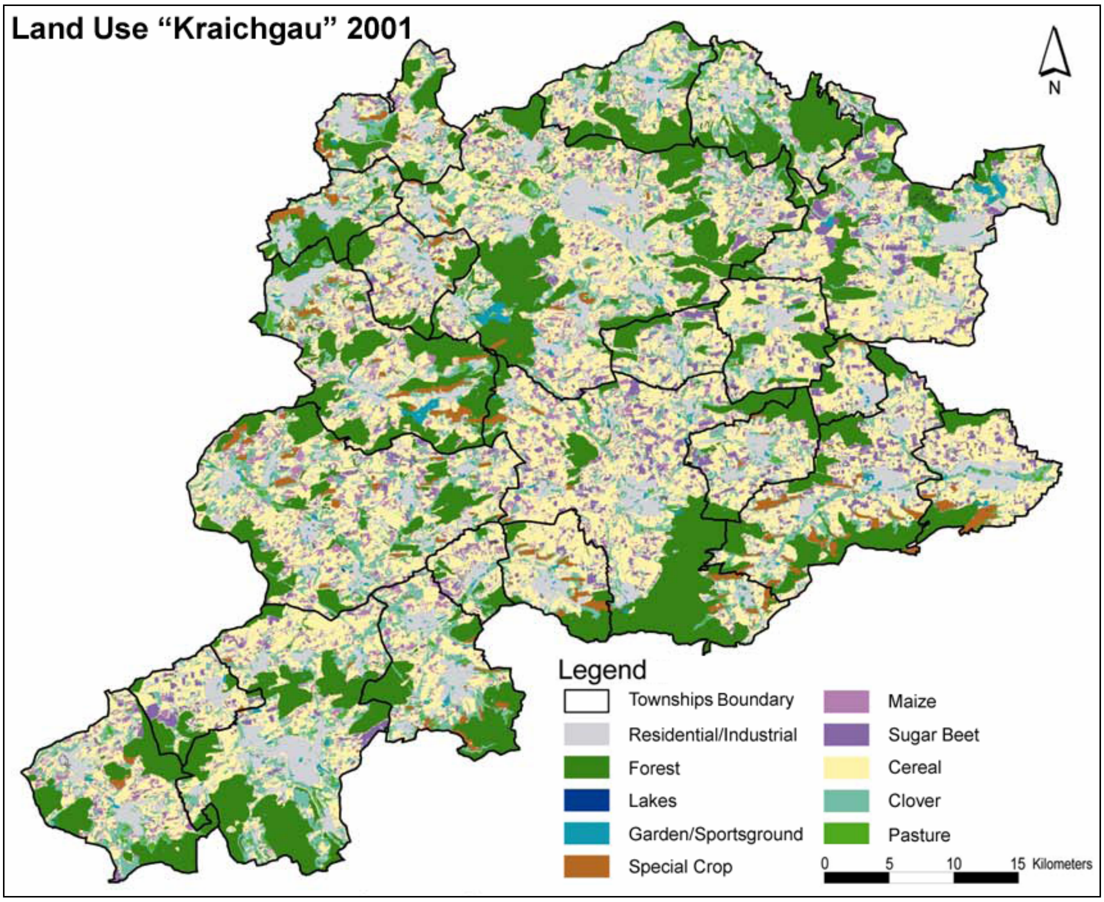

Figure 2. MDA land use map for the "Kraichgau" (Rohierse and Bareth 2004)

3.2 Agricultural land region "Rur-Watershed"

The collaborative research centre TR32 works in the Rur-Watershed in Western Germany on exchange processes between soil, vegetation and the adjacent atmospheric boundary layer. The overall research goal is to yield improved numerical models for the prediction of water-, CO_2- and energy-transfer by accounting for the patterns occurring at various scales.

Researchers from several departments of the Universities of Aachen, Bonn, and Cologne as well as of the Forschungszentrum Jülich are involved in the project: Chemistry, Landscape Ecology, Geography, Geophysics, Meteorology, and Soil Science. More information about the project is available online (http://www.meteo.uni-bonn.de/projekte/tr32-wiki/).
For the proposed MDA for the Rur-Watershed, ASTER data and official topographic data, the German ATKIS, were purchased. Besides the overall Rur watershed, the TR32 is conducting intensive field research in the 3 sub-watersheds which are indicated in Fig. 3. The yellow rectangle indicates the test area for the proposed MDA which is presented in this contribution.

In a first step, ASTER data was pre-processed and analyzed. The 'Advanced Spaceborne Thermal Emission and Reflection Radiometer' (ASTER) is a multispectral sensor onboard NASA's TERRA platform that records reflected and emitted radiation in 14 spectral bands, three in the visible near-infrared (VNIR), six in the shortwave infrared (SWIR) and five bands in the thermal infrared regions, with 15, 30 and 90 m spatial resolution, respectively (Fujisada 1995, Yamaguchi et al. 1998). Due to its suitable spectral coverage for landcover mapping, especially in the VNIR and in the SWIR region, in combination with the good spatial resolution, ASTER AST_07XT data from May 01, 2007 was chosen for the classification. This ASTER data product is already radiometric corrected for sensor crosstalk (Iwasaki and Tonooka 2005) and atmospheric attenuation (LPDAAC). For the supervised classification, extensive field surveys were carried out in order to sample training and evaluation data. This data is applied for the classification and for the evaluation of the results. To better utilize the huge information content of modern multispectral remote sensing datasets like ASTER, Spectral Angle Mapper (SAM) (Boardman and Kruse 1994) was used for the mapping of land cover types. SAM is a physically-based classification algorithm that compares the spectral similarity between image spectra and reference spectra (Kruse et al. 1993). The error matrix was created by using the surveyed evaluation data and not by applying the training data again.

The generated remote sensing land use data were overlayed with available ATKIS land use data (see above) in a second step. The result are land use data containing the RS and ATKIS land uses. The third step, knowledge-based rules were applied on the ASTER/ATKIS land use database table to determine the final MDA land use from the different sources. In this study, only the ASTER information for arable land was considered. All other land use information as well as the main feature outlines are ATKIS properties.

The error matrix for the considered land use classes of the test area show very good results (Waldhoff and Bareth 2008). The overall accuracy for the surveyed evaluation data which was not used to train the classification is 98,5 % and the Kappa Coefficient is 0.98. It is obvious that the classification of the various field crops worked very well. All crops were identified with an accuracy of > 90 %.

The quality of the ATKIS data is very large due to the fact that it is created from data in scale of 1:5.000 - 1:10.000 and has to fulfill the high administrative quality standards for topographic data 1:25.000.

In Fig. 4, the results of the MDA for the considered test area are visualized. It is clearly visible that the information detail for land use by applying the MDA increased significantly. Arable land is now differentiated in different arable crops land use classes.

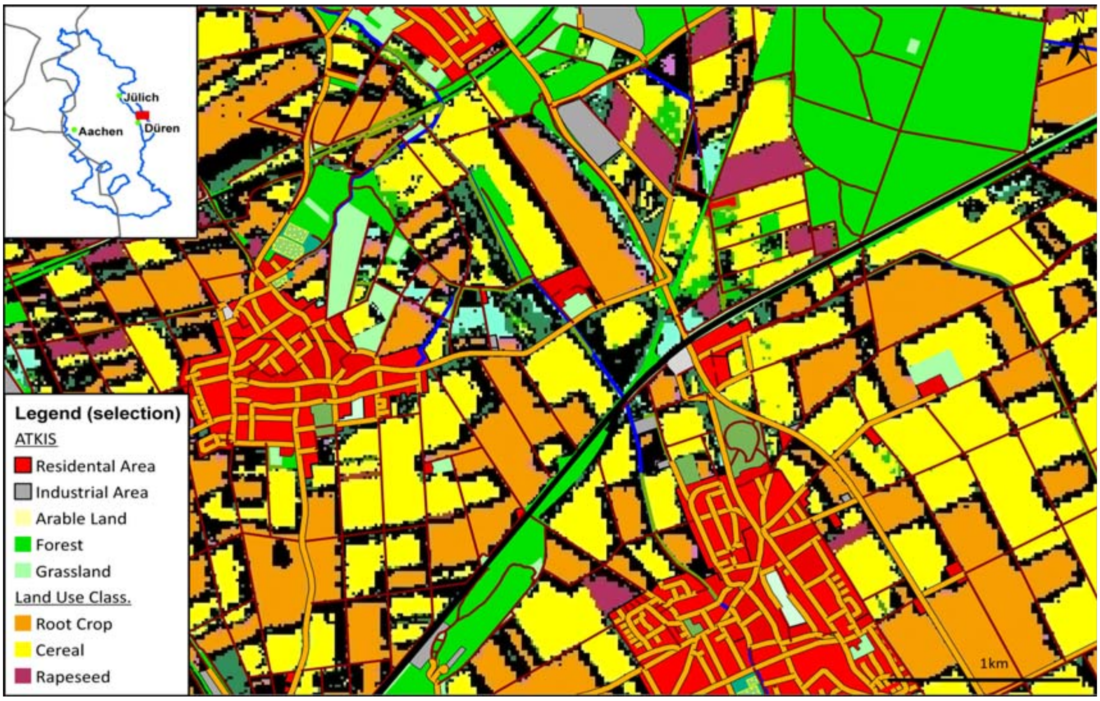

Figure 3. MDA land use map for the “Rur-Watershed” (Waldhoff and Bareth 2008)

3.3 Arable land region "North China Plain"

The Sino-German Project between the China Agricultural University and the University of Hohenheim, Germany, started in November 1998 for 4½ years and was located in Beijing. The project was funded by the German Ministry for Education and Research (BMBF). The main research interest of the project was on sustainable agriculture in the North China Plain (NCP). Sustainable agriculture is a big issue in China. One major focus of the project was the establishment of an experiment field near Beijing to investigate different agricultural practices and their impact on yield and environment. The second task was to set-up a GIS based Agricultural Environmental Information System (AEIS) for the North China Plain (NCP), which exceeds almost the size of Germany. Researchers from several departments were involved in the project: Agricultural Economics, Agricultural Informatics, Vegetable Science, Landscape Ecology, Phytomedicine, Plant Nutrition, Plant Production and Soil Science. The major aim of the AEIS for the NCP is to provide information (i) about agriculture in the region, (ii) about the impact of agricultural practices on the environment and (iii) of simulation scenarios for sustainable strategies. Consequently, the integration of disaggregated land use data in the AEIS was one of the research tasks.

For the land use information system, three different data sources were used:

(i) Official land use data were purchased in a scale 1:100,000 (Beijing Municipality) and 1:250.000 (North China Plain) from the Institute for Remote Sensing Application (IRSA) of the Chinese Academy Sciences (CAS).
(ii) The official Chinese topographic vector data base was obtained from the National Geomatics Institute (NGI) of China. The vector data 1:250.000 was used which is available since 1999.
(iii) Landsat-TM data was ordered for Beijing municipality in order to analyze current land use.

The differentiation of agricultural land use is again not satisfying in the Chinese official land use and topographic databases. For the aimed regional modeling purposes of winter wheat agro-ecosystems, disaggregated land use information is essential. Therefore, the results of a supervised land use classification of a Landsat scene were incorporated into the official land use data.

In a first step, the arable land use class of the official land use database was selected and overlayed with the official topographic database. All area left with an agricultural land use were used to mask the Landsat image. Finally, the maximum-likelihood analysis was applied on the image based on training data in order only to identify winter wheat. The latter was surveyed with differential GPS. The classification on the masked data resulted in an accuracy of 84%.

The results of the MDA are shown in Fig.4. The official land use data is extended with one more land use class(see legend) for winter wheat. Winter wheat is displayed in black. It is clearly visible in Fig.4 that the MDA enables in this study the identification of one specific crop within the official spatial land use class for arable land. This disaggregated land use information was then applied for regional modeling of winter wheat agro-ecosystems (Bareth and Yu 2007). For the latter purpose, regional knowledge of the management (N-input, pest management, harvest et.) were linked to the spatial database, too.

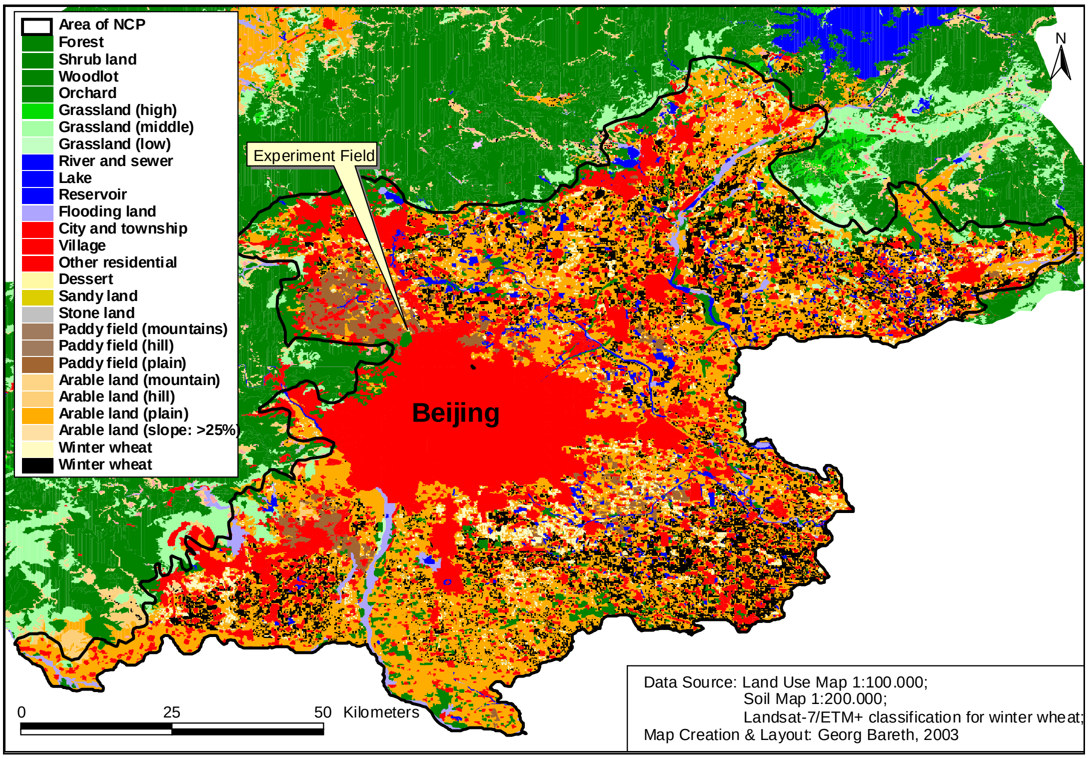

Figure 4. MDA land use map for Beijing Municipality (North China Plain) (Bareth 2003)

4 DISCUSSION, CONCLUSION AND OUTLOOK

The use and combined analyses of multiple data sources like remote sensing land use classification and official topographic or land use vector data results in a much higher information detail of spatial land use information (Waldhoff and Bareth 2008). In the desribed case studies, the combined retrieval of land use information from official land use data and remote sensing analyses following the MDA clearly has advantages compared to pure remote sensing based analyses. Official topographic datasets like the ATKIS provide vector layers containing various land cover information. By selecting distinct spatial information, depending on the task, the quality of a land cover/land use analyses can be increased essentially. For example, by using the high quality spatial information for residential, industrial, urban vegetation etc. from ATKIS, no agricultural land use is classified within these classes. Same counts for sport grounds, parks, vegetation covered roofs etc. Vice versa, in this study it is proved that the spatial land use information for agriculture can be disaggregated be incorporating the remote sensing classifycation into the ATKIS or official Chinese land use data. Additionally, combined approaches can be used also for geometric update of data which is described by Butenuth et al. (2007). The authors developed an algorithm to solve geometric discrepancies when combining various data sets.

The availability of such disaggregated land use data is a key parameter for successful regional (agro-)ecosystem modeling (Bareth and Yu 2007). Process-based models like the DNDC (Beheydt et al. 2007) are applied on regional or national scale but usually do not use adequate land use or management data (Kersebaum et al. 2007). Therefore, the disaggregated land use data was used to derive spatial management data on regional scale (see Fig.5).

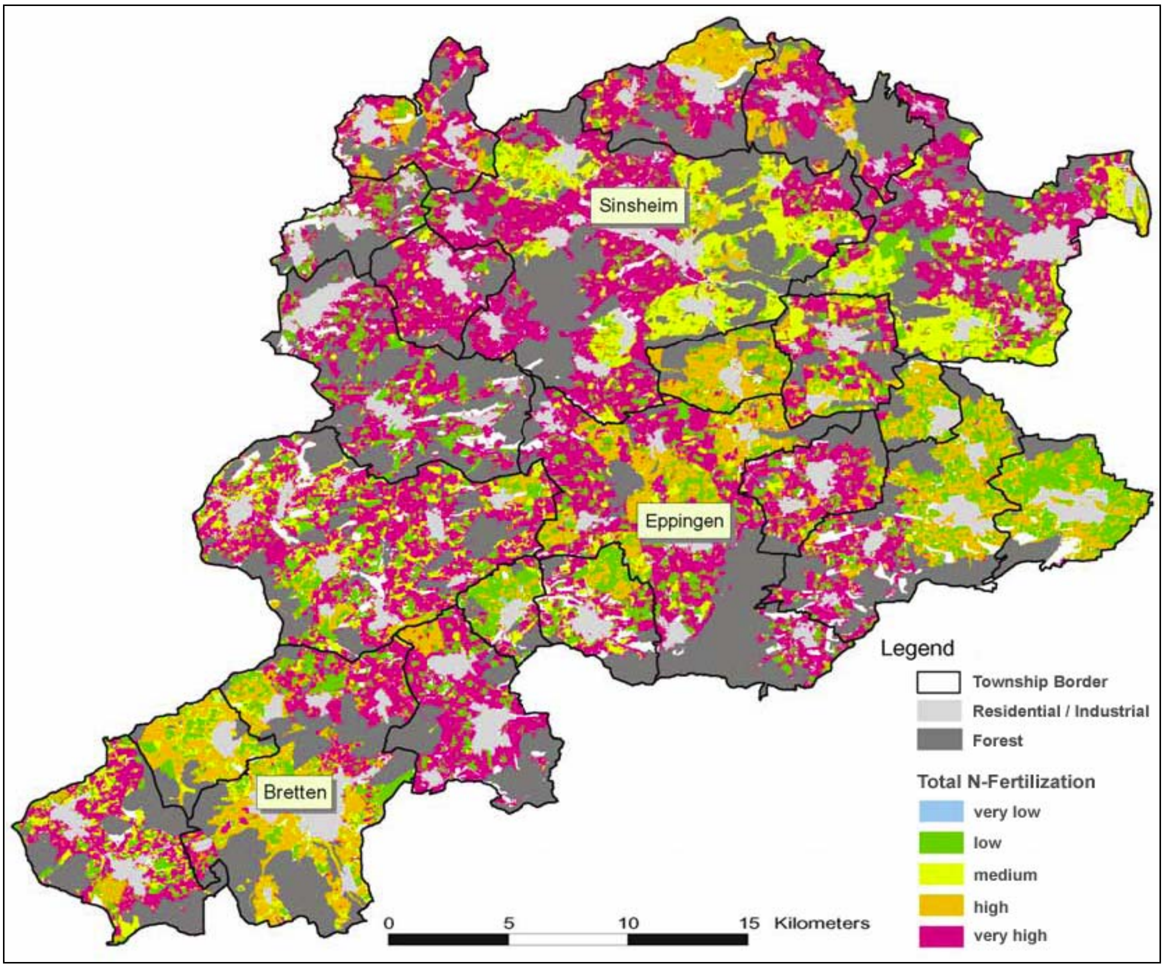

Figure 5. Regionalized total N-fertilizer input based on the MDA land use map for the Kraichgau (Rohierse 2003)

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