# Applicability of available Geodata in high mountain environmental research – examples from the Khumbu Himal Area (NEPAL)

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## 1. Introduction

GIS- /RS- based analyses in high mountain environments in general follow a typical scheme: Evaluation of available (digital and analogue) data sources, homogenization, digitalization, standardization, GIS-database creation, data management and - last but not least - the analyses itself.

Cartographical products as well as digital geodatasets are thematically oriented abstractions of real world phenomena. Cartographic data types are most often digitized, taken over into GI-Systems, merged together with data from other sources and providing extensive analyses. In these cases the quality of data fusion and the benefit of analyses are heavily influenced by a number of issues depending on the amount of different data sources. Due to this statements a lot of requirements will be important to handle within GIS based analyses: Is there a complete metadata set existing, and – if not - are we able to understand the correct meanings of the foreign data? Will the semantics be identical? Do we know all parameters about the datums and projections of the used cartographic material; what might be the best reference system to use and how can errors in reprojecting the maps into this target system are avoid? Does the accuracy of the analogue data fit to the accuracy of the digital database and does it meet the requirements of the intended analyses, is the precision of the analogue and digital data good enough? How to handle the time gap between the date of the field survey/edition date of different sources of data; are we allowed generating time series and deriving models out of this data? All these important requirements for building up a GIS based analyses are even difficult to handle in a well documented (that means with a long tradition in cartographic survey) region. In a developing country like Nepal, public topographic maps are still not available for the whole country until now. Different editions with a comparable scale are available only for special areas, like Khumbu or Annapurna Himal. Therefore within the last fifty years different researchers and institutions have produced various topographic maps and most of them show the full palette of problems mentioned above. Nevertheless the topographic maps of the Khumbu area are often used as basic information for environmental research topics, often without or with only a little bit consideration on to their accuracy. An additional aspect for generating accurate databases is the integration of remotely sensed databases. On the one hand aerial photographs and satellite images (from CORONA in the Sixties up to high resolution images of the new millennium) need topographic information for georeferencing, on the other hand they itself provide useful information for high quality mapping output.

This study is focused on the analyses of glaciers in the Khumbu Himal area. Different maps from different years (from the Fifties up to the official map of Nepal from 1997) and remote sensing data (aerial photographs and satellite images) are critically analyzed for their applicability in glacier inventories.

## 2. Available Geodata

The selection of used geodata is based on their easy availability, low or no costs and their common applicability for typical high mountain research tasks. Figure 1 gives an overview over the earthbound and the air and space borne geodatasets used for this study. Other thematic maps like a Vegetation Map (Miehe, 1991), Mountain Hazards Map (United Nations, 1985) or other thematic maps of Nepal described by Pradhananga (2002), etc. are not integrated into this study, because in these cases the thematic layers are only draped over already existing topographic maps.

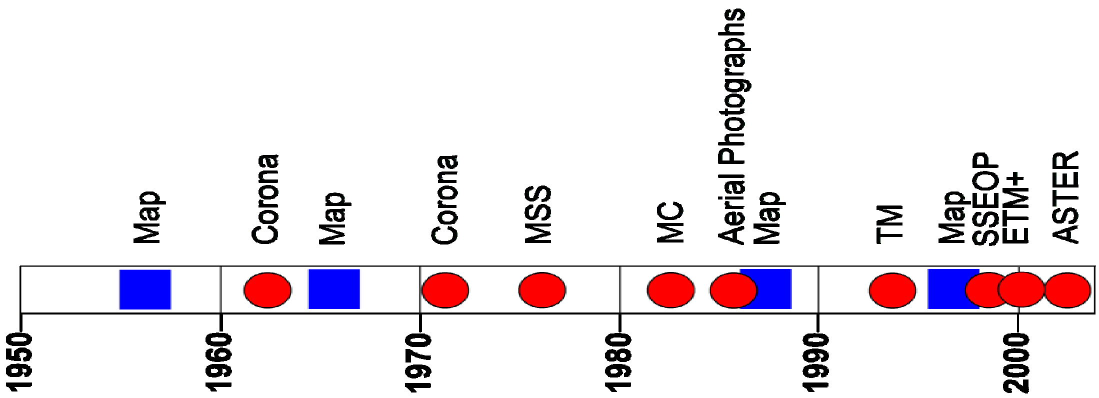



**Figure 1: Used Geodata in Khumbu Himal**

### 2.1. Topographic Maps

Topographic maps of high mountain regions provide useful information about terrain (contour lines, height points, etc.) and about the surface conditions – land cover (rocks, snow and ice, vegetation, etc.). For a comparative study (including monitoring tasks) following basic informations about the maps a required:

- Reference systems with location and height. Referring to this, Heine & Kostka (1998) are documenting results of investigations due to GPS measurements in the Himalayan Region.
- Acquisition and analyses methods and conditions, which are responsible for the accuracy of the product. Such investigations for terrestric-photogrammetric and for aero-photogrammetric studies have been done by Kostka (1980) within high mountain environments.
- Selection of cartographic representation, which is most essential for comparative studies, their possibilities, advantages and disadvantages, are well documented within the cartographic community.

| Name | Scale | No. of sheet |
|---|---|---|
| Lumbini Zone | 1:25,000 | 81 |
| Eastern Nepal Topographical Project | 1:25,000 | 255 |
| Eastern Nepal Topographical Project | 1:50,000 | 37 |
| Western Nepal Topographical Project | 1:25,000 | 254 |
| Western Nepal Topographical Project | 1:50,000 | 79 |

**Table 1: Topographic Maps of Nepal (Source: Pradhananga, 2002)**

Table 1 shows the available topographic maps of Nepal. It is taken from Pradhananga (2002), who gives a report of all existing (Topographical, Land Resource, Thematic, Derived, etc.) maps of Nepal's Topographical Survey Branch prepared on different dates by different donor agencies.

The most important parameters of the available topographic maps of the Khumbu Region are summed up in the following section (Table 2):

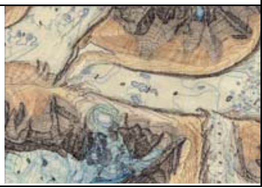
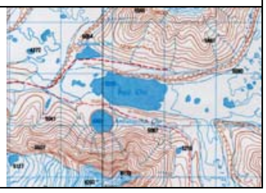
| | **Chomolongma-Mount Everest** | **Khumbu Himal** | **Mount Everest** | **Sagarmatha** |
|---|---|---|---|---|
| Edition | 1957 | 1966 | 1987 | 1997 |
| Scale | 1 :25.000 | 1:50 000 | 1:50 000 | 1:50 000 |
| Ellipsoid | • Bessel Ellipsoid | • Bessel Ellipsoid | • Bessel Ellipsoid | • Everest 1830 |
| Projection | • Gauß-Krüger Projection<br>• 3° Meridiansections<br>• 87°E Central Meridian | • Gauß-Krüger Projection 3° Meridiansections<br>• 87°E Central Meridian | • UTM Projektion<br>• 87°E Central Meridian | • modified UTM Projection<br>• 3° Meridian sections<br>• Central Meridian 87°E, m=0,9999 |
| Height | • Mt. Everest 8848m | • Intersected Points of the Survey of India | • Mt. Everest 8848m. | • Mean Sea Level (India). |
| Acquisition and interpretation | • Triangulation and terrestric photogrammetry | • Triangulation and terrestric photogrammetry<br>• Complements from existing maps and Hasselblad-aerial photographs | • Situation and height information from intersected points of the Survey of India<br>• Additional stereo interpretation of the Metric Camera Experiment (Kostka 1987) | • Photogrammetric Acquisition and interpretation |
| Cartographic representation | • Equidistance of 20m,<br>• also within rocky areas<br>• height points,<br>• smooth shading,<br>• rocks after method of Ebster (ÖAV),<br>• glaciers in blue | • equidistance of 40m<br>• also within rocky areas<br>• height points,<br>• smooth shading,<br>• rocks after method of Ebster (ÖAV),<br>• glaciers in blue | • equidistance of 40m<br>• no contour lines within rocky areas<br>• height points,<br>• smooth shading<br>• rocks after Swiss method,<br>• glaciers in blue | • equidistance of 40m<br>• height points,<br>• no shading<br>• no rock representation<br>• glaciers in blue |
| Representation of Imja Glacier |  |  |  |  |

**Table 2: Basic information of available topographic maps in the Khumbu Himal**

### 2.2. Remote Sensing Data

Especially in high mountain regions Remote Sensing techniques provide useful information about the environment. Remote sensing images from space - in this case - can be very helpful for high mountain research. Their quality is isimilar to images taken independently and is only influenced by the platform and the sensor. The critical examination of the quality (e.g. geometric resolution) as well as the selection of available or possible dispositions (e.g. height of orbit, orientation) can proved in test sites and so the chosen product can be optimally adapted to the actual task. For investigation of high mountain dynamics remote sensing data are available since about 40 years, with different geometric and spectral resolution.

Remote sensing methods and data are used in Nepal mainly for the following purposes (Oli, 2002):

- Base Mapping at the Large Scale
- Revision of Map
- Land Cover Classification and change detection
- Generation of DEM and up dating maps
- Geological Study
- Remote Sensing and GIS

The following Table 3 will give an overview about available/useful remote sensing data of the investigation area. The products have been selected by their image quality, especially with good weather conditions, less amount of actual snow cover, coverage of the whole investigation area and last but not least low or no costs.

| **Sensor** | **analogue/ digital** | **Acquisition date** | **Resolution (m)** |
|---|---|---|---|
| CORONA | a | 1962 | 10-15 |
| CORONA | a | 1972 | 10-15 |
| LANDSAT MSS | d | 1976 | 79 |
| METRIC CAMERA | a | 1983 | 15 |
| AERIAL PHOTOGRAPHS | a | 1986 | 1 |
| LANDSAT TM | d | 1992 | 30 |
| SSEOP | a/d | 1988 | 10-15 |
| SSEOP | a/d | 2000 | 10-15 |
| LANDSAT ETM+ | d | 2000 | 15/30 |
| ASTER | d | 2003 | 15/30 |

**Table 3: Remote Sensing datasets used for the project**

### 2.3. GIS Data

Actually GIS and RS – activities in the Himalayan region still stand at their beginning, that means that different organizations - for example ICIMOD – are on the way to install whole region covering, vector type geodatasets in well documented data formats like ArcView-Shape. As so-called basic datasets content thematic layers like administrative boundaries, hydrographical features, topography, geographical names and – last but not least – even socio-economic information (Pradhan & Bitter, 1998). Unfortunately many of these datasets are generated by digitizing topographic maps scaled 1:250,000 so in most cases the spatial and semantic resolution of information is to poor to be used in glaciological analyses for example. On the other side digital data extracted from 1:25,000 or 1:50,000 scaled maps only cover small parts of the investigation area and therefore seldom meet the needs (for a more complete description of available datasets http://www.icimod.org/focus/gis/datasets.htm or www.nepal-gis.net/nepal_myasp/meta/metadata; both sites also provide a complete set of according meta-information. Antonietti (1998) describes a project, where the aim of it is to create a seperate GIS of the Mt. Everest area, which is as simple as possible, so that the final product may be widely disseminated without the obstacles of excessive costs or size of the software/hardware tools employed. The GIS will be organised with different layers containing geographical, geological, biogeochemical and hydrological information of the area, collected from the available cartography, enhanced remotely sensed imagery and in situ field studies. In so far as the GIS data base has been built up is still unknown to the authors.

## 3. Uncertainty, Precision and Accuracy

The main goal of the study is to set up a time series of the surface of selected glaciers and lakes and visualize their behavior of the ice masses and water bodies throughout the years. Due to the lack of adequate datasets which can be used for 3D-analyses, topographic map sources had to be heavily employed for derivation of terrain datasets; following this strategy implicates the analogue to digital – conversion step (including all known back draws). The major problem of this change of use has been pointed out by Siva Kumar & Joshi (1999): “Cartographers feel little need to communicate information on accuracy, except indirectly through map quality statements or in detailed legends.” In short words: In most cases - especially in development countries - there is a lack of metadata about the cartographic data reducing the usefulness of such kind of data in a medium precision environment and complicating the construction of spatiotemporal databases.

As mentioned above a comparative study based on heterogeneous geodata is very difficult (see Smith et al., 1996). The workflow of the study is divided into the following steps:

- Acquisition and evaluating of available datasets
- Testing and carrying out the possibilities of analogue- digital conversion
- Integration and combination of data types and data formats from different sources
- Unification of map projections
- Digital image enhancement and classification of Remote Sensing data
- Analyses and documentation of applicability of geodata for high mountain research tasks within two topics (glacier and lakes)

For comparative studies (time series), merely the geometric defined information content of a topographic map can be analyzed. Point with heights and contour lines are representing the relief. Points, lines and polygons are representing the situation (shaping) of a landscape. Information about scale and representation of map elements without additional information are insufficient to derive exact precision information. Quality criteria like objective accuracy or completeness (actuality) can only be achieved by field survey.

To get figures about the geometric accuracy the whole process of map production must be analyzed. There is also the fact that the knowledge and skills of the cartographer influences the quality of the map, considerably. Statements about accuracy with numerical values or exact qualitative expressions are not possible, in fact. A comparison of identical elements can be achieved by a relative quality check, at least. Real figures about accuracy can be achieved by referencing with independently produced information. Experiences with this method can be documented since the Eighties of the last century (Buchroithner & Kostka, 1994). Remote Sensing techniques and digital methods of data analyses can provide an accuracy assessment, independently from the local situation and the cartographer, nowadays. The values in Table 4 may give an impression about the horizontal and vertical deviation referring to the position identical ground control points have in the topographic map from 1997.
The results seem to be almost the same as in a study published by Welsch in 2004, who produces a detailed discussion of the precision and accuracy problems of the main Himalayan map products.

As mentioned above, Remote Sensing data can be seen as an accuracy tool for topographic maps, especially in remotely high mountain environment like Khumbu Himal. The accuracy (geometric, spectral, etc.) of Remote Sensing data and derivates are well documented within the scientific community and are not described in this paper, additionally. With respect to the results of the investigation of the maps within this study and the analyses of Welch (2004), the geometric accuracy is situated within the accuracy width of the maps.

| | Deviation 1957/1997 | | | Deviation 1966/1997 | | | Deviation 1987/1997 | | |
|---|---|---|---|---|---|---|---|---|---|
| **GCP-ID** | **z** | **x** | **y** | **z** | **x** | **y** | **z** | **x** | **y** |
| 1 | 5 | 95 | -92 | 5 | -32 | 243 | 14 | 2 | 266 |
| 2 | 0 | -77 | -36 | 0 | -18 | 270 | 0 | -22 | 265 |
| 3 | -15 | -110 | -19 | -15 | -39 | 285 | -15 | -8 | 277 |
| 4 | 1 | -120 | -13 | 1 | -24 | 287 | 4 | -13 | 269 |
| 5 | -2 | -132 | 60 | -2 | -39 | 352 | -1 | -14 | 291 |
| 6 | 45 | 114 | 76 | 45 | -4 | 339 | -13 | 42 | 264 |
| 7 | 34 | 24 | 39 | 34 | 15 | 338 | -5 | 30 | 246 |
| 8 | 31 | 68 | 66 | 31 | 5 | 393 | 3 | 2 | 280 |
| 9 | 23 | 100 | 44 | 25 | 1 | 392 | 7 | 44 | 290 |
| 10 | 68 | 74 | -15 | 68 | -95 | 231 | 16 | -17 | 277 |
| 11 | 72 | 115 | -48 | 72 | -50 | 333 | 29 | 206 | 143 |
| 12 | 97 | 320 | 23 | 100 | 280 | 326 | 71 | 285 | 358 |
| 13 | 16 | -106 | 39 | 16 | 22 | 273 | 13 | -21 | 274 |
| 14 | 28 | -35 | 27 | 28 | 41 | 291 | 17 | -34 | 278 |
| 15 | 36 | -47 | 24 | 36 | 62 | 273 | 16 | -74 | 283 |
| 16 | 42 | -9 | 20 | 42 | -11 | 240 | 14 | 29 | 233 |
| 17 | 8 | -3 | -24 | 8 | 15 | 223 | 12 | -4 | 277 |
| 18 | 24 | 5 | 69 | 24 | 94 | 420 | 8 | 17 | 290 |
| 19 | 5 | -10 | 33 | 5 | 42 | 367 | 13 | -17 | 273 |
| 20 | -4 | 5 | 18 | -4 | 54 | 352 | 11 | -17 | 279 |
| 21 | -3 | 44 | 36 | -3 | 107 | 354 | 13 | 20 | 292 |
| 22 | 10 | -69 | 19 | 0 | -101 | 372 | 19 | -17 | 267 |
| 23 | 22 | 35 | -24 | 22 | -11 | 300 | 19 | -10 | 260 |
| 24 | 22 | 75 | 101 | 22 | 83 | 401 | 15 | 58 | 373 |
| 25 | 29 | 76 | 18 | 29 | -51 | 355 | 15 | -6 | 281 |
| 26 | -85 | -60 | 56 | 15 | -62 | 385 | 17 | -2 | 278 |
| 27 | 12 | -8 | 46 | 12 | -102 | 364 | 18 | -1 | 271 |
| 28 | 15 | 6 | 30 | 15 | -41 | 325 | -3 | 22 | 256 |
| **Median** | **19** | **5** | **25** | **19** | **-8** | **336** | **13** | **-3** | **277** |

**Table 4: Horizontal and vertical deviation of the GCP's measured in meters.**

## 4. Applications

Two examples of a wide spread applicability of topographic maps, Remote Sensing and GIS data in high mountain environment are chosen to document the possibilities and limits of existing geodata. Glaciers and glacier related lakes itself represent features in the high mountain environment of the Khumbu Himal which can be detected within an easily understandable time and are important features and parameters of a changing environment.

There exist several studies about the glaciers in the Khumbu Himal (Fushimi, 1977; Moribayashi & Higuchi, 1977), most of them are focused on especial glaciers like Khumbu or Imja glacier (Yamada, 1993; Watanabe, 1995, Tartari et al., 1998). Mool et al. (2001) built up an inventory of glaciers, glacial lakes and the glacial lake outburst floods of Nepal. This study is based on the analyses of topographic maps and interpretation of various remote sensing data. With the focus on the Honku glacier area southeast of Ama Dablam the authors want to document the possibilities of monitoring the change of glaciations with available geodata.

Figure 2 documents mapping with remote sensing data (left) and drawing of glaciations in the topographic maps. This simple comparison shows the problems of remote sensing methods on the one hand and on the other hand the limits in quality within topographic maps. As shown in an example, the extention of the glaciation in the official topographic map of Nepal (1997) is too large, reaching nearly the boundaries of the 1850 moraine. This false extent of the glaciation is also documented within the GIS data base of the glacier and lakes of Nepal (Mool et al., 2001). Due to well known limits of remote sensing techniques in high mountains (Kostka & Buchroithner, 1994) real good figures of glaciations can be achieved within the lower borders of glaciations, only. Mapping has done by a poor visual interpretation of geocoded Remote Sensing data and digitally by a combined classification of original images and ratio images (NDVI, TC, etc.), mostly based on the differentiation of snow and ice with other landscape features. The detection by hybrid methods of analogue and digital analyses provide the best results.

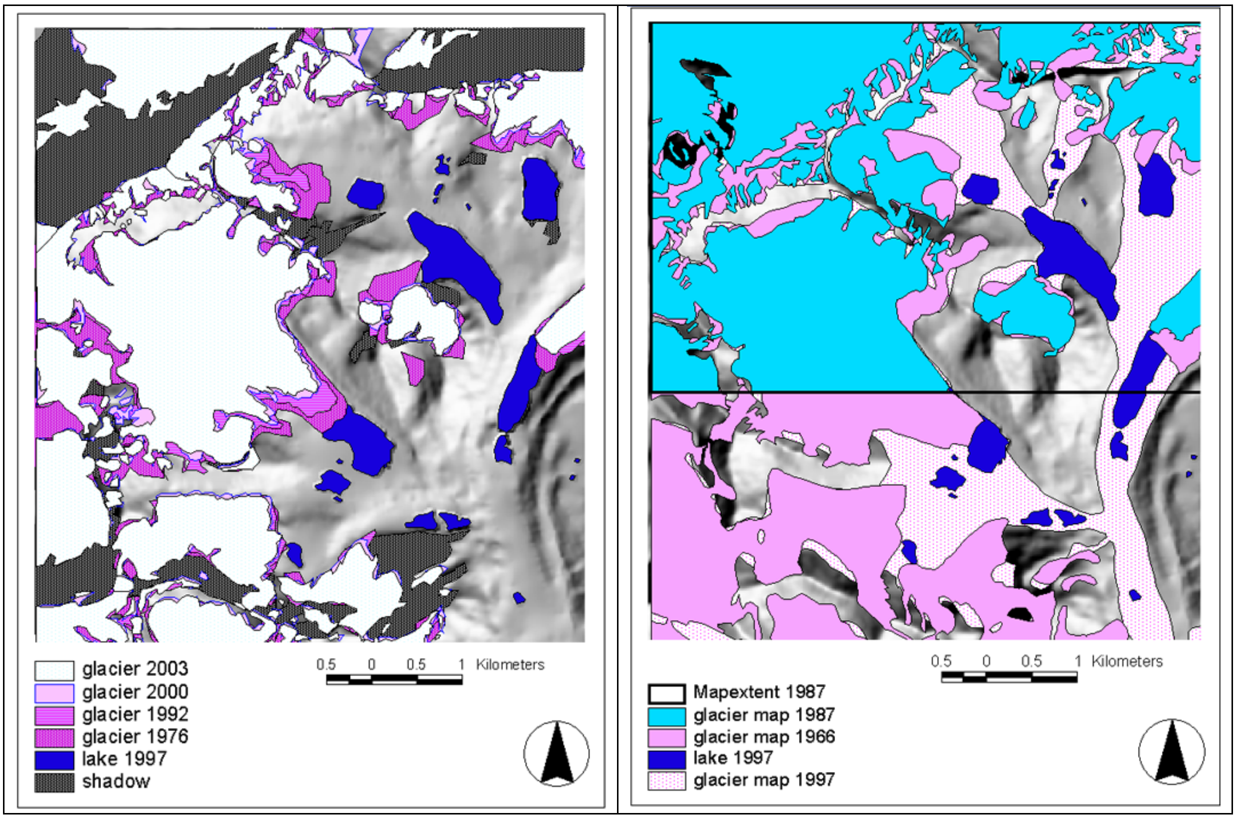



**Figure 2: Glacier Study: 1976 - 2003**

Figure 3 shows the change of the lakes on the Imja Glacier tongue including the Imja Tso, a famous lake that has a high potential of outburst hazard. Glacier lakes are part of sensitive glacial and periglacial environment. The rate of the growth of the lake indicates the potential of a hazard situation. The Imja Lake started to form by melting about 45 years ago (P.K. Mool et al., 2001, p. 144). The maps of 1957 and 1965 are showing the same figures of small ponds (see Table 2). This example documents the main problems of map acquisition, mentioned above. The first time 1976 a significant lake can be detected with the used satellite images. From then on the lake is growing and has his largest extent in 2003 (about: 1,5 km$^2$). Huge lakes, especially within a periglacial environment (Imja glacier is backtracking to the east and in front of the tongue, the lake fills up within the moraine ridges.

The second largest lake south of the Imja Tso has not changed his environment since this investigation period due to his situation outside of the main moraine ridge of Imja glacier. Other small lakes can change with time intervals of view days or even daily.

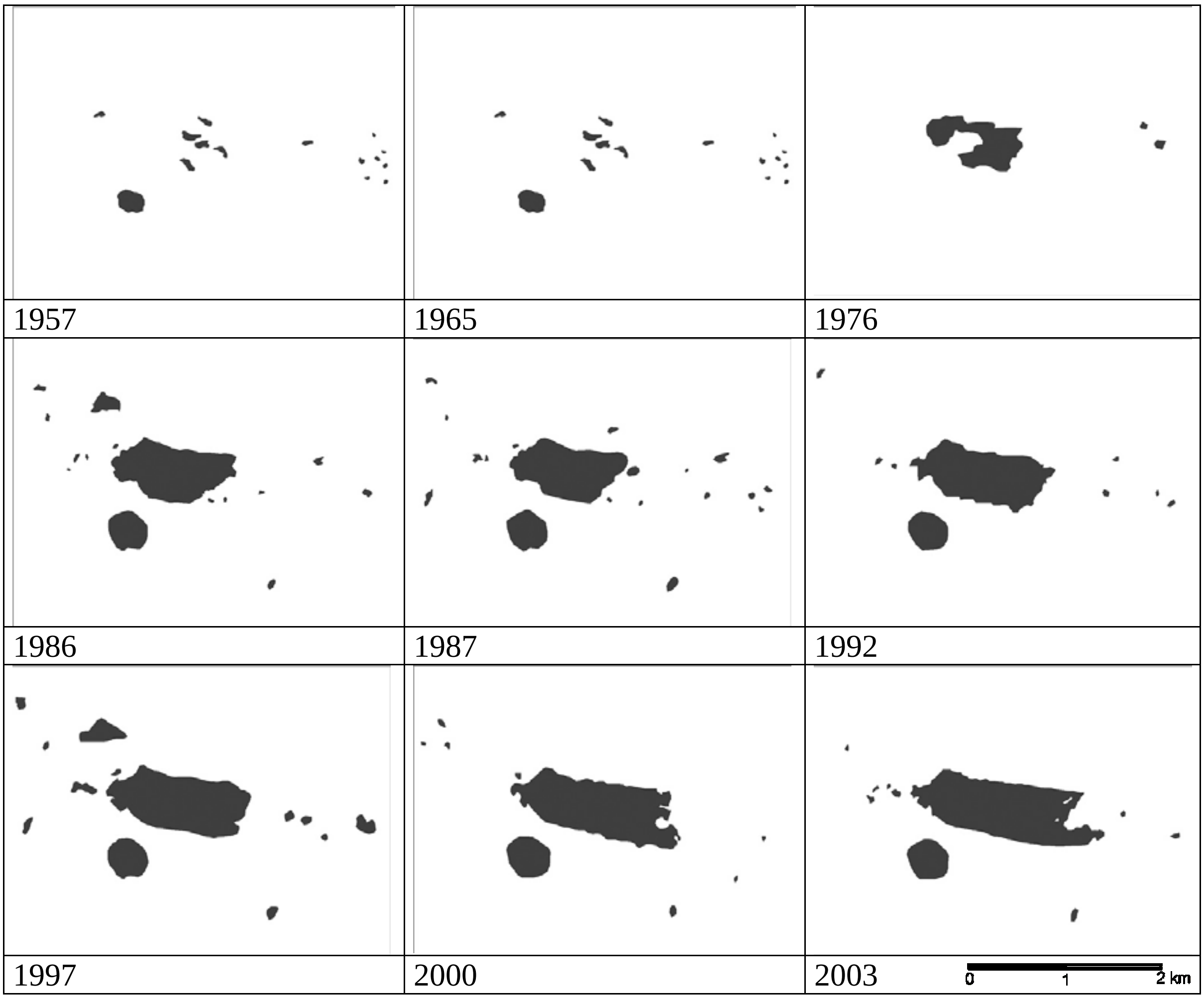



**Figure 3: Development of the Imja Lake Area**

Another example deals with the possibilities and problems of joining multitemporal geodatasets to real time series. As in traditional (non-spatial) time series analysis the major benefit results from adding a dynamic component to the dataset, which enables time dependent analyses, spatiotemporal modeling, forecasting and dynamic visualization. Especially in high mountain environments this kind of monitoring can be used not only for water resources management or for tourist purposes but also to prevent damage on man and human made infrastructure by reducing the risks of avalanches, glacier surges and floods caused by glacier lake outbursts.

In most cases the monitoring of elements of the high mountain landscape (glaciers, rock glaciers,…) is done acquiring data from airborne data sources. These methods are well documented and employ glacier surface modeling techniques based on laser scanning in conjunction with digital photogrammetry (Favey et al., 2000), mass balance and flow variation calculations based on DTM's constructed from aerial photographs (Willis et al., 1998) and, with a clear focus on dynamic visualization of the changes, Kaufmann & Ladstädter (2004) and Böttner (2004).

In contrast to the cited papers and mainly caused by the lack of stereo photographs covering an adequate part of the Khumbu Himal region the authors had to adopt the known methods and tried to derive the spatiotemporal datasets direct from analogue cartographic material. The data processing consists of three main packages: data acquisition and correction, data densifying and dynamic visualization of the results.

A/D – Conversion has been done by scanning the paper maps with a resolution of 400 dots per inch. This step was followed by a non-automated vectorization process, that means manual on-screen-digitizing of the surface-relevant map features (contour lines, spot heights, breaklines and other shape describing landform elements, hydrography) within a standard desktop GIS – environment (Arcview 3.2). After that a reprojection of the datasets into the more common UTM/WGS84 – System, a topological cleaning, attributation and the minimization of the positional errors have been done. Finally based on the Topogrid – Module of ArcInfo according to each topographic map a hydrological correct DTM - grid (year-grid) has been constructed.

The data densifying package consists of two core elements; the sampling procedure, which produces the z-test data, and the surface modeling procedure. For sampling a uniform, north-south/west-east oriented measurement network of equidistant sampling points has been draped over the whole test area. Based on the experiences made during similar studies in the Tyrolean part of the Alps and according to the recommendations given by Pelto (2001) for the Columbia Glacier (Alaska) and the Lemon Creek Glacier (Washington) a point-to-point distance of 100 meters (i.e. 100 points/km²) has been used.

Instead of the methods discussed in Huang & Shibasak (1995) or Priyakant et al. (2003) a curve fitting based algorithm has been used to derive models of surface development from the z-values collected in each sampling site and for all year-grids. Typically the glaciers of a region produce fitting curves (fitting models) differing in gradient and shape. So classes of fitting models can be identified, depending on the position of the test site on the glacier. On principle the calculation of individual fitting models for each sampling location would be possible but this would only increase the processing time without levering up the accuracy level of the results in a significant way.

This partitioning method leads to a rationalization of the test area, where each part of the glacier is represented by a typical class of fitting curves; vice versa for densifying the data of each partition the fitting model calculated for this partition can be used to interpolate for example an annual rhythm of observations. In a final step the in this way generated regionalized z-values were combined to a complete grid of the interpolated annual surface which is ready to be used for further analyses.

The visualization of dynamic processes can be done in two ways, by shortening the time interval between the single observations in the interpolation procedure or by image morphing. The first method may produce results, which are mathematically more exact but might be much more time consuming. For this study producing motion pictures by morphing hill shades of consecutive states of a glacier's surface has been proofed to be a cheaper, a faster and much more flexible way to demonstrate dynamic processes.

## 5. Conclusion

The selection of the best suitable Remote Sensing data sets as well as the sequence of time series are highly responsible tasks in the frame of topographic mapping and monitoring. The best solution of the mapping and monitoring process is an outweighed relation between extensive expense and satisfying suitable solutions reached by low costing. The study indented to enable low cost assessment over high mountain environment, which can be applied on other high mountains regions of the world.

But as a matter of fact more than in other applications the quality of the results in the high mountain environment depends on the quality of the cartographic material. Especially positional errors, feature inaccuracies and even attribute errors (obviously caused by misinterpretation during the survey) provoke a serious handicap for the methods discussed in this paper. Nevertheless the strength of the method lays in densifying existing data (interpolation), the quality of forecasting results has to be proofed.

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