Modelling of settlements-dynamics by object-oriented image and change detection analysis on Tenerife

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ABSTRACT: Since the 1960’s the island Tenerife is characterized by an increasing tourism – about 4.9 mio. accommodate tourists in 2003 – which causes a lasting change of the socio-economic situation and a rural exodus. On account of this development the situation of land cover and land use changed in the same time: Fallow land, land wasting and decreasing settlements are some of the main consequences. This leads to a growing necessity of geoecological analysis and to an increasing demand for an adequate monitoring database.

An interface connection between remote sensing and geoecological information systems (GEIS) is used to analyse the spatial pattern and its spatial temporal changes of land use on Tenerife from end of the 70s to the present in different scales. An object-oriented image analysis technique has been applied to classify the LANDSAT MSS 3- and ETM+ 7-data as well as orthophotos. Based on these results, an in pair post-classification method was used to detect spatial and categorical land use and land cover changes for the basis of a monitoring system. Different socioeconomic data types have been clipped within GEIS and correlated with the results of the land cover land use changes to derive the interface between natural conditions and human influence. Based on the data of the preceding development of changes of settlements and non-built up areas and of changes in socio-economic conditions a regional environmental model is created to forecast the development of settlements in about 25 years and to analyse the vulnerability of natural ecosystems to human-induced changes.

1 INTRODUCTION

The study area for the modelling of settlements-dynamics is Tenerife, Canary Islands. Due to its horizontal and vertical extent (2,052 km² area, up to 3,718 m height) as well as its position in the mid-Atlantic the island offers a variation of climatic, vegetational and geoecological aspects, leading to a heterogeneous landscape (Siegmund & Naumann 2001).

On account of these physical geographical characteristics, the island is a popular destination for tourists, especially from European countries. Being in its infancy in the 60s, the mass tourism increased from 1978 to 2002 by almost the triple factor to about 4.8 million tourists a year. This development involved a social and economic change from an agrarian to a service society. In fact in 2002 more than 75% of the number of persons employed on Tenerife worked in the tourism sector, whereas in 1978 it comprised only 56%. Due to the fact that only 19% of the total island can be used for building caused by the topography, the changes in the socioeconomic system leads to a spatial concentration of the settlements and touristical infrastructure near to the coast.

Different technologies of remote sensing and geographical information system were used to
analyse the changes in land cover and land use for an appropriate period of about 25 years. Based on two-period LANDSAT-scenes of Tenerife and on high resolved orthophotos of some areas on the island, an object-oriented algorithm for the classifications was used leading in a post-classification method to detect the changes. The extracted spatial pattern and its spatial temporal changes of land cover and land use can be regarded as basic information, describing the composition and the configuration of the area, which is related to geoecological conditions and reflected the social, cultural and economic development. To derive the interface between natural conditions and human influence, different socioeconomic data types have been clipped and correlated with the results of the land cover and land use changes as the second intermediate step. Especially the increasing settlements which have been calculated, comparing the years 1978 and 2002/1996 and the consequences for the regional planning system leads to the construction of a model showing a scenario for the development of the cities and villages in about 25 years by constant trend of driving forces in different classes of probability.

2 DATA

The classification and detection of land cover and land use changes of the whole island of Tenerife based on data of LANDSAT 3 MSS taken on the 13th of November 1978 and LANDSAT 7 ETM+ taken on the 11th of February 2002. To receive more detailed information especially about distinguish frequencies of touristic infrastructure, four areas were selected, covered by aerial photograph of 1978 and by orthophotos of 1996. Belonging to that kind of remote sensed data, it was secured to work on the land cover and land use change with a bigger scale and a higher spatial resolution than the satellite scenes are able to.

To derive a knowledge-based classification of the remotely sensed data it was necessary to collect training areas of all expected classes. On account of the heterogeneous topography, the size of the island and the desired high number of classes 311 ground truth data could have been collected, approximately 5.4% of the area of Tenerife (Keuchel et al. 2003). Some of the training areas were separated to use them as ground check data for the accuracy assessment afterwards.

As previous studies showed unsatisfactory results concerning the amount of different land cover and land use classes, as well as the poor accuracy of the classification, several collateral data were elevated for increasing the classification results. Conditional on the dependence of land cover and land use classes on topographic factors, like slope, aspect and altitude a Digital Elevation Model (DEM) has been created.

The socioeconomic driving forces which embed in the model based either on municipality data derived from ISTAC (Instituto Canario de Estadistica) and from Servicio Tecnico de Desarrollo Economico en Tenerife. The data enclose information about the amount of inhabitants, employees per sector, number of tourists and number of beds in hotels and apartments in temporarily resolution.

3 METHODOLOGY

The methodology of deriving a model for the dynamics of settlement on Tenerife based on four major procedures: preprocessing of the used remotely sensed data, object oriented classification, change detection analysis and clipping the results with socioeconomic data (see Fig. 1).

3.1 Preprocessing

Before the actual classification of the used remote sensed data (satellite images, aerial photography, orthophotos) an appropriate preprocessing was unavoidable. The modules which were processed for the LANDSAT 3 MSS-scene of 1978 and the scene of LANDSAT 7 ETM+ of 2002 contain geometrical correction and georeferencing to UTM Zone 28 North map projection, image fusion, histogram- and Principal Component Analysis (PCA). To the scene of 1978 a radiometric correction in the case of removing bad lines by destriping was necessary in addition. Concerning image and
classification enhancement the Normalized Differenced Vegetation Index was carried out for both satellite images. Due to the different spatial resolution of the two LANDSAT-systems and due to the necessity of same spatial resolution for all images to read data in the following used object oriented image analysis software (eCognition), the images have been expanded to a 15*15 m pixel size.

The aerial photography of the four selected areas needed to be registered to a planar coordinate system, so that they can be overlaid by other geographical data of this area. The differential rectification was realized with the help of a DEM, and the ground-to-photography and photography-to-image transformation parameters (A. Krupnik 2003). Finally the rectified data of 1978 and the orthophotos taken in 1996 had a spatial resolution of 5*5 m.

### 3.2 Object-oriented image classification

Experiences with traditional pixel-based classification performed by no contextual methods, like maximum likelihood classification and support vector machines, as well as by iterated conditional modes showed unsatisfactory results (Keuchel et al. 2003). The reason seem to be the heterogeneous landscape concerning different topographic, geologic, pedologic, climatic and vegetation areas which leads to a large scaled mosaic structure, that cannot be extracted by the used pixel-based classification technique. Especially the resulted small number of classes, salt and pepper effects, insufficient accuracy and the difficult handling of programming the algorithms leads us to apply a Fractal Net Evolution Approach (Baatz & Schäpe 1999).

The technique incorporated in the software eCognition is based on segmentation and object-oriented framework. One of the advantages of using objects instead of pixels as classification basis are shown in the potential of spatial information about the segments on its own as well as their relationship on below the others (Naumann & Siegmund 2004). With the help of the segmentation the picture elements with similar spectral or textural values can be united in homogeneous objects (color and shape) by minimizing the heterogeneity in the image (Baatz & Schäpe 2000). Summarized, the segmentation leads to generating the image in meaningful objects, which represent shapes of real-world-objects and includes the knowledge of the neighbouring objects in horizontal and vertical direction (P. Hoffmann 2001). With the help of a semantic net it was possible to classify in different levels of scale, based on a multiresolution segmentation as a heuristic optimization procedure.
Follow on the image-segmentation into object primitives in different scale levels, these have to be grouped into objects by classifying them. The knowledge based classification algorithm implemented in eCognition is done by fuzzy logic and assumes a hierarchy where the classes are implemented. The feature extraction is based on rules defining membership functions or nearest neighbor functions (Niemeyer & Canty 2001). The fuzzy algebra is used to define the membership functions of each class, translating feature values into fuzzy values between 0 and 1 (Bauer & Steinnocher 2001). The class descriptions can contain spectral, geometrical and statistical information of the objects, as well as relations between the objects. Because of the ability to classify objects in different scale levels, it is possible to aggregate a number of small objects to a larger object and to split a large one to a number of smaller objects. An example based on a part of an orthophoto in Fig. 2 shows the applied methods in steps beginning on the image (a), segmentation (b), object features by mean (c) and a classification on a course level (d).

![Figure 2. Four steps to classify remotely sensed data by segmentation and object oriented classification.](image)

Researches with pixel-based classification of the same area using LANDSAT 5 TM-data shows insufficient results, mainly because of the impossibility to incorporate additionally needed information into the classification process (S. Naumann 2001). In eCognition this deficit is removed by allowing direct implementation of existing layers like “a priori” knowledge into data analysis. This advantage of information beyond spectral characteristics for classification was used and needed to get an optimal result. The dependence of land cover and land use on Tenerife on mainly altitude, aspect (including indirectly also climatic information because of the dominating wind systems) and slope as well as on geological and pedological circumstances leads us to use this additional spatial information for separating classes in the hierarchy.

### 3.3 Change detection

A variety of algorithms has been developed concerning change detecting of land cover and land use, which can be assumed into two groups. One considers image enhancement and is based on unclassified remote sensing data: image rationing (Howarth & Wickware 1981), image regression (J. R. Jensen 1983) (A. Singh 1986), vegetation index differencing (R. F. Nelson 1983) etc. The other group of change detection methods is based on classified bi- or multi-date images, as the so called post-classification comparison (Rutchy & Velcheck 1994), which has been applied in this research.

The advantage of using a change detection matrix based on a pixel-by-pixel comparison is the contained information about the area where the change has occurred (spatial information) but also about the “from-to-class” (subject information). The accuracy of this procedure depends on the accuracy of each of the independent classifications, since every error in the individual classified map will be presented in the change detection result (Lillesand & Kiefer 2000). Concerning this fact all classified image data have been tested with the help of an accuracy assessment based on ground check areas, which have been taken on several field trips. Likewise using object-oriented classification method the accuracy seemed to be better than using a pixel-based approach.
3.4 Modelling scenario for dynamic of settlements with socio-economic data

The development of the model belongs to an index-method where the driving forces will be recorded separately and their importance will be weighted (Juang et al. 1992). To use this method it was necessary to define homogeny areas of each factor where the parameter is constant. Based on pixel with the spatial resolution of 15 m we build three groups: group land cover and land use, group topography and group socioeconomic, which based again on individual levels (see Fig. 3).

Figure 3. Flowchart for modelling the expansion of settlements with the help of the index-method.

After the principal of the decision tree in three parts first the individual factors in the levels have been assessed to the probability to get settlement areas ($I_1$). The weighting mainly based on correlation analysis from data of changes between 1978 and 2002. Afterwards the levels have been assessed after their weight inside the group ($I_2$), where the sum of the indices of each group has to get 1. Finally the groups one below the other have been weighted ($I_3$) and up to the final risk or probability to get settlement areas in the future. The result has been controlled with the help of the past changes and have been adapted iterative to get the optimal correspondence to the real situation. The susceptibility of each homogeny area resulted of the addition of each factor levels.

The level land cover and land use based on the classification and change detection of the satellite images 1978 and 2002. Concerning on the total area the following relative decline of classes to the favour of settlements have been calculated: agriculture acreage (13.8%), cardonal (9.5%), coastal zone (13.1%) and tabaibal (9.9%). Buffering the areas of settlements of 2002 and comparing them with the areas of 1978 it shows, that the new built-up areas are mainly lying within a radius of 3 km. Therefore the level proximity to settlements have been separated in three graduated factors with 3, 2 and 1 km distance. The data showing the changes in amount of tourists are divided into four zones, whereas the changes data of the population belongs to municipality level. The levels have been separated in four factors (tourists zones) and six factors (population) incipient with regression, stagnation and four graduate factors of progression. The level altitude and slope represent the natural limited factors of the expansion of settlements and have been entered in the model with six factors in the first case and eight in the last case (see Table 1).
After preparing, weighting and adding all indices which determine the process of expansion the settlements a result could be calculated within GIS with five-scale probability categories. At last the potential new settlements which are situated in nature reserves have been eliminated. The validation of the model is still in process by applying the indicators and methods on another period of time using the already existing classified LANDSAT 3 MSS-scene and a LANDSAT 5-TM scene of 1986 as the starting point so that the results of the model can be validated by already existing data.

4 RESULTS

4.1 Object-oriented image classification

The method and result of the object-oriented image classification will be explained by the classified image of whole Tenerife based on LANDSAT 7 ETM+-scene from 2002. In fact the classification based on a multiresolution segmentation approach with which different scales of segments can be classified into separate levels. Furthermore not only the spectral information of the remote sensed data have been used for the classification but also non-spectral information, like altitude, slope and aspect, as well as a geological map. The image classification bases on a class hierarchy with different levels.

The classification, based on an object-oriented method, additional geographical data and “a-priori”-knowledge, includes 20 land cover and land use classes (see Fig. 4). An accuracy assessment based on ground truth data comes to an overall accuracy of 98,9% and a Kappa-Index of 97,9. Checking the omission and commission error for each class of the image also gives optimal results, especially compared to a former pixel-based classification of the area with considerably fewer classes, where overall accuracy only reached 90,2%.

4.2 Change detection

The detection of changes in land cover and land use classes, based on a post-classification method was done by a matrix, showing the from-to-class in the time from 1978 till 2002 for Tenerife. An extract of the matrix is shown in Fig. 5, concerning the classes cardonal (shrub, sparse vegetation, euphorbia), agricultural acreage and settlement. In this connection the classes cardonal and agricultural acreage lost area from 1978 to 2002, whereas settlements increased. Areas of cardonal in 2002 belonged to nearly 14% agricultural acreage, whereas about 83% had been to cardonal before. Concerning the area under cultivation in 2002 the change detection shows an opposite trend, but one has to take into consideration that the total area of agricultural acreage decreased from 1978 to 2002 by 20%. The settlements gained 275% area, which initially belonged to the classes tabaibal, cardonal and agricultural acreage.

<table>
<thead>
<tr>
<th>Level</th>
<th>Assessment level (I2)</th>
<th>Group</th>
<th>Assessment group (I3)</th>
<th>Total index I1 = I2I3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land cover and land use</td>
<td>0.6</td>
<td>Land use</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Proximity to settlements</td>
<td>0.4</td>
<td></td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>Tourists</td>
<td>0.6</td>
<td>Socioeconomic</td>
<td>0.4</td>
<td>0.24</td>
</tr>
<tr>
<td>Population</td>
<td>0.4</td>
<td></td>
<td></td>
<td>0.16</td>
</tr>
<tr>
<td>Altitude</td>
<td>0.4</td>
<td>Topography</td>
<td>0.1</td>
<td>0.06</td>
</tr>
<tr>
<td>Slope</td>
<td>0.6</td>
<td></td>
<td></td>
<td>0.06</td>
</tr>
<tr>
<td>Per group $\sum = 1$</td>
<td></td>
<td>$\sum = 1$</td>
<td></td>
<td>$\sum = 1$</td>
</tr>
</tbody>
</table>
This analysis shows the expansion of settlement during the last 24 years at expense of other natural vegetation formations and agricultural acreage. On account of the increasing mass tourism on the island since the 60s of the last century, the increasing population and the socio-economic changes have been a big demand for more development area for housing estates and especially tourist infrastructure, like hotels apartments etc.

4.3 Scenario for dynamics of settlements

The model used to build a scenario for the dynamics of settlements is based on spatial land cover and land use data just as on socioeconomic data. The result of this scenario mapped with the actual road network and the situation of settlements in the year 2002 is shown in Fig. 6.

The five classes describe the probability with which the respective area will be built up. In particular the south part of the island, next to the already existing big tourist cities Playas de las Americas and Los Cristianos holds a very high probability. Just as the Orotava-valley in the north
holds a great potential to be built up completely, like analysis showed that since 1982 every year 68 ha of the valley fall victim to development area (R. Pott 2003). Due to the proximity of the capital Santa Cruz de Tenerife and the university-city La Laguna the area in the north eastern part shows a high probability.

5 CONCLUSIONS

The used object-oriented classification method showed in its results better accuracy than traditional pixel-based methods, a cause of the heterogeneous landscape of Tenerife. This is mainly based on the "a-priori"-knowledge which can be inserted in the classification process by fuzzy-logic based membership functions. Another advantage is given through the integration of additional layers, like altitude, aspect, slope etc. which show a high dependence on the distinguished vegetation formations.

The index-method for calculating the model by weighting the driving factors in a three step process with the help of qualitative indices seemed to achieve optimal results. The procedure of modelling areas for the development of settlements will be furthermore validated by using a satellite image of 1986.

The increasing tourism on Tenerife show lasting effects to the ecosystem – among others the expansion of settlements and fallow land. Concerning the manner of development for example in steep valleys (Barrancos) can result in hazards e.g. at high precipitation incident, when avalanche of gravel find there way down unhindered due to the sparse vegetation density on ancient agricultural acreage. This case took place on Easter 2002 in the area of the capital Santa Cruz de Tenerife, where precipitation of 224 l/m² per hour had been measured, that led to a catastrophe with a damage of about € 120 million.
REFERENCES