Photo-Textured Digital Terrain Models as a Basis for Regional and Local Planning

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SUMMARY: Many cities in the second and third world experience currently strong urbanization and are expanding fast. These development dynamics are so strong, that the traditional maps as a basis for planning are often out of date or are in certain cases just not available. However, to monitor, control and guide these development trends, up-to date maps are needed as a basis for urban and regional planning.

We will show in our contribution how a new form of digital map – a photo-textured Digital Terrain Model (DTM) with integrated information for planning measures - can be produced efficiently and used in the planning process: For the study area of named "Greater Kunming Area" we produced a DTM. Then we geocoded and orthorectified LANDSAT 7 ETM MS and IRS-1C PAN satellite images. In a special process of image fusion we combined the information of high spectral information (MS – Multi-spectral with 30 m pixelsize) and high metric resolution (PAN – Panchromatic, 5 m pixelsize) to a joint image representation. Planning information is used as a third layer of data. The combined datasets can be interpreted as a photorealistic 3D map, which can be accessed and represented by modern visualization tools. Finally we show how such a 3D digital model can be used for illustrating planning approaches.

1. Introduction

In recent years, many cities in the second and third world have experienced a strong urbanization. Due to the improvement of transportation infrastructures, rural migration as well as high natural birth rates, expanding economies and the effects of globalization in general, these cities increase quickly in size and get a regional extend. Meanwhile, planning remains mostly local and focused on the main urban area of a region, while urbanization prevalently occurs outside of it. Development is often so rapid that traditional maps are even not any more accurate enough to serve as a planning basis.

The result is that local authorities gradually loose control and overview over the development of their region. The lack of region- and sustainability-oriented planning strategies and a comprehensive planning approach provokes an uncontrolled and uncoordinated urban development. Indeed, there is a huge risk that many development potentials will get lost, synergies will remain untapped, and that environment pollution as well as traffic problems will get out of control.

The new task for planning in these emerging metropolitan areas of the second and third world is to manage the space in a wider extend, to coordinate local and regional functions, and to create sustainability-oriented urban transportation and settlement patterns. To keep the overview over development dynamics, the suggested planning system should include monitoring and controlling approaches as well. Meanwhile, the planning basis - the basic map and its geo-oriented information - should be comparatively cheap, easy and fast to provide and ultimately up to date. Finally, the planning approach as such should be simple to apply, adapted to planning level and scale, and strongly coordination- and sustainability-oriented.

The analysis of the future development potential and a first modeling of future settlement and transportation patterns by means of GIS-based scenario design has shown that current and future development dynamics threaten many of the region's stunning natural potential and even endanger, if nothing is done, the economic competitiveness and long term sustainability of the city and its hinterland.

Therefore, a quick adoption of sustainability-oriented planning policies, which shall meet and reverse the threatening development tendencies, and the implementation of a GIS-based comprehensive surface-covering planning system, to guide settlement expansion, control land use and monitor regional development in general, has been suggested to the city and its agglomeration, the Greater Kunming Area (GKA) (Figure 1).

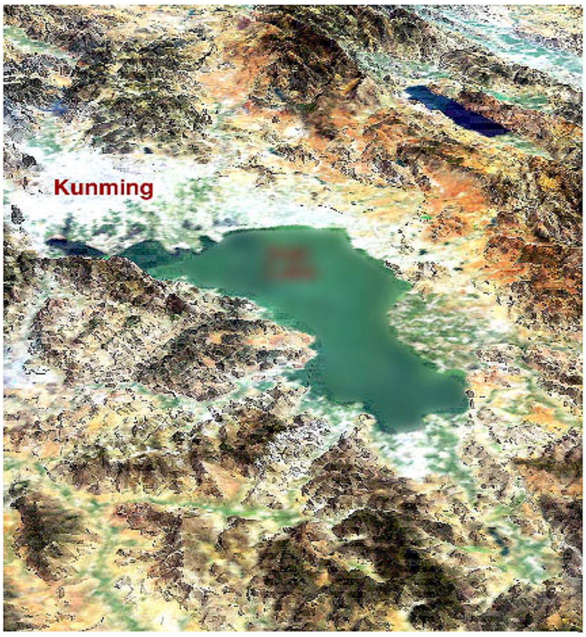

Figure 1: Greater Kunming Area, 3D modelling based on DTM and satellite images

The approach is in now in its pilot project phase. In principal it includes the following steps:

(a) Setting the legal and administrative framework

? Definition of the planning goals and contents

? Definition of the administrative levels concerned with spatial planning

? Definition of the territorial division

? Definition of the stakeholders

? Definition of the organizational setup

? Definition of a the planning process and time frame

(b) Individual definition of guiding ideas and planning principles for the planning units on the regional, sub-regional and local levels

(c) A stepwise implementation of regional, sub-regional and local surface-covering planning, by using cross-sectorial and multi-disciplinary approaches.

As a basis for the implementation of this planning approach, reliable and up-to-date maps are prerequisite.

2. The Creation of a Planning Basis

Nowadays, traditional maps, either classical or digitized, are very often outdated and incomplete. On the other hand, recent satellite or aerial images are usually available or can be easily ordered. Moreover, their purchasing price sinks constantly. Therefore, a high resolution satellite image data in combination with a Digital Terrain Model (DTM) generates, as a 3D image map, a viable product for planning purposes. The data is 3D, or 2.5D to be precise and contains the most recent image-based information available, As such it will be used as a basic layer on a GIS-based planning system.

In out project we have generated an image-textured DTM of the Greater Kunming Area (GKA). which comprises approximately 9500km^2. The image-textured DTM serves as a basis for the design of the regional and sub-regional guiding plans.

In the following, we will explain how this model was generated and how it is used by means of GIS technology.

3. Generation of a Textured 3D Model

3.1 Study Area and Primary Data

The geographical location of the project is an area of 150?120 km^2 around Kunming in Southwest China. It is covered by 12 pieces of standard 1:100,000 scale topographic maps. Two LANDSAT 7 ETM+ multi-spectral images (ETM+ 2, 3 and 4 bands are used) with 30 m spatial resolution and three IRS-1C panchromatic images with 5m resolution have been used (see Table 1).

Sate. Name	Image NO.	Band	Pix. Size(m)	Imaging Date
IRS-1C	121-54B	PAN	5	2 June 1999
	121-54C	PAN	5	1 Feb. 2001
	121-54D	PAN	5	2 June 1999
LANDSAT 7	129-42	MS	30	15 Sept. 2000
	129-43	MS	30	23 Mar. 2000

Table 1: The satellite images used in our work

On the 1:100,000 scale topographic maps (generated 1962 in Russia), the 20m contours and some break-lines were digitized. All the digitized data, given originally in the geographic coordinate system, is then transformed into UTM coordinates. The DTM interpolation software package DTMZ, developed by ETHZ, was used to generate a 50m grid DTM.

To integrate this data for urban planning and 3D visualization requires the geometric correction process ortho-rectification to correct the image data according to the ground reference system and an image fusion process which merges the high spatial resolution IRS-1C PAN images and the low resolution multi-spectral LANDSAT 7 ETM+ images.

3.2 Geocoding and Ortho-Rectification of the Images

Compared to other satellite images the radiometric quality of IRS-1C PAN imagery is limited by the 6 bit (64 levels) gray value representation. Therefore, before starting with the ortho-rectification process a radiometric enhancement and a despeckle procedure were performed. The poor contrast of the original images was improved with a non-linear lookup table resulting in visually satisfying images. After that, a MMSE (Minimum Mean-Square Error) based despeckle process (Oliver, Quegan, 1998) was performed in order to improve the signal-to-noise ratio of the original images. The results are shown in Figure 2.

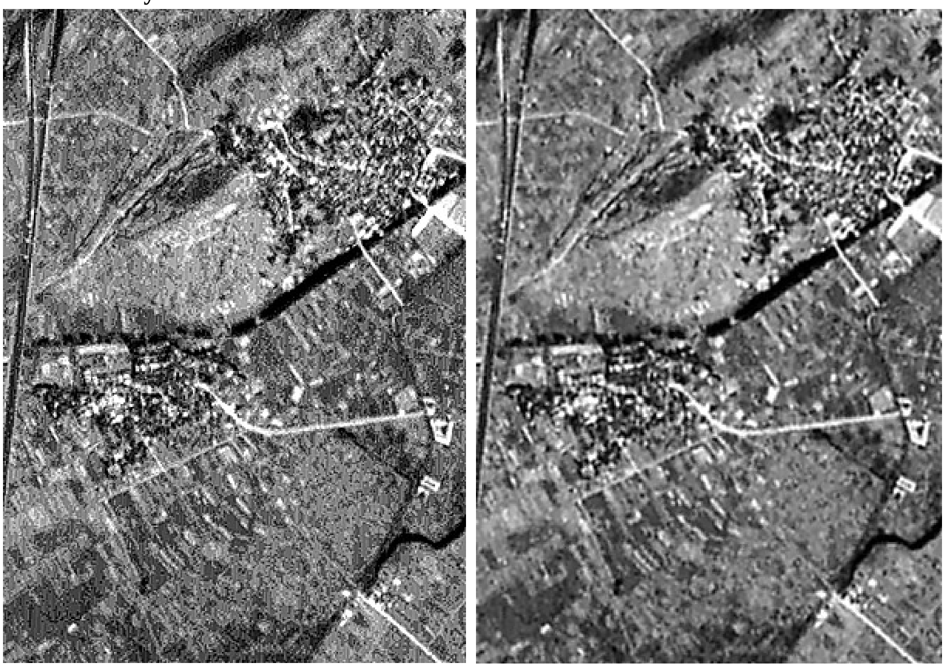

Figure 2: The IRS-1C image after radiometric enhancement (left) and that after despeckle filtering (right)

The LANDSAT 7 ETM+ and IRS-1C PAN images were geocoded by using the geometric model developed by V. Kratky (Kratky, 1989). This model reflects the physical reality of the complete imaging process. The geometric solution combines the principle of rigorous photogrammetric bundle formulation with additional constraints assuming an elliptic satellite orbit. The sensor position is derived from known nominal orbit relations, while the attitude variations are modeled by a simple polynomial model (linear or quadratic). For self-calibration 2 additional parameters, the focal length and the principle point correction, are added. The exterior orientation and the additional parameters of the sensor model are determined in a general formulation of least squares adjustment. The use of additional information, for example the supplemented data files, is not mandatory, but if this information is available it can be used to approximate or preset some of the unknown parameters.

28-43 ground control points were collected from 12 sheets 1:100,000 topographic maps for each image and the coordinates of these ground control points were transformed into the UTM coordinate system. Using the geometric model mentioned above, the exterior orientation parameters for each image were computed. The residuals of the ground control points were between 2.3-31.0 m (0.5-6 pixels) for the IRS-1C PAN images and 5.0-56.2 m (0.2-1.9 pixels) for the LANDSAT ETM+ images. These relative large residuals can be explained by the following: The acquisition time of the satellite images lies in 1999-2001. There are big differences compared with the topographic maps, generated in 1962, which were used to collect the ground control points. It must also be assumed that the maps are not very accurate (0.5 mm error in the map corresponds already to 50 m in the terrain).

After the geocoding process, the relation between the pixel coordinates and UTM coordinates was established. Using the grid DTM data the ortho-rectified images can be generated. Two 5m resolution ortho-rectified images were generated from three IRS-1C PAN images and one LANDSAT 7 ETM+ image respectively using the commercial software VirtuoZo. Since these two ortho-rectified images are in the same coordinate system, they can be combined to generate a composite image which preserves the high spatial resolution of the IRS-1C PAN image and the spectral information of the LANDSAT 7 ETM+ image. In order to get good results of image registration for the following image fusion, several hundred homologous points were extracted from these two ortho-rectified images by using a semi-automatic least squares matching algorithm. Using these points, the ortho-rectified image generated from LANDSAT ETM+ image was resampled by cubic convolution. This procedure is needed to remove the small differences between these two ortho-rectified images, resulting from the relatively low accuracy geocoding procedure and the errors in the grid DTM.

3.3 Image Fusion

The panchromatic imagery of the IRS-1C is characterized by a high spatial information content, well suitable for human interpretation and analysis on a regional scale. The multi-spectral images of the LANDSAT ETM+ provide essential spectral information for small scale thematic mapping applications such as landuse surveys. In order to take benefit of the high spatial information content of the panchromatic images and the essential spectral information of lower resolution multi-spectral image channels, the fusion of these two types of images is performed in order to produce pseudo high resolution multi-spectral images. The fused images should have the highest possible spatial information content while still preserving good spectral information quality. Different fusion methods and algorithms have been proposed in the literature, for example, the Principle Component Analysis (PCA) method (Chavez et al., 1991), the Intensity Hue Saturation (HIS) method (Chavez et al., 1991), High Pass Filters (HPF) (Showengerdt 1980) and Wavelets based fusion algorithm (Yocky, 1996). All of these algorithms produce fusion images with different quality for spectral information preservation.

We use the Local Mean and Variance Matching (LMVM) algorithm (Bethune *et al*., 1998) to merge the IRS-1C PAN and LANDSAT ETM+ ortho-rectified images. This filter was specifically designed in order to minimize the differences between the fused image and the low resolution multi-spectral images, hence to preserve most of the original spectral information of the low resolution channels. This filter applies normalization functions at a local scale within the images in

$$F_{i,j} = \frac{(H_{i,j} - m(H)_{i,j(w,h)})s(L)_{i,j(w,h)}}{s(H)_{i,j(w,h)}} + m(L)_{i,j(w,h)}$$

order to match the local mean and variance values of the PAN images with those of the original low resolution spectral channels. The small residual differences remaining correspond to the high spatial information stemming from the high resolution PAN image.

The LMVM algorithm is given by:

Where $\boldsymbol{F}$ is the fused image, $\boldsymbol{F_{i,j}}$, $\boldsymbol{H_{i,j}}$ and $\boldsymbol{L_{i,j}}$ are respectively the fused, high and low spatial resolution images at pixel coordinates ($\boldsymbol{i, j}$); $\boldsymbol{m(H)_{i,j(w,h)}}$ and $\boldsymbol{m(L)_{i,j(w,h)}}$ are the respective local means calculated inside the window ($\boldsymbol{w,h}$); $\boldsymbol{s(H)_{i,j(w,h)}}$ and $\boldsymbol{s(L)_{i,j(w,h)}}$ are the respective local standard deviation.

This formula was applied to fuse the panchromatic IRS-1C image $\boldsymbol{H}$ with the three used channels (ETM+ 2, 3 and 4) of the multi-spectral LANDSAT image $\boldsymbol{L}$ sequentially. The three fusion product $\boldsymbol{F_{ETM2}}$, $\boldsymbol{F_{ETM3}}$ and $\boldsymbol{F_{ETM4}}$ were then merge into one pseudo high resolution multi-spectral image. This type of filtering drastically increases the correlation between the fused image $\boldsymbol{F}$ and the low resolution channels $\boldsymbol{L}$. The amount of spectral information preserved in the fused product can be controlled by adjusting the filtering window size (Bethune *et al.*, 1998). An 11?11 window size was used in our fusion procedure. Figure 3 shows an image window of the 5 m ortho-rectified IRS-1C image (a), the 5 m ortho-rectified LANDSAT ETM+ image (b) and the fused image product (c).

The image fusion results in a pseudo high resolution multi-spectral image. The image dimension is 19,782?28,200 pixels, it covers about 14,000 square kilometers and contains about 1.6 GBytes RGB true color texture data. For the 3D display of such a big image a special software package "*Terrain3D*" was developed.

Summarizing, we have shown how a photo-textured DTM was generated for the Greater Kunming Area. We have ortho-rectified LANDSAT ETM+ image and IRS-1C images and fused them in order to draw advantage of the high spectral resolution of the ETM+ MS images and the spatial resolution of the IRS-1C PAN images. The fused image product was overlaid on the DTM and appropriate software was developed for visualization of very large datasets.


Figure 3a: A window of the IRS-1C PAN image (Kunming City)


Figure 3b: A window of the LANDSAT ETM+ image (Kunming City)

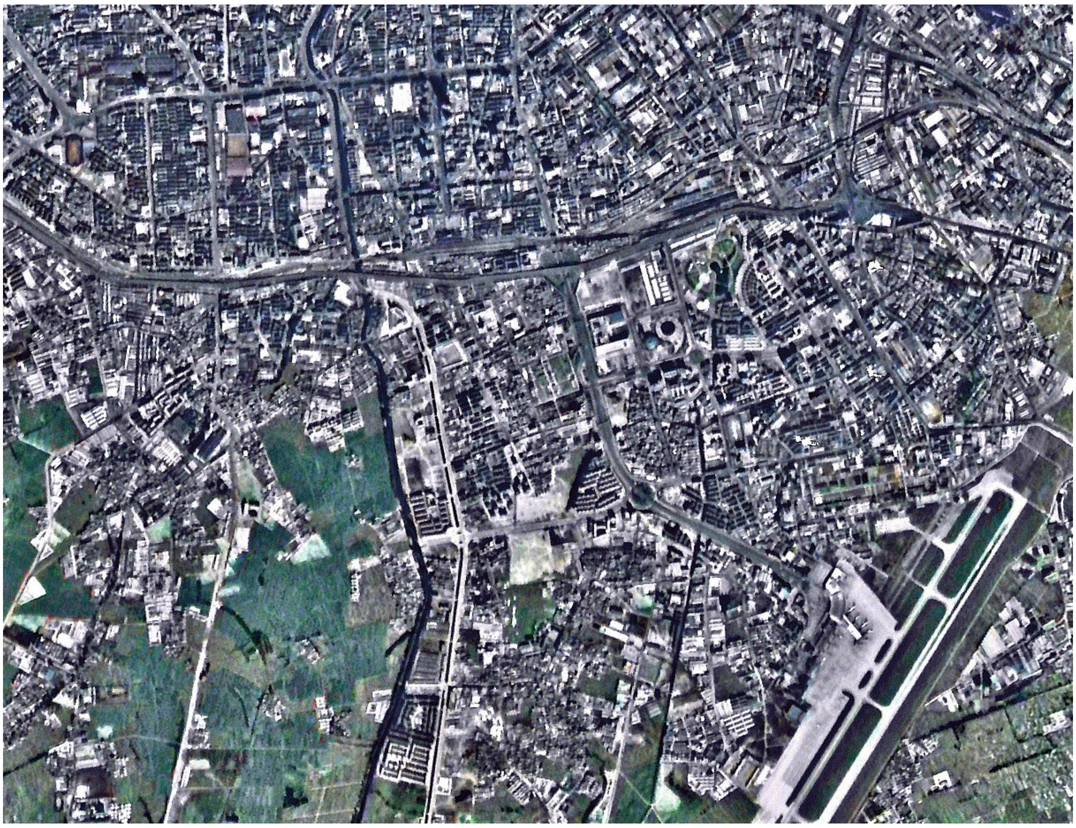

Figure 3c: A window of the fused image (Kunming City)

4. The Use of Digital Models for the Planning and Visualizatin of the Greater Kunming Area

(a) 3D Visualization

Texture mapping is a popular way to create a photo realistic 3D model. Usually, the system memory or dedicated texture memory is restricted by technical or economical constraints. On a standard graphics workstation such as SUN SPARC 10/20 and O2 Silicon Graphics, the size of one single texture image is limited to a resolution of 1024?1024 pixels. But in the fields of GIS and Remote Sensing textured models can easily exceed 10,000?10,000 pixels, so that we cannot directly use the texturing power of graphics workstations to render this kind of textured models. We developed a software package in order to render a very huge texture generated from satellite or aerial images on the grid DTM that represents the terrain. In this software, the following features and methods were considered to solve these problems.

? Tiling of the whole texture image into an array of texture tiles. For each texture tile, a special tile number was assigned for the following selection paradigm which only loads those tiles that appear in the display window and reduces the amount of necessary memory. In our software, 1024?1024 pixels is the dimension of the texture tiles.

? Generation of the MIPmap pyramids. In the field of texture mapping, filtering techniques like MIPmapping (Neider et al., 1994) have been developed to adapt the texel-size used in object-space to the pixel-resolution of the texels in screen space. With this filtering paradigm, a hierarchy of texture images is generated from the original texture, the so-called MIPmap pyramid. After this procedure, a MIPmap pyramid is attached to one single texture tile. Each of these MIPmap pyramids now provide a possibility to adapt to the user's viewing position by only loading those pyramid levels of the texture which are necessary. The question of which levels are necessary can be answered with the three-dimensional bounding box of the polygons which shall be textured with this pyramid. The projection of this bounding box on the viewing plane of the users depict the maximum pixel number necessary to texture the content of this bounding box correctly. Rounded up to a power of two the maximum of the dimensions can be used to determine the maximum level of this MIPmap pyramid which has to be loaded into the memory. In addition, if the projection of one bounding box is outside of the displaying screen, the polygons related to this bounding box can be omitted.

? Dividing the whole grid DTM into an array of small patches, the dimensions of these patches are adapted to the dimension of texture tiles. After that, a different representation level of DTM data with small dimension and lower resolution are generated for each DTM patch. When rendering using our software, only the DTM data which adapt to the MIPmap pyramids level is loaded into memory and displayed. That is, when a DTM patch is far from the user's viewpoint, only the low resolution level DTM data is displayed.

? Storing all the MIPmap pyramids and DTM patches on the disk space. Loading a small file into memory absorbs only little time.

Using these techniques, our software can render the textured 3D terrain model at a acceptable speed. As an example, our dataset of 2971?3044 DTM points and 1.6 GB image data can be manipulated with an update cycle of 4-5 seconds on a SUN SPARC 20 workstation.

Figure 4 shows some screen-snapshot results of 3D visualization produced from our software.

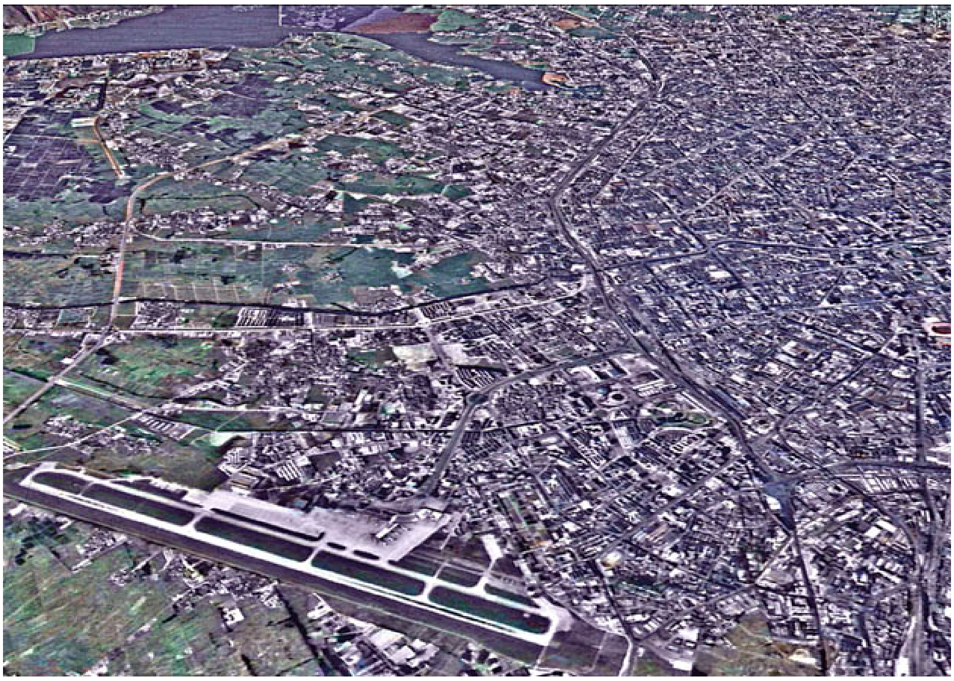

Figure 4: 3D visualization of the textured model

(b) Partial Planning Base for Regional and Sub-regional Guiding Planning

Once the photo-textured Digital Terrain Model is available, it substitutes maps and physical models and forms the topographical basis for the drafts of the GIS-based guiding plans on the regional and sub-regional levels. For the local level, satellite or aerial images with a higher resolution (1m or better) are required. Further documents necessary as basic data required for the generation of the guiding and zoning plans are:

? basic reports on main development issues

? precise geo-related data (current land use and infrastructures)

With this dataset, the design of the GIS-based guiding plans can be taken at hand. Guiding plans usually thematise main issues of regional coordination, regulation and protection, including the present state and planned projects. In the case of Kunming, they are split up in the following thematic fields:

(1) Settlement and Landscape,
(2) Transportation,
(3) Supply and Disposal,
(4) Public Infrastructure and
(5) Lake Protection.

On the local level, a comprehensive plan resumes all the thematic fields and serves as well as a zoning plan.

Considering implementation, in a first stage, drafts of the plan are submitted to concerned government institutions and stakeholders which will discuss and consolidate it. After being adjusted the plans will be approved by the different institutions and will get a legal status.

So far, The GIS-based planning model is flexible and can easily be adapted to changing circumstances, as altering land use for example. In principle it can be continuously updated. Due to its topographical precision the model can indicate the quantity and quality of the different land uses. The very recent satellite image data (which can also be periodically updated) provides a highly actual basis.

By this, spatially relevant processes (e.g. urbanization) and development issues (e.g. consumption of fertile land, or the state of pollution of lakes) can be controlled and monitored.

Furthermore, the current state, the development scenarios, the zoning proposals and the expected results can be very well visualized in two and three dimensions. By this, it becomes an important pillar for decision making and a powerful tool for planners.

5. Conclusions

We have shown how a photo-textured DTM was generated for the Greater Kunming Area. We have ortho-rectified LANDSAT ETM+ image and IRS-1C PAN images and fused them in order to fused them in order to draw advantage of the high spectral resolution of the ETM+ MS images and the spatial resolution of the IRS-1C PAN images. The fused image product was overlaid on the DTM and appropriate software was developed for visualization of very large datasets.

This kind of approach is very adapted to rapidly developing urban regions, where the governmental institutions have the capacity to carry out comprehensive planning, as it is the case in P. R. China. Indeed, in many parts of China, development pressure is so strong, and the consumption of fertile land and the increase of the pollution level so fast, that the implementation of comprehensive and surface covering planning is urgently needed. Though being still in the pilot project phase, we consider the selected method as well feasible and promising.

The technical approach we took is adapted to all locations where "normal" maps were not available or where development is so fast, that existing information is not any more up to date. Ideally it should be combined with the above mentioned implementation of GIS-based planning. Last but not least, the visualization capacities of the GIS-model are very helpful for communication between administrators, planners and stakeholders in the planning process.

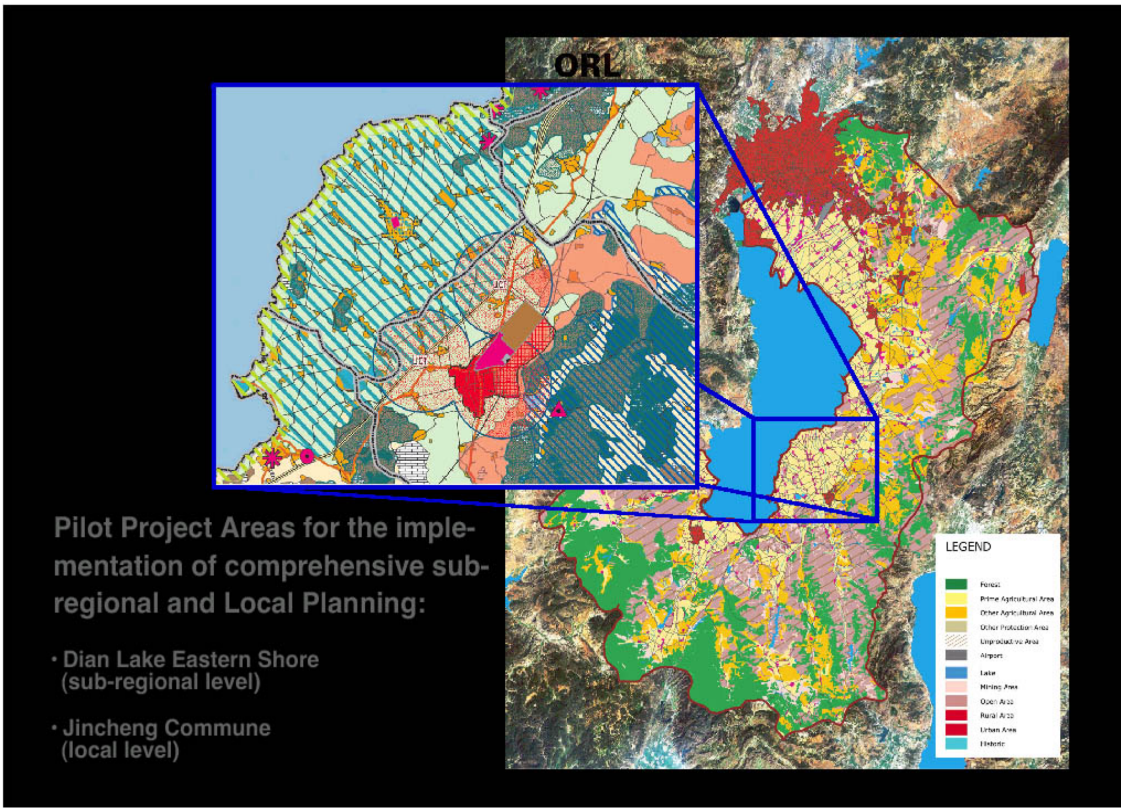

Figure 5: Pilot Project advocating the implementation of comprehensive regional and surface-covering local planning

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