GENERATION OF A CONSISTENT SPATIAL DATABASE FOR A LAND USE PLANNING PROJECT IN SOUTH EASTERN CHINA (SILUP)

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ABSTRACT:

The joint German-Chinese research project SILUP (Sustainable Integrated Land Use Planning) aims in developing and implementing a strategy for sustainable land use planning in a rapidly developing study area south of Nanjing, Jiangsu province, China. Because of the rapid development of the site there is a high pressure for land to be transferred from agricultural use into industrial use. Sustainable development in this context means simultaneously respecting the ecological and socio-economical value of land, judging it and finding the best suited areas to fulfil the demands. For the ecological side, water management aspects as well as biodiversity and soil aspects are of importance. Areas with important functions for groundwater recharge, surface water runoff, biotopes and the like have to be identified and protected from land use change. The output of the SILUP system is a categorized map which shows land use planners, where agriculturally used areas can be a target for further development. This paper presents the integration of various data sources into a consistent spatial database which was the working fundament of all institutes participating in the SILUP project. The emphasis of the project work was not set in the highest possible degree of automation for each task but on the generation of a consistent database which is usable by all project partners with their strongly different demands on accuracy and attribution. The SILUP project could be finished successfully and was highly acknowledged by the German BMBF (Federal Ministry for Education and Research) and the UNESCO.

1. INTRODUCTION

"Sustainable development" became a generally accepted principal objective of development planning and policy in the past years. A lot of effort has been made to concretise the principles involved. But there is still missing some sort of a general agreement on how to make the different effects of programmes and plans formally comparable in order to come to overall assessments that allow the preparation of the best possible decisions in the field of public development responsibilities. This issue will remain the most fundamental challenge of development in the near future. The SILUP project brought together experts from the most concerned disciplines in order to elaborate a procedure that would allow development planners to consider simultaneously well-founded compromises between socio-economic requirements and ecological constraints. As one major goal, land use planners should be given reliable and administratively applicable guidelines for minimising errors and negative effects associated with the land use part of development decisions.

The SILUP project started in September 1998, was terminated for three years and consists of 4 major groups: hydraulic modeling, socio-economy, ecology and GIS / Remote Sensing. For each group there is an institute from Stuttgart and one or two from Nanjing. The role of the GIS and Remote Sensing group was to provide the basic database in an actual and consistent way.

1.1 Study Area

The SILUP study area is located south of Nanjing, Jiangsu province, China. Nanjing is located at the Yangtze river, about 300km west of Shanghai. Because of the rapid development of the site there is a high pressure for land to be transferred from agricultural use into industrial use. Besides the successful developments there is coexisting a terrible waste of land resources and destruction of ecological systems. This has been a result of excessive attention on immediate interests, neglecting the loss in ecology and resources. But above all, there is a lack of a scientific basis and methods when experimenting with new development projects.

1.2 General Methodology

The SILUP project supports land use and land development planners with well-founded information and a methodical tool, with particular attention given to an appropriate set-up of basic data required for modern planning approaches. The basic idea of integrating all available information ist expressed in the use of a matrix aggregation scheme as proposed by (Ju, 1998). The matrix aggregation tree leads to a so called Final Classification Matrix (FCM).

The fundamental idea is that the FCM brings together the assessment of "socio-economic needs on the one hand, and the "ecological value of land", on the other (Figure 1). Both input channels are the result of a hierarchical matrix aggregation. Four input classes were defined, ranging from "low" to "very high". Thus the matrix contains 16 fields. While the extreme fields ("very high socio-economic requirements" and "low ecological value of land", on the one end, and "low socio-

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economic requirements" and "very high ecological value of land", on the other) suggest an easy classification of land as "available for transfer of non-settlement land to settlement purposes", in the first case, and "absolute protection", in the second case, the other 14 fields of the matrix have to be clustered into intermediate classes. The resulting FCM map thus provides a classification for unsettled surfaces that constitutes a valuable basis for the land use planners' decisions on where to conceive further transfers of non-settlement land to settlement purposes.

Conditions for Transfer		"Ecological Value of Land"			
		low	medium	high	very high
"Socio-Economic Needs"	very high	unrestricted use	on the basis of simplified env. impact analysis	after normal env. impact analysis only	on the basis of special studies only
	high	on the basis of simplified env. iImpact analysis	on the basis of simplified env. impact analysis	after normal env. impact analysis only	to be used in exceptional cases only
	medium	on the basis of simplified env. impact analysis	after normal env. impact analysis only	after normal env. impact analysis only	absolute protection
	low	on the basis of simplified env. impact analysis	after normal env. impact analysis only	to be used in exceptional cases only	absolute protection

Figure 1. The Final Classification Matrix

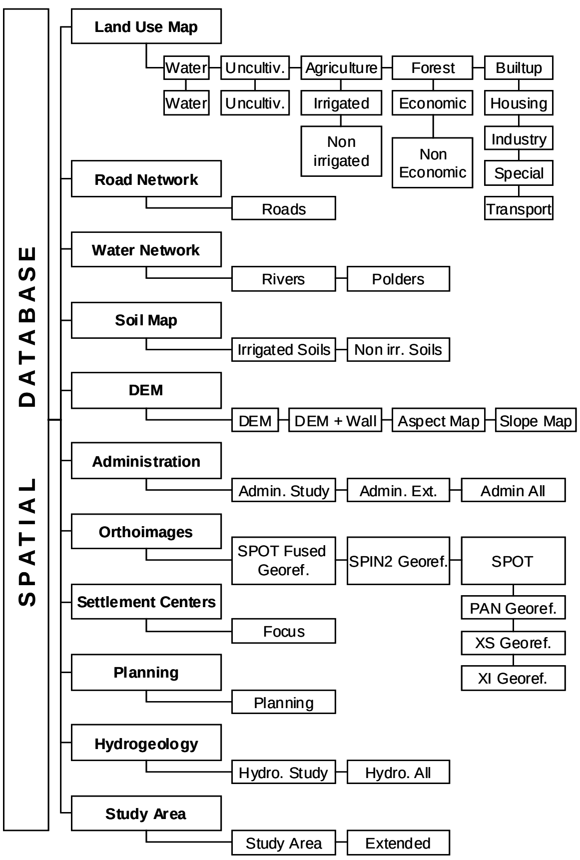

Figure 2. The hierarchical structure of the Spatial Database

2. THE SPATIAL DATABASE

All spatially related information which was used for further processing was organized in the SILUP spatial database in a hierarchical way, as illustrated in Figure 2.

The layout of the database was discussed and worked out jointly with Chinese and German partners. The layer-wise organisation provided a fast and easy access to all relevant spatially related data. In the spatial database exclusively such data were included which are consistent to each other, i.e. all layers have the same coordinate reference and map projection. Furthermore, care was taken that the single polygon layers neither do overlap nor do form gaps, in order to provide a unique and dense coverage of the whole study area. The land use map, e.g., was firstly set up and topologically structured completely, then decomposition into the various sublayers was performed.

3. DEM RECONSTRUCTION

A 50m-DEM was generated for the whole study area based on topographic information. In order to obtain a DEM which is hydrologically correct, constraints were applied to the DEM generation procedure using the TOPOGRID module from ARC/INFO (Hutchinson, 1988). The supporting data were in detail: polder areas, water bodies and river middle axes (Figure 3). The river middle axes were digitised manually from a topographic map and the water bodies layer of the spatial database. All rivers inside polder areas were removed since polder areas were decided to be treated as closed units. All river segments were oriented downstream, which is a prerequisite for the TOPOGRID module. Water bodies were used outside the polder areas. With the applied TOPOGRID module, firstly gradient directions perpendicular to the contour lines are computed and then the oriented river network is iteratively respected in order to interpolate a regular elevation raster with gradient directions consistent to the river network (Hutchinson, 1996). In the final run, 2000 iterations were carried out. After all raster cells were assigned the correct value, the lake and polder polygons were used to level all DEM cells inside the same polygon to a common elevation, which is the lowest one occurring on the polygon boundary. In this way, gradient and flatness constraints were introduced into the DEM generation process. The DEM generation was performed in close interaction with the hydraulic engineering group in order to ensure the usability of the results.

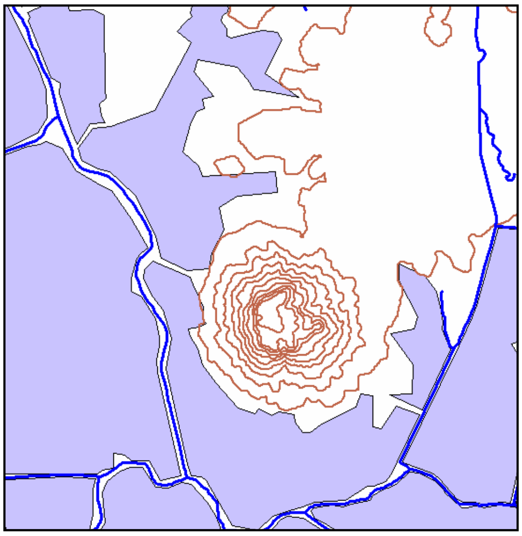

Figure 3. Input data for the DEM generation: Elevation zones (contour lines), oriented river middle axis, water bodies and polder areas

The hydraulic computations from the resulting DEM showed that some water flows inside the polder areas which should not occur. Since with the procedure applied so far this could not be generally avoided, an extension was developed. In order to avoid any inflow into polder areas, an artificial "wall" was introduced into the DEM. For the generation of this wall, all cells from the 8-neighborhood of cells touching any polder boundary were checked for their elevation. The central DEM cell was then set to the highest elevation in the 3x3-window plus additional 2 m. With this technique, any inflow into polder areas could be avoided in the subsequent hydraulic computations. The effect of the artificial wall generation is illustrated in Figure 4.

From the 50m-DEM without wall, slope and aspect maps were computed (Sasowski, et al., 1992). The generated DEM contains 22 of the 28 GCPs. For these 22 GCPs, the standard deviation in elevation computes to 3.70 m. For future studies, it is recommended to partition the remotely sensed image in mountain areas, hill areas and flat areas since the interpolation part of the process can be optimised for different terrain types. Then, the DEM will be generated individually for each terrain type instead of globally for the whole study area. Additionally, increasing the number and accuracy of ground control points could improve the DEM accuracy (Giles et al., 1996). For further aspects on the accuracy of DEM generation from SPOT data see (Al-Rousan et al., 1998).

Shaded 50 m DEM with polder areas

50 m DEM with 2 m walls at polder boundaries

Figure 4. Generation of an artificial wall + 2 m relative height at the polder boundaries in order to prevent surface water flow into the polder areas

4. EXTRACTION AND MAPPING OF THEMATIC INFORMATION

A SPOT-4 XI (21.1.1999) scene which consists of four multi-spectral bands: Band 1 (0.59-0.59 mm, green), Band 2 (0.61-0.68 mm, red), Band 3 (0.78-0.89 mm, near infrared) and Band 4 (1.58-1.75 mm, middle infrared), and SPOT-2 XS scene (10.8.1998) with three bands (B4 is missing) were used to extract thematic information like water bodies, roads and settlements and mapping them (SPOT, 2002). In this section, methods and techniques of extracting the information from SPOT data are described and probed, especially an improved method of land use/land cover classification by using SPOT images and ancillary data. In information construction and classification, the feature sets containing the SPOT original bands, ratios, the normalized differential vegetation index (NDVI), and a digital elevation model were tested using unsupervised ISODATA clustering (Schowengerdt, 1997). Incorporation of elevation data was found to be able to improve land cover discrimination (Haala, et al., 1999). Further improvement in the classification accuracy was obtained when using elevation data under a supervised technique.

4.1 Extraction of Water Bodies

In the SPOT scene of the study area five typical land cover classes were determined and training samples were taken to calculate their means and standard deviations.

The range (mean plus and minus two standard deviations) for each of the five spectral classes at each band is depicted in Figure 5 which clearly shows that the spectral values of water and other objects are overlapping at B1 and B2.

The spectral values of water body and shadow at B3 are lower than those for the other three classes, but they are overlapping, and the shadow class has only little overlap with the vegetation class. There was a clear distinction between the clusters of water, shadow and the remaining three classes at SWIR (Short Wave Infrared), but there is still a big overlapping area between water and shadow. Based on the analysed spectral characteristics of five land cover classes in the SPOT XI scene, the following different approaches were used for extracting water bodies and the results were evaluated.

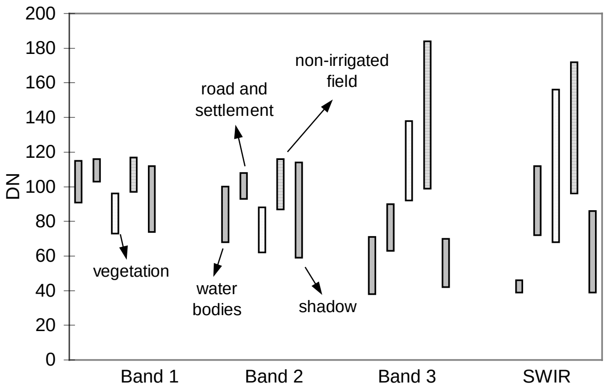

Figure 5. The spectral response range for typical object classes in SPOT2 XS rsp. SPOT4 XI multispectral data

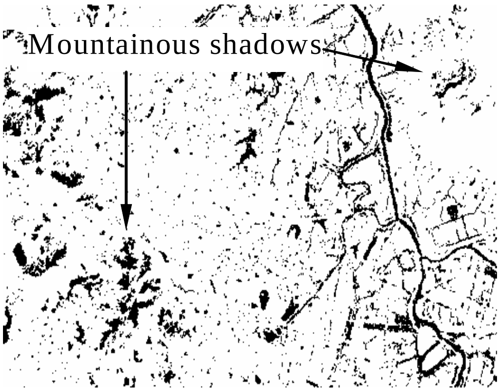

Figure 6. Water image extracted using thresholding at SWIR

The methods of extracting water, like thresholding, segmentation (Figure 6), Landsat chromaticity coordinate, proportion estimation, descriptive algorithm based on knowledge of water spectrum feature, have been applied to a variety of satellite data in management of water resources and monitoring of floods (Barton, et al., 1989; Liu, et al., 1996; Lu and Li, 1992; Du, et al., 1998). In this study, several techniques of extracting water information from SPOT XI data were investigated. An algorithm of decision-tree (DT) classification with several classifiers based on spectral values was designed to derive water bodies (for an improved result see Figure 7).

The decision tree classification algorithm based on both spectral values and auxiliary information of DEM and slope, a supervised classification method of maximum-likelihood classification (MLC), and unsupervised classification method of interactive self-organizing data analysis technique (ISODATA) were also used to extract water bodies in the same area (Lillesand, et al., 1987). The results and accuracy of the methods were compared and evaluated. All of the four methods mentioned above were used to extract water bodies. Then, the accuracy of each method could be assessed by calculating the user-accuracy coefficient K and computation-accuracy coefficient C, which were defined in the following way:

$$K = \frac{WATER}{WATER^{-} + WATER^{+}} \quad (1)$$

$$C = 100 - \frac{WATER^{-} + WATER^{+}}{WATER^{R}} \quad (2)$$

where:

- $WATER$ number of pixels which are labelled with water both on reference map and compared map
- $WATER^{-}$ number of pixels which are labelled with water in reference map and non-water in compared map
- $WATER^{+}$ number of pixels which are labelled with non-water in reference map and water in compared map
- $WATER^{R}$ number of pixels which are labelled with water in the reference image.

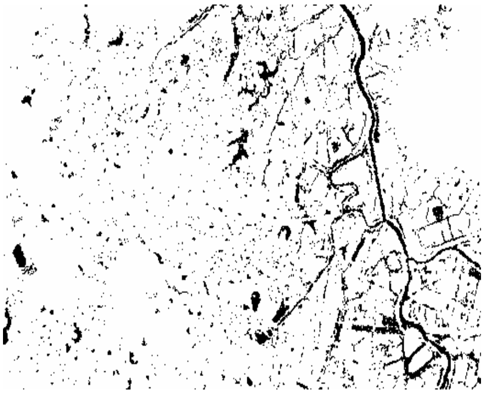

Figure 7. Water image extracted using DT classification

Because of the lack of ground truth data, especially for water bodies which are varying with time, the method was supposed to be of high accuracy if the extracted water bodies show a good visual coincidence with the original image. The DT method achieved best results by comparison. Therefore, the results obtained by DT method were used as reference data set for accuracy assessment.

Method	WATER	WATER	WATER	K(%)	C(%)
DT	1220488	0	0	100	100
DTDS	1201883	18605	93025	93	91
MLC	1194441	26047	78141	94	91
ISODATA	1209325	11163	271633	82	77

Table 1. Accuracy assessment of four multispectral classification methods for the extraction of water bodies

4.2 Extraction of Roads and Settlements

The spectral response curve of roads is similar with the one of settlements, therefore it is difficult to distinguish one from another based on spectral characteristics only. However, their spectral response curves differ from other objects, so they could be extracted from the image by using threshold methods of multi band images. Due to the distinct difference between roads and settlements in shape (roads always occur as a long and narrow line, settlements as polygon zones) the roads could be withdrawn using edge detecting methods while settlements could be obtained by subtraction (Li, 1995). The procedure of deriving roads and settlements could be as described in Figure 8.

Firstly, roads and settlements are derived from the image using a threshold method. Secondly, roads are extracted from the image using linear detection approach. Finally, settlements are derived by subtracting road pixels from the mixed road and settlements image.

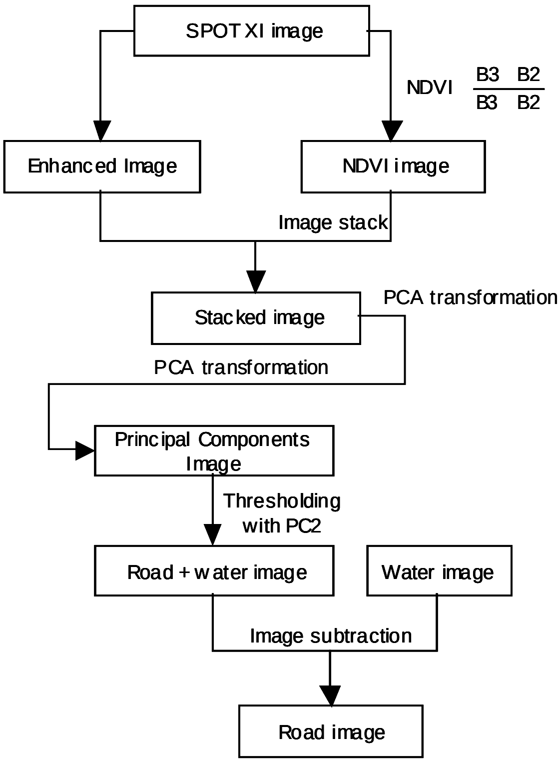

Figure 8. The procedure of road extraction

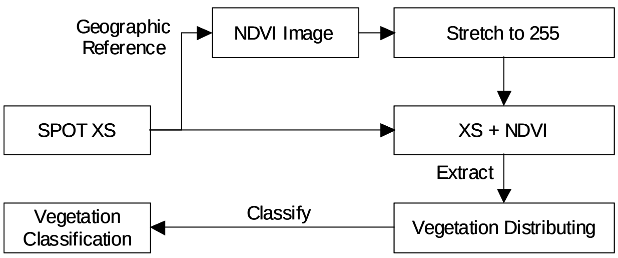

Figure 9. Workflow of vegetation information derivation from SPOT image

4.3 Extraction of Vegetation Coverage

The spectral response characteristics of typical vegetation are shown in Figure 5. This work was performed in two steps. Firstly, vegetation information was extracted, using a threshold method with the multispectral scene. Secondly, non-vegetation pixels were masked out and classification of the combined image (SPOT XS + NDVI) was performed on the vegetation pixels only (see Figure 9).

4.4 Extraction of Land Use/Land Cover

SPOT XS (10.08.1998) data was used to extract land use/ land cover information (Sabins, 1996). It is important to understand the spectral response characteristics of each land use/land cover type for the extraction of land use/land cover information using RS data. In Jiangning County, land use/land cover types are mainly irrigated field, non-irrigation field, forest and water. The irrigated fields are distributed mainly in Qinghuai Valley. Most of the non-irrigated field is located in the southwest and the northeast of Jiangning County. There are broadleaf, pine and shrub concentrated in the hills. The prevention tree belts are extensively distributed over the whole county. Two methods, supervised classification (MLC) and unsupervised classification, were performed in the land use/land cover classification. The classification results showed that rice and some of the woodland cannot be distinguished. In order to improve the accuracy of land use/land cover classification, an extended spatial parameter which includes terrain factors like height data was computed. This method was very effective to distinguish rice and some of the woodlands.

After adding the terrain factor, the classification of land use/land cover was carried out by supervised and unsupervised classification. This led to more satisfying results, obtained by the combination of supervised and unsupervised classification. Firstly, the coarser classification was carried out in an unsupervised way. Then, the characteristic spatial parameters produced by the unsupervised classification were added to the characteristic spatial parameters of supervised classification. Then, improving operations, such as merging, erasing etc. were applied. Lastly, the characteristic parameters of supervised classification were formed. The classification pattern was set up.

4.5 Land Use/Land Cover Map

The integrated land use map was edited by data processed from satellite images (Figure 10). Linear elements including roads and rivers, and polygon elements such as settlements, water, paddy fields, woodlands and so on were extracted. Because of extracting these elements different methods and means were used, some problems among them still need to be investigated further. Especially sub-classifications required in the project could not be realized completely by automatic classification. Therefore, they needed to be perfected by field survey and references to other thematic maps.

The land use map was edited in ArcView. Firstly, the data of settlements, water, vegetation, roads and rivers were overlaid on the basis of merged SPOT images, referring to topographic data, administrations and DEM data from topographic maps. Then, spatial data of every element in vectors was put in and the attributes were named according to the requirements for land use data in the project. Lastly, topological relation of data was established in ARC/INFO.

4.5.1 Mapping of agriculture land use data: According to the requirements of the project, agricultural land use includes paddy fields, dry lands and others, such as orchards, tea gardens, mulberry gardens and so on. Most of these elements can be well discerned from the images well by vision. The data related to these land use types can be obtained accurately by their characteristics of topographic distribution.

4.5.2 Mapping of built-up area data: The built-up area data in the land use map include land use for town, settlements of villages, land use for development zone, industrial and mining land use. Land use for town and settlements in villages can be discerned correctly by the scale of land use characteristics of speckles in the images and administrations. Because small-scale mining in Jiangning County mainly takes place on mining stones, which have characteristics of spatial distribution and graphs, these data can be obtained correctly.
The characteristics of development zones and large-medium industrial areas on the images are also relatively obvious. The old industrial areas can be tested by pertinent data (e.g. Map of Land Use in Jiangning County in 1996).

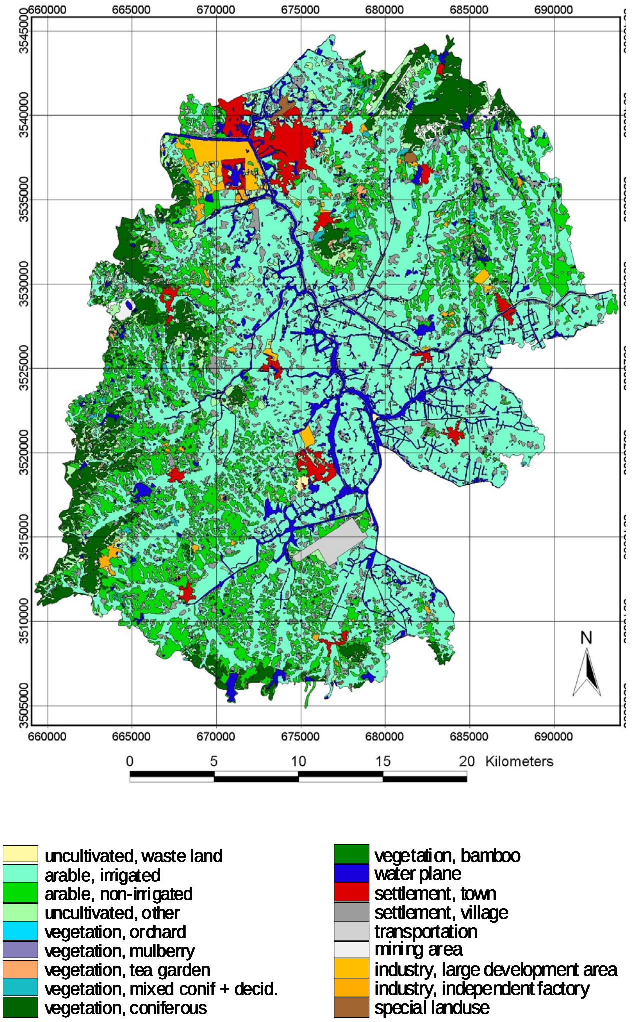

Figure 10. Land use map for the SILUP study area

4.5.3 Mapping of vegetation data: Vegetation data includes forests and other vegetation except agricultural land use. Woodlands in Jiangning County are mostly distributed in highlands and hills. Most of them are conifers, while distribution of sub-broadleaf is small-scale, which can not be displayed due to speckles on the present image scale. In addition, some relatively large-scale distributions of bamboo and tea gardens in some areas can be discerned clearly from the images. Generally, some grasses, shrubs and springwoods of sub-broadleaf are distributed around the woodlands, which are bare areas on winter images.

4.5.4 Mapping of water data: Water data are obtained through editing and modification on the basis of data extracted automatically. Water bodies from the topographic map were merged with the classification results in order to improve the layer quality. Manual cross check was performed finally for high reliability.

5. FURTHER DATA

Although the actual land use map and the DEM were the main products for this project, a number of additional maps were generated. All data were stored in the project spatial database as depicted in Figure 2.

5.1 Land Planning Map

Original data for land use planning information was digitised from the "Map of Agriculture Protecting Area in Jiangning County". Three planning relevant classes were distinguished: “Primary Agriculture Land”, “Normal Agriculture Land” and “Priority Transferable Agriculture Land”. Topological correctness was established within ARC/INFO.

5.2 Soil Map

The available soil map of the study area was developed from the Second Soil Survey of China, which was conducted between the late 1970’s and the early 1980’s and published by Soil Survey Office of Jiangning County, Soil Survey Office of Nanjing City, and Soil Survey Office of Jiangsu Province in 1985. The map scale is 1:125,000. Soil species in the soil classification system, consisting of soil order, type, sub-type, family, and species, are a basic unit of the soil map. Soil species are named locally. The soil map was digitised using the Chinese MAPGIS software package. When the digitised soil map was overlaid with remote sensing data, only partially satisfying matches as well as some errors in the digitised soil map were detected. Therefore, the digitised soil map was calibrated respectively according to the following error sources:

1. Errors caused by paper soil map digitisation
   When the soil map was digitised, some light and/or thin lines in the original soil map got lost. This partially led to erroneous merged soil units. For eliminating the errors caused by digitising the original soil map, a manual calibration took place.

2. Naming of new soil polygons
   The spatial scale of the satellite image used in the study is much larger than the scale of the original soil map hence the satellite image is able to provide more and better soil units than the original soil map. By overlaying the satellite image and the digitised soil map, new soil polygons could be identified. The identified new polygons are assigned to a soil species by similarity checks with polygon shape and colour of known soil species in satellite image and topography. The GIS/RS team is aware of the pragmatism of this procedure, but it was considered a practical solution when no field verification was available.

3. Errors caused by shrinking of original soil map
   Generally, the geo-reference of the soil map could reasonably match the satellite image. But because of distortions of the paper soil map, some polygons were shifted from their correct location. For instance, when overlaying the digitised soil map and the satellite image, some polygons of paddy soils in the digitised soil map were found in the mountains in the satellite image. For correcting such errors, the digitised soil map was carefully examined and the spatially shifted polygons were identified by comparison of original soil map and satellite image and manually shifted into the correct location.

The polygons were also adapted to the land use layer of the spatial database, especially to the borderlines of the layers describing the spatial distribution of irrigated/non-irrigated agricultural land. The hypothesis of this procedure is, that irrigated land use and paddy soils are correlated positively. Since this does not hold true in all cases, manual final checking was carried out by a Chinese soil scientist. Due to the limitation of funds, not all calibrations described above were verified in the field. The calibrated areas in the digitised soil map accounted in the total study area are therefore considered of lower reliability

6. GEOREFERENCING

For thematic information mapping, the remote sensing scenes were geometrically corrected, based on 28 ground control points (GCPs). The map projection is of Gauss-Krüger type, the applied datum is Pulkovo ’42. Firstly, suitable GCPs were defined in the existing topographic database. It was checked that each GCP is visible in all SPOT scenes. Secondly, the control points were measured in all available scenes.

Through field measurement using handheld GPS equipment, the coordinates were proven within the accuracy of the applied method. In an iterative procedure, a linear transformation between scene and topographic reference data was estimated and erroneous GCPs were removed. An affine transformation was estimated from the reduced set of GCPs using a least squares fit algorithm. The procedure is illustrated by Figure 11.

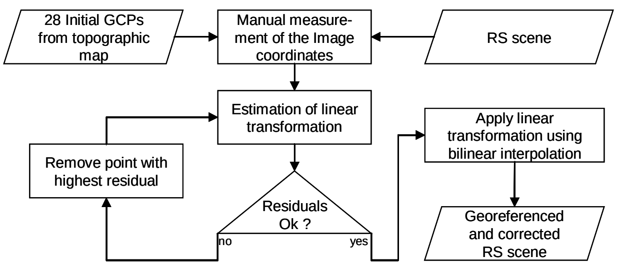

Figure 11. Workflow of the georeferencing procedure

Care was taken that the remaining 10-12 GCPs for each scene are well spread over the scene (Veillet, 1992). Finally, the optimised linear transformation was applied and the scenes were resampled using bilinear interpolation. Differential rectification was not performed for the whole study area since a reliable DEM could be finished only in December 2000. The results showed that the total root mean square (RMS) error was less than 1.5 pixels for the Landsat TM images and about 1.0 pixels for SPOT data.

7. DATA INTEGRATION AND DATABASE MANAGEMENT

The main task of the GIS/RS group was the establishment of a consistent and integrated spatial database using GIS and Remote Sensing techniques. For this purpose, all spatially related input data had to be corrected, updated, homogenized and brought to a common reference system. The map projection type of all spatial data is Gauss-Krüger with the central meridian at a longitude of 117°00’00’’ east. The datum is Pulkovo ’42, the spheroid is Krasovski 1940 (a=6,378,245 m / b=6,356,863.0188 m). These settings are taken from the basic topographic map at scale 1:50 000. It was decided, that the final dataset format for vector layers is ARC/INFO coverage. Raster data are stored as images with corresponding World file or as grids.

For all German partners, a common database was set up from the beginning of the project. Data coming from Nanjing was integrated subsequently. In regular intervals, copies of the complete database were transferred to all partners in Nanjing. This strategy proved to be very practicable, especially since all German partners had free access to the database. All integrative work was done under ARC/INFO and ArcView where specific tasks, such as the SPOT stereo DEM generation or multispectral classification made use of other software (Virtuozo, ENVI, Erdas Imagine). For certain image processing tasks, AAI’s package KBVision was used.

8. CONCLUSIONS AND OUTLOOK

The SDB, as it was established within SILUP, may serve as basis for future sustainable land use planning projects. The whole procedure for the setup of the SDB by integrating input data of very different origin, scale, accuracy and level of detail may also serve as guideline for other projects with similar suppositions. Starting from the consistent SDB data, updates can be carried out e.g. for the land use map. The existing and verified land use map may serve as GIS basis for the automatic generation of training areas in a procedure similar to the work of Walter et al. (1998). This will make the multispectral classification of future remote sensing data easier and more reliable, although final field verifications should not be omitted. GIS data either taken from the existing databases or captured by space borne or airborne sensors were the basis for all other work in the project. Therefore, development of generally applicable, reliable algorithms and procedures for an efficient, highly automated provision of basic data is of very high importance. An improved planning application orientated geographic information system should be established through revision of the existing database, standard coding of different data types and integration of multi-source information. The following points are considered to be of central importance:

- Flexibility
  For real operational use, the system to be implemented should be able to handle alternative data sources, either exclusively or in an integrated way.

- Data details
  The level of data details of the SILUP Project should be increased in order to meet the demands of land use planning. For automated detection of linear features like roads and smaller channels and canals, high resolution imagery is necessary (pixel size 1-5 m).

- Time
  The SILUP Project showed that it is necessary to carry out multitemporal analysis in order to learn about developments in the past and to elaborate well founded predictions for further development trends.

In order to visualize the contents of the spatial database, a 3D flight over the study area was generated where the fused SPOT PAN+XI image was draped over the DEM. Occasionally, fades into the co-registered land use map, road and water network or to administrative units are integrated in order to demonstrate the consistence and quality of the SDB.

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