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Remote sensing based mapping and characterization of soil and vegetation quality of potential plantation areas in the desiccated Aral Sea area

by

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Составление карты при помощи дистанционного зондирования и характеристика свойств почвы и растительности потенциальных зон лесопосадок в высыхающем бассейне Аральского моря

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КРАТКИЙ ОБЗОР

Одной из крупнейших экологических катастроф, которую когда-либо видел мир, является высыхание Аральского моря. Большая часть водного бассейна уже испарилась, а интенсивная аэоловая эрозия (ветровая эрозия) происходит от зоны высыхающего моря до прилегающих к нему орошаемых зон, приводя тем самым к огромным экономическим потерям в сельском хозяйстве и серьёзным проблемам здоровья населения. Одной из возможных стратегий нейтрализации этих процессов является уменьшение ветровой эрозии путем создания лесопосадок в зоне высыхания Аральского моря.

С целью нанесения на карту и точной характеристики потенциальных лесопосадок в пределах огромной зоны высыхающего бассейна (приблизительно 4 270 468 га) были успешно использованы различные методы спутникового дистанционного зондирования. Первые проделанные анализы спутниковых данных 2000 года указывают на то, что площади с высокой степенью засоленности, где происходит сильнейшее усыхание, включают в себя 476 347 га (11%) области высыхающего Приаралья. Эти возможные лесопосадки должны рассматриваться с учетом трех перспектив:

1) Установленные, при использовании данных 2000 года, площади лесопосадок, вероятно, представленны без учета протяженности размеров недавно образовавшейся зоны, вследствие высокой динамики осушения в 2001 и 2002 годах. Эту площадь высыхания, которая постоянно увеличивается в своих размерах, можно непосредственно наблюдать путем визуального сравнения спутниковых данных 2000

года с обзорным изображением этого региона со спутника, полученным в 2002 году. С целью более точной оценки протяженности, высохшей за последнее время, зоны необходимо получить, обработать и проанализировать спутниковые данные 2004 года.

2) Необходимо произвести местную оценку данных по протяженности на поверхности и характеристике возможных лесопосадок на сильнозасоленных почвах для калибровки, настройки и сверения спутниковых данных с данными подспутниковых наблюдений. Только в сочетании с полевыми данными в пределах самой зоны могут быть получены подтвержденные, подробные и высококачественные материалы дистанционного зондирования, предназначенные для эффективного планирования и наблюдения за лесопосадками.

3) Установленные площади лесопосадок относятся к зонам с высокой концентрацией соли, которые вследствие высыхания, представляют серъёзную угрозу орошаемым сельскохозяйственным землям. Для того, чтобы выработать согласованнную стратегию для создания лесопосадок в осушенной зоне будут необходимы обсуждения с потенциальными партнерами по совместному проекту такими, как эксперты GTZ (Германское Общество по Техническому Сотрудничеству, Гамбург), ZEF (Центр по Исследованию Развития) и DLR-DFD (Аэрокосмический центр Германии - Центр данных дистанционного зондирования) для того, чтобы определить какие другие тематические области (например, поддержка существующих зон растительности) должны быть установлены, нанесены на карту и охарактеризованы по свойствам почвы и растительности при помощи методов дистанционного зондирования и подспутниковых наблюдений.

С целью осуществления проекта, спутниковые данные могут быть обработаны для создания различных материалов, относящихся к ландшафтному планированию и мониторингу, например, а) тематические бумажные карты и цифровые ГИС (Географическая Информационная Система) карты регионального и местного масштаба, б) классификация потенциальных зон лесопосадок по различным характеристикам почвы и растительности, и в) идентификация и мониторинг „горячих точек“ в Приаралье с динамикой значительного высыхания.

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ABSTRACT

The desiccation of the Aral Sea is one of the largest ecological catastrophes the world has ever seen. Large parts of the water body have already evaporated and intensive aeolian erosion (deflation) has occurred from the desiccated Aral Sea zone to the adjacent irrigation areas, causing heavy economic losses in agriculture and serious health problems to the inhabitants. This damage is particular aggravated by the deflation from the saline soils and salt crusts within the desiccated zone. One potential strategy to counteract these effects is to reduce the deflation by establishing salt and wind tolerant plantations within the desiccated zone.

Satellite remote sensing techniques were successfully employed in order to estimate and approximately map the potential plantation areas in the large Aral Sea desiccated zone (approx. 4,270,468ha). First analyses of satellite data from the year 2000 show that the areas with a high degree of salinization, on which the severe salt deflations occur, include 476,347ha (11%) of the desiccated Aral Sea terrain. These potential plantation areas should be interpreted keeping three perspectives in mind:

1) The detected potential plantation areas using data from 2000 are likely to represent a distinct underestimate of the extent of the recently developed area due to the high desiccation dynamics in 2001 and 2002. The rapidly growing desiccated area can be directly observed by visual comparisons of satellite imagery from 2000. In order to assess the recently desiccated area to more exact, recent satellite data should be obtained, processed, and evaluated.

2) The information on the surface extent and the characterization of potential plantation areas in soils with high salinization must be locally assessed to calibrate, adjust, and verify the satellite data with ground truth data. Detailed, high quality, and validated remote sensing products, appropriate for effective planning and monitoring of plantations areas, can only be generated in combination with field data from the desiccated zone.

3) The estimated plantation surface refers to areas with high salt concentrations which, because of deflation, present the most serious threat to the irrigated agricultural areas. For a concerted strategy of planting in the desiccated zone, expert discussion with potential partners in a joint plantation project, such as with experts from the GTZ (Deutsche Gesellschaft für Technische Zusammenarbeit GmbH) and ZEF (Center for Development Research) would be helpful. The aim of these discussions could be to discover which other specific areas (e.g. support of existing vegetation zones) should be identified, mapped, and characterized in terms of soil and vegetation properties using remote sensing and ground truth methods.

For project implementation satellite images can be processed to create various products relevant for landscape planning and monitoring. These remote sensing results can contribute thematic paper maps and digital GIS (Geographic Information System) maps on regional and local scales. The applied techniques allow spatial demarcation of the potential plantation areas in terms of different soil and vegetation qualities. Furthermore, present operational remote sensing systems such as MODIS assure long-term identification and monitoring of hotspots in the Aral Sea basin with extremely high desiccation dynamics.

1 INTRODUCTION

The desiccation of the Aral Sea is one of the great ecological catastrophes and has caused dramatic economic consequences. At present, intensive aeolian erosion is taking place since such large parts of the endorrheic water body have evaporated. The transport and deposition of fine soil particles such as sand, silt, clay, as well as salt particles originating from the original sea, present a considerable hazard to the people and the agricultural production of the adjacent intensively-used agriculture (Létolle and Mainguet 1996). The input of aerosols with high salt concentrations additionally causes salt deposition and accumulation in irrigation and groundwater which leads to reduced soil productivity. Wind erosion commonly results in damage to cotton and, in particular wheat crops, which further reduces yields. This decrease in agricultural production occurs simultaneously with the deterioration of hygienic conditions and nutrition. As a consequence the entire Aral Sea region is characterized by high rates of diseases such as anemia, tuberculosis, cancer, and lung illnesses, as well as a high rate of infant mortality and low life expectancy (Létolle and Mainguet 1996). An intensification of these effects is expected with the ongoing desiccation process: toxic substances from the deposits of previous weapon experiments may possibly be brought into the irrigation system by aeolian deposition (Ziyatdinova 2002).

Remote sensing with the assistance of operational satellite data offers the only possibility of cost-effective monitoring changes in large areas, particularly when they are located in remote regions. The physical measurement of multispectral reflections and the resulting recognition of different land surface conditions offers the basis to characterize areas in qualitative, quantitative and site-specific ways. The DLR-DFD has wide-ranging experience with the mapping of changing land surfaces on various scales in many areas of the world. Additionally, since the start of the 1990s the DLR-DFD has ongoing experience with the Aral Sea desiccation process (Ressl and Micklin 2004). Many studies have been carried out, investigating this desiccation process and analysing the irrigated agriculture (Dech and Ressl 1993; Ressl and Dech 1996; Ressl et.al. 1998; Ressl 1999). Since the beginning of the year 2000 the DLR-DFD has concentrated its activities on the Khorezm region of Uzbekistan (Vlek et al. 2001). As a partner in the ZEF-UNESCO project on land and water restructuring in Khorezm, the DLR-DFD is working on various biophysical parameters on modeling and optimizing plant growth and water resources in the framework of a Land Use Conversion Model (LUCM). Consequently, data and knowledge on the geographic region and the present ecological problems are already available at the DLR-DFD.

2 PILOT STUDY ON THE ESTIMATION OF THE POTENTIAL AVAILABLE PLANTING AREA

2.1 Data and methodology

Numerous international studies and many years of experience at the DLR-DFD show that data products from Landsat TM or Landsat ETM+ are suitable sensor systems for performing surface analyses in dry areas by remote sensing (Collado et. al. 2002; Novak and Soulakellis 2000). The spatial ground resolution of 30m×30m per satellite image pixel and 6 multi-spectral bands, spanning from visual to mid-infrared wavelengths, offer sufficient information for recognizing different substrates and consequently detecting potential plantation surfaces. The spatial resolution can be improved by means of a further channel for visual interpretations to 15m×15m ground resolution. The satellite image size of approximately 180km×180km allows a survey of the entire Aral Sea region using six images. A Landsat satellite image is thus (at US $600) far cheaper than aerial photos covering a similar scale or time-consuming ground investigations on the ground. Other satellite systems with higher spatial or spectral resolutions do not offer complete coverage of the region (e.g. ASTER) or exceed financial limits by far (e.g. SPOT 5, IKONOS). Unfortunately, substantial errors have occurred in Landsat imagery since May 2003 (USGS 2005). The MODerate resolution Imaging Spectro-radiometer (MODIS) covers a similar spectral resolution to Landsat and offers a free-of charge alternative, even though the spatial resolution of 500m may be problematic. However, this limitation can be neglected, because high resolution data (e.g. SPOT 5) can be integrated to monitor the vegetation plots on different scales. The following pilot study focuses on already available Landsat data of 2000.

High resolution satellite images in the DLR-DFD's possession allow complete coverage of the Aral Sea region between 1960 and summer 2000. Further available data include near-complete spatial coverage in 1999 as well as complete spatial coverage between 1987 and 1989. The available data from 2000, relevant for this pilot study, was processed using modern remote sensing methods in order to roughly assess the surface area of potential planting areas. The applied methodological steps are presented in Figure 2.1.

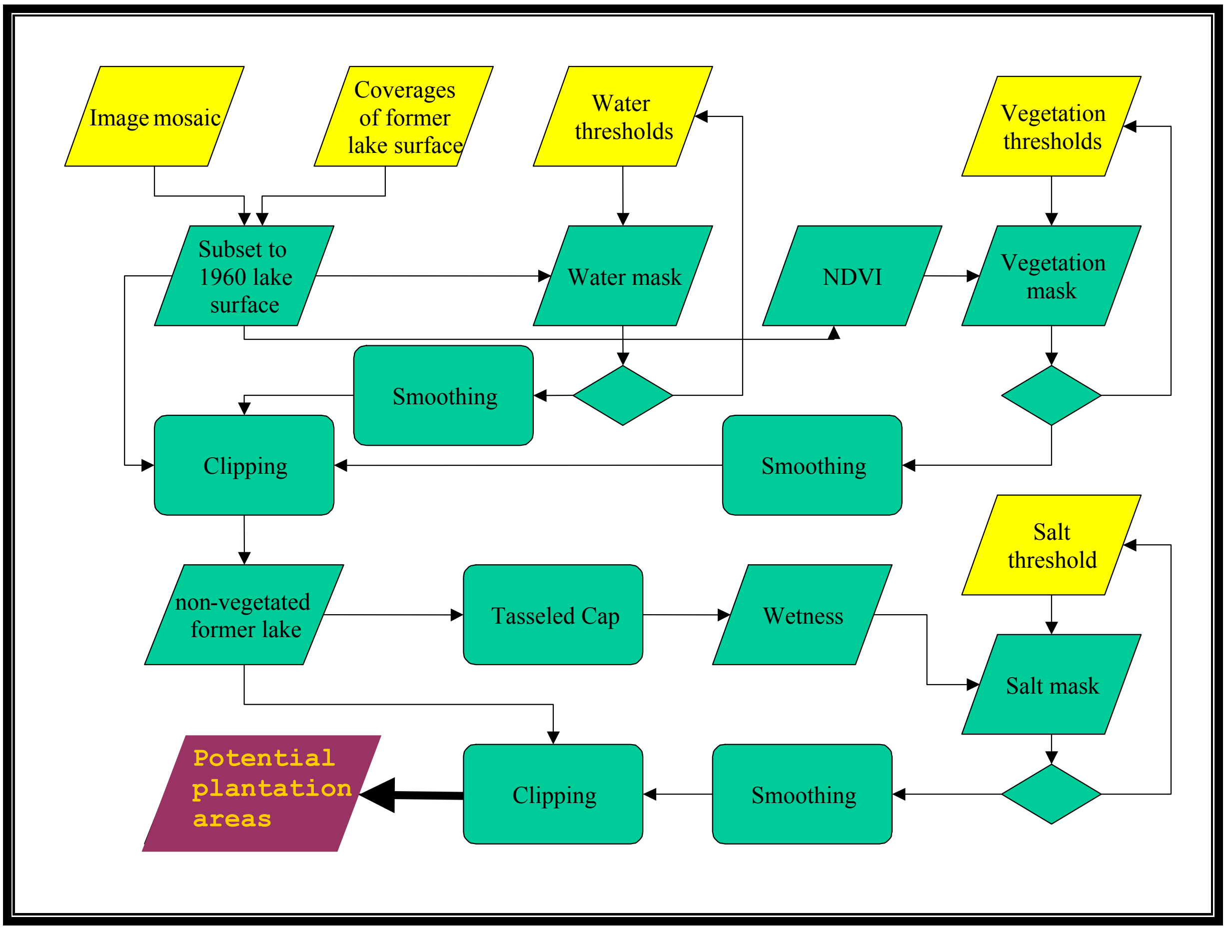

Figure 2.1: Methodology for partially-automated assessment of potential plantation areas in the desiccated zone of the Aral Sea in 2000.

On the basis of a satellite image mosaic consisting of nine Landsat-7ETM+ images covering the Aral Sea region in 2000, the borders of the Aral Sea area from 1960 were extracted by spatial intersection with TIROS satellite images from 1960. The total water surface area remaining in the year 2000 was then subtracted from this area. Inside the displayed terrestrial desiccated areas, vegetation zones were cut out and remaining areas were assessed as potential excessively saline soils or potential plantation areas of the surface.

2.2 Estimation of the potential plantation area in the desiccated zone

Initial analyses using remote sensing data from 2000 showed that that 61%, and thus 4,270,468ha (42,690 km^2) of the Aral Sea surface of 1960 is now dry (Figure 2.2).

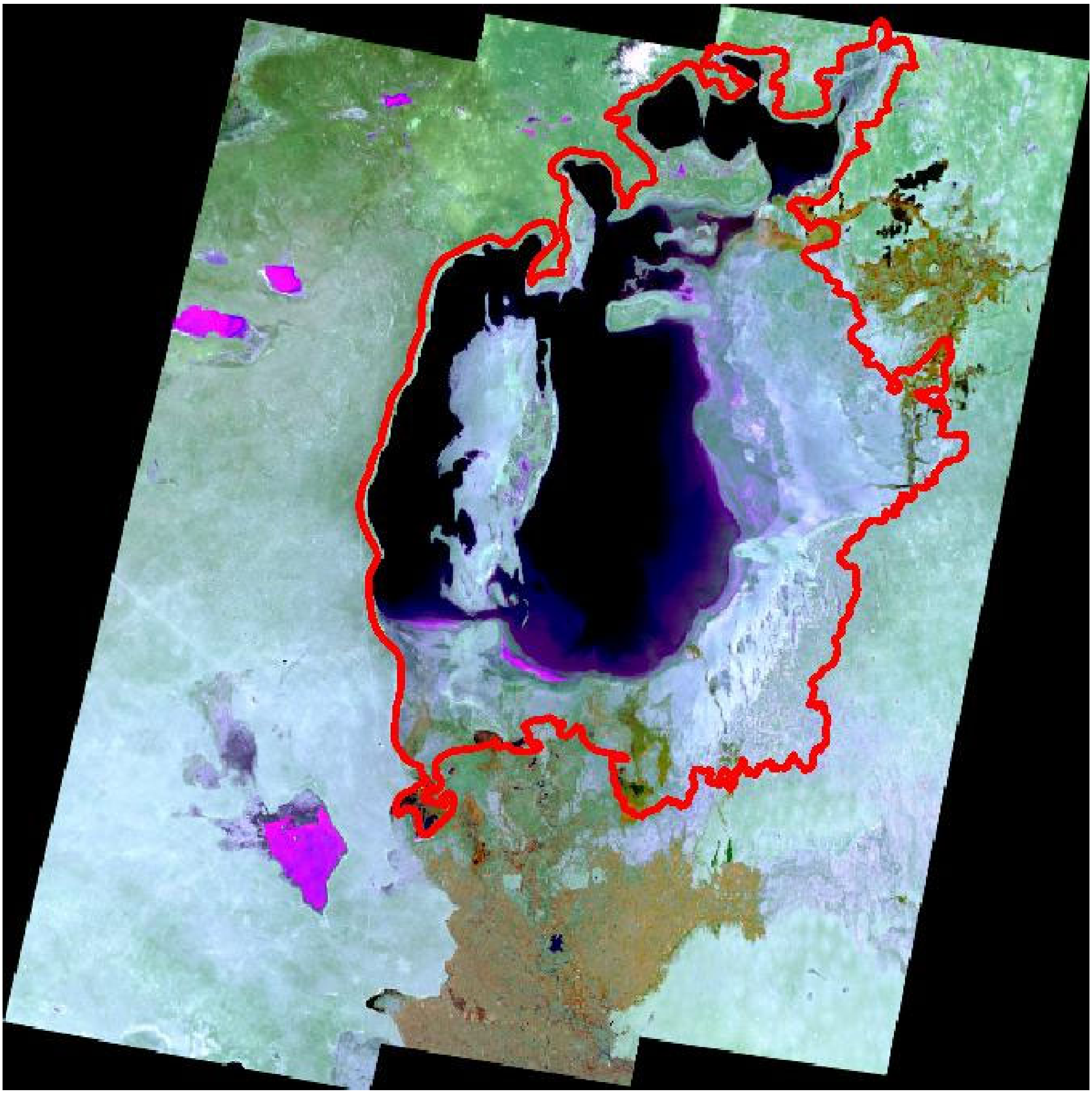

Figure 2.2: Spatial extent of the Aral Sea in 2000 inside the former shore boundaries of the lake in 1960 (red line).

Figure 2.3 presents the desiccated area that has developed since 1960 together with the extent of the Aral Sea in 2000, which has been estimated at the DLR-DFD by means of satellite remote sensing since the 1960s.

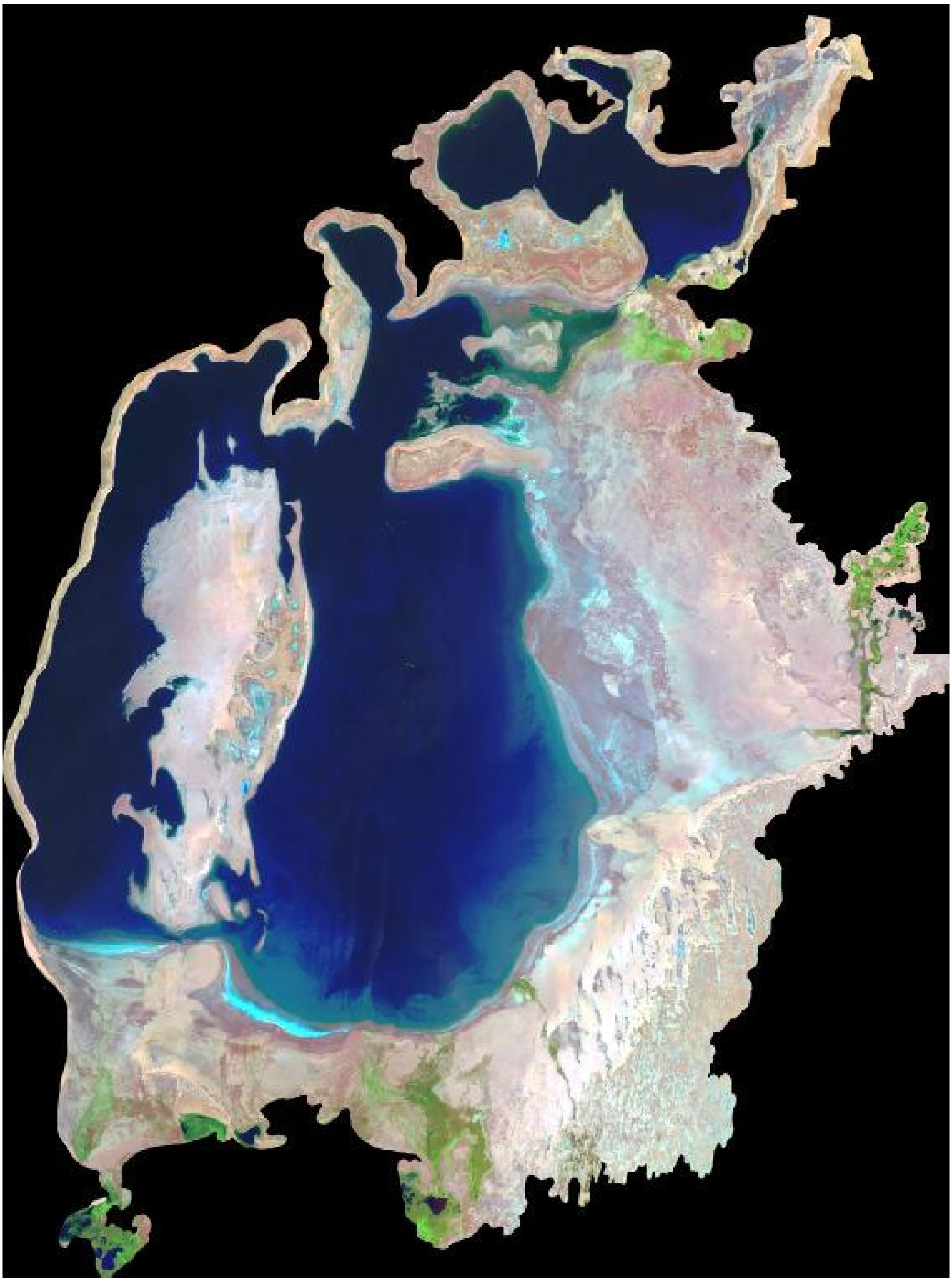

Figure 2.3: Desiccated area that has arisen since 1960 and the Aral Sea in 2000 within the borders of the previous 1960 extent of the Aral Sea.

Various surface types of the Aral Sea extent in 1960 were estimated from the Landsat data and summarized in Table 2.1.

Table 2.1: Surface area estimation by semi-automated analysis of year 2000 satellite data

Surface types	**Surface area**			
	Absolute		**Relative**	
	[ha]	**[km^2]**	**Proportion of desiccated area in 2000 [%]**	**Proportion of sea area in 1960 [%]**
Sea surface in 1960	7,155,388	71,529	-	100
Water surface in 2000	2,774,471	27,735	-	39
Desiccated surface in 2000	**4,270,468**	42,690	100	61
Clay and sandy surface in the desiccated Aral Sea area in 2000	3,683,673	36,824	87	53
Vegetation-covered surface in the desiccated Aral Sea area in 2000	110,449	1,104	3	2
Potential plantation areas (strongly salt affected) in the desiccated Aral Sea area in 2000	**476,347**	4,762	**11**	7

Note: Last row with a potential plantation area of 476,347ha, corresponding to 11% of the desiccated area in 2000.

The comparison of partial areas inside the desiccated area clearly shows the areas interpreted on the screen as highly salt-affected and extracted by semi-automatic remote sensing methods make up about 476,374ha or 11% of the total desiccated area.

2.3 Remote sensing supported and concerted planting strategy

Planting of the salt-affected areas inside the desiccated zone with suitable salt-resistant plants stabilizes the soil substrate and thereby reduces the deflation of salt particles and the strength of the surface winds in the irrigation area. Concerted planting of the desiccated zone, which exceeds spot-focused vegetation planting on scattered salt surfaces, requires that the differing site characteristics of this large area are surveyed, mapped, and characterized in relation to ground, vegetation, and relief quality by remote sensing. Building on this information, the most suitable vegetation for these areas can be inserted in order to achieve maximal impacts on reducing the problems of desiccated areas described above, for example the planting of particular vegetation types on surfaces:

- with differing ground substrates (e.g. sandy, clayey, or areas with high salt contents), in order to reduce both the deflation of acute hotspots (such as salt areas), and also to protect areas with relatively few salinization problems (such as clay and sand areas) from stronger salt deposition;
- with existing vegetation supported by additional vegetation to achieve a higher and denser windbreak for the irrigation areas;
- of varying height inside the former Aral Sea area, to reduce wind and aerosol transport through dense vegetation to the highest sites in the desiccated zone.

The satellite-based mapping and characterization of the different surface types for plantations must be complemented by fieldwork in the desiccated zone. In this field campaign the spatial distribution and qualitative differentiation of vegetation, soil, and relief types will be identified on the ground. In the subsequent preparation of the information on the computer, the collected small-scale field data will be incorporated in order to verify and calibrate large-scale data from the satellite image. Qualitatively and quantitatively verified information products can only be produced for a large area and be useful for plantation planning when satellite and terrain detail is combined in the assessment.

Satellite information can also be quickly and simply applied to observe large areas of vegetation growth. Satellites, e.g. MODIS, can regularly monitor the development of the entire plantation area and thereby demonstrate the success of the project. Similarly, problem areas where vegetation growth has fallen behind or stagnated can be early recognized inside the planted areas (Ruecker and Conrad 2003). This feedback from remote sensing can be utilized to carry out specific actions for the observed problem areas.

2.4 High desiccation dynamics and rapidly expanding desiccated areas

A visual comparison of multi-temporal satellite image quicklooks from 2000 and 2002 highlights the apparent and dramatic desiccation dynamics. Areas with intensive water surface retreat are found, for example, in the inflow area of the Amu Darya river. Clearly visible retreats can be observed on the east bank of the sea which can be observed in the Quicklooks in Figures 2.4 and 2.5. This temporal comparison of Quicklook satellite data from 2000 and 2002 made the weaknesses, such as the lack of current data, of the pilot study evident, while at the same time showing potential for improvement. Based on the data from 2000 the size of the current desiccated surface and thus the size of the potential plantation area were underestimated. In order to survey the desiccated zone as exactly as possible and characterize the spatial and qualitative differentiation of the various vegetation and ground types, it is necessary to obtain recent satellite data and process it as described.

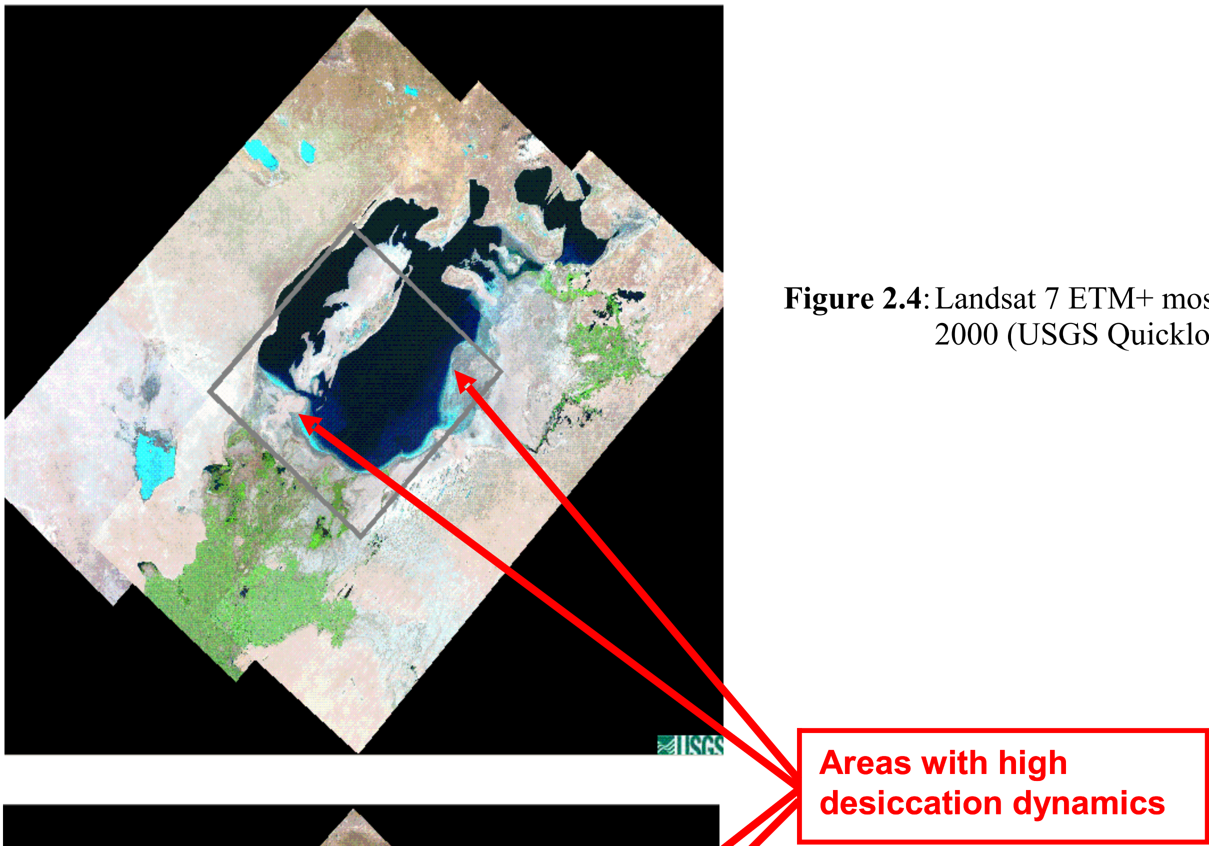

Figure 2.4: Landsat 7 ETM+ mosaic from 2000 (USGS Quicklook)

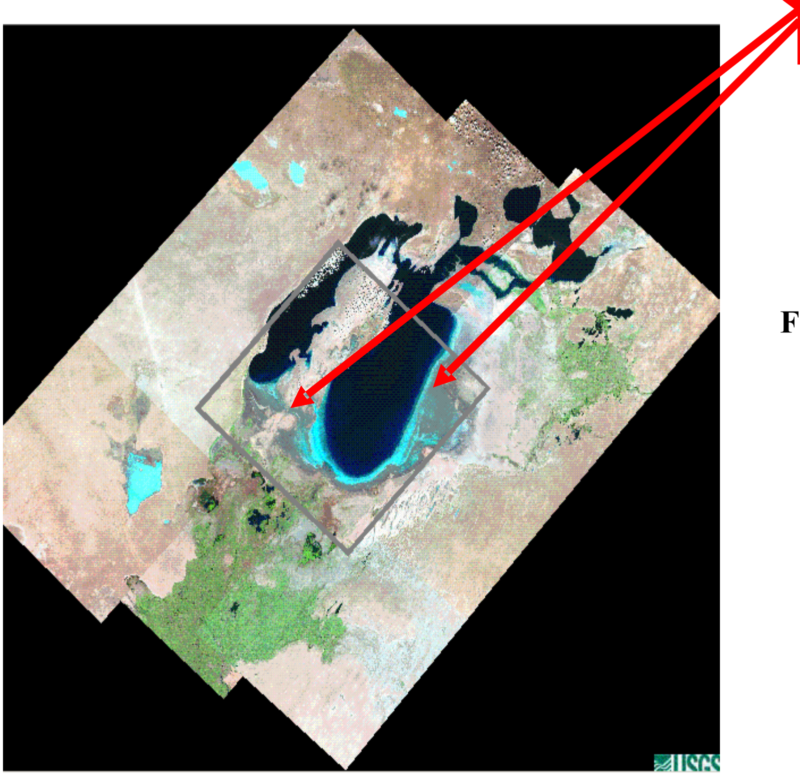

Figure 2.5: Landsat 7 ETM+ mosaic from 2002 (USGS Quicklook)

3 A METHODOLOGICAL APPROACH TO MAPPING AND CHARACTERIZATION OF SOIL AND VEGETATION QUALITY OF POTENTIAL PLANTING AREAS FOR PLANNING PURPOSES

The main steps of the methodological process on the accurate mapping and characterization of soil and vegetation quality of potentially planted areas are presented with proposed time budgets in Figure 3.1.

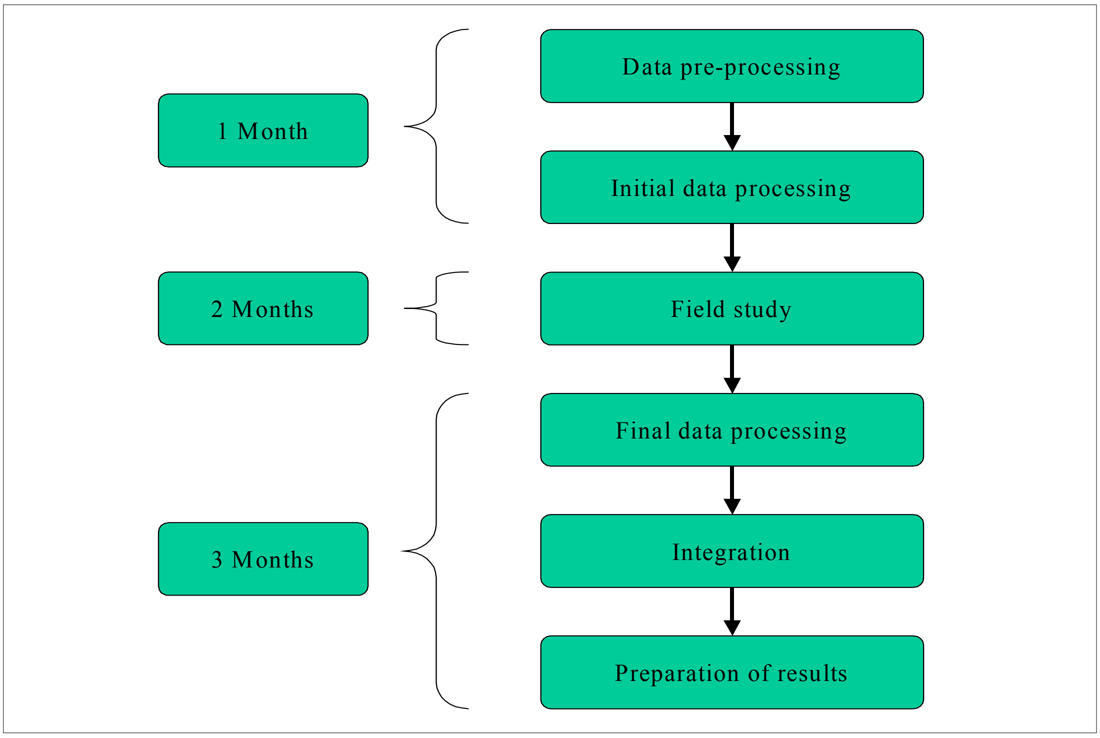

Figure 3.1: Conceptional steps in the procedure concerning accurate mapping and characterization of potential planting areas

The analysis is structured into three phases: 1) data pre-processing and initial data processing (1 month), 2) field campaign (2 months), and 3) final processing using terrain data, integration, and preparation of the results for the planning of plantations (3 months).

3.1 Use of current satellite data in the precise mapping of desiccated areas

Due to the satellite data used in the pilot study, which is now already four years old, the large desiccated areas that have arisen in recent years could not be surveyed (compare the satellite data from 2000, Figure 2.4 and 2002, Figure 2.5). With the procurement of recent satellite data from 2002[1] or up to date MODIS data it would therefore be possible to survey the current desiccated areas and verify them by means of a prompt field study to ensure quality assurance of the satellite products. Furthermore, a comparison of satellite data between 2000 and 2002

[1] Landsat data from 2003 cannot be used for the investigation at this time, since the sensor system, which has functioned flawlessly for a long period, experienced technical problems in summer/autumn 2003 and could not record data.

may illustrate areas of differing planting priority in relation to the desiccation dynamics for a temporal coordination of planning.

For the description of hydrological, pedological, and geomorphological site characteristics during the identification of plantation areas in the field study and the satellite processing, it is also necessary to integrate the corresponding digital dataset from the Geographical Information System (GIS) into the analysis. Such datasets can be obtained from Uzbek cartography institutions (Ruecker and Ruzieva 2002).

The satellite and GIS data will be imported into the image processing software package ERDAS IMAGINE. The images will be compiled and georeferenced to geo-coordinates (eg. longitude/latitude or a local coordinate system) to facilitate scale-true planning of potential plantation areas. After this processing the separate images can be combined in a mosaic, so that an interconnected image product is generated. The pre-processing is completed when the relevant study area (the extent of the Aral Sea in 1960) is cut out of the mosaic (clipping).

A very important step in the preparation for the field campaign and the generation of the resulting products is a meeting with project participants and partners to clearly define the exact goals of the participants and adjust expectations. Here software systems and data exchange formats can be agreed upon from a data-technical standpoint, which has been a weak point in many other projects. Additionally, a meeting in the initial phase offers an opportunity for personal exchange, which can become very important in later phases, when for example regional knowledge of the natural resource conditions in the desiccated zone are necessary for solid interpretation of the results.

3.2 Characterization of the ground and vegetation quality of desiccated areas

Building on the strategy agreed in the pilot phase on which areas should be identified, divided and characterized as potential planting areas, remote sensing techniques can be used to selectively differentiate general land cover classes. In this way water surfaces can, for example, be separated from terrestrial surfaces by means of spectral differences in the multispectral infrared bands. The land surfaces can be further differentiated as vegetation and non-vegetation. Additionally, remote sensing relevant vegetation indices can be used that particularly help to distinguish the differences between these two land cover classes. Some techniques, which have yet to be assessed by field campaigns, can roughly separate salt and clay areas from sand surfaces and bedrock, as is depicted in Figure 3.2 for an area in the south east of the Aral Sea.

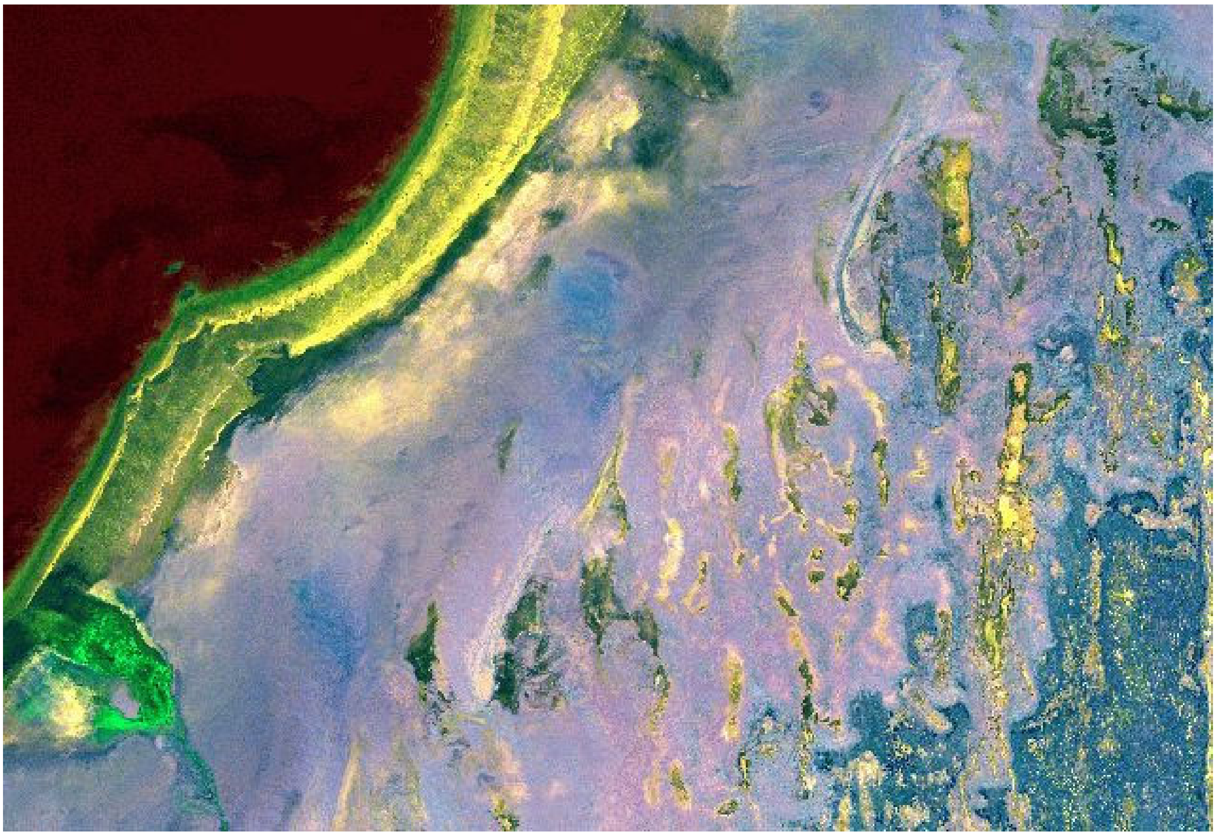

Figure 3.2: Close-up view of a desiccated area in the south east of the Aral Sea. Potentially salty areas appear yellow, vegetation light green, and presumably sand-covered areas pink.

These first data products, which in the satellite image solely present differing colours and spectral areas, always rest on the interpretative capability of the analysts and information from the literature and must be complemented by a subsequent field campaign for exact verification.

3.3 Field study, final data processing, and integration

A field campaign in the dry Aral Sea bed is an integral part of the remote sensing analysis, in particular when interpretative capabilities and techniques that remain to be validated flow into the processing chain. Additionally, a field period serves to gather training and test areas for the classification process from potential plantation sites for comparison with the remaining areas. Training areas are points or polygons which are needed in order to calibrate remote sensing to classify different land surfaces. In this study the following classes should be differentiated: water, vegetation, sand, clay, salt, and bedrock. Project participants must identify which uncovered ground surfaces should be selected for the plantings.

The field campaign for collecting suitable training and test data will be performed by means of navigation satellite measurements (GPS) in areas distributed as widely as possible throughout the area under investigation. The field campaign allows the image analyst a real picture of the possible ground covers which occur in the study area. Without the impression of regional conditions the exactness of image analysis of this type is reduced, thus areas can be surveyed which do not belong to the corresponding class or vice versa, which can eventually lead to planning and implementation of failures and therefore to faulty project intentions and financial input. The recording of test and training areas helps to perform the area mapping with a high degree of accuracy. The communication with actors on the ground and other scientists with good regional knowledge improve the precision of the remote assessment work package and thus the planning maps for the plantations.

Remote assessment data will be calibrated and adapted to regional conditions during the fieldwork. The results of the field campaign will be integrated into the surface mapping process. Further image interpretative capabilities of the analyst which are required by this role are clearly improved by their impression of the local situation. In the following data processing phase the adjustment of the product follows at a large-scale level in order to allow sufficient precision at local levels. The intensive work with the GPS allows a quantitative assessment of the results' precision, which is a necessary criterion for producers and users of the maps.

3.4 Expected products from satellite data

The results of the remote sensing based investigation on planting various surfaces of the dry Aral Sea bed can be divided into three product groups:

1) Maps and tables on the geographic identification and limits of plantation areas;
2) Area statistics in regional and local scales, for example the entire Aral Sea region or smaller definable areas, in order to estimate the number of plants needed for cost calculations and further planning;
3) Maps and reports on characterization of area quality in reference to vegetation and soils or relief characteristics and in order to recommend priority areas for the plantations. This product information can on the one hand be derived from the substrate e.g. sand, clay and salt, but also from the multi-temporal dataset (2000 and 2002) and thus the desiccation dynamics. Using GIS in the form of digital maps, these data can then be linked with the previously identified areas.

All map products for the plantations will be available in regional and local scales. These results will be presented as thematically plotted maps on paper or printed statistical tables and reports, as well as digital in the GIS system and in the data exchange formats to be agreed upon, with meta information and as PDF files.

3.5 Integration of planning products in a potential planting project

This step of the work concerns itself with the integration of the remote assessments' results in a potential planting project in the Aral Sea desiccated area. For this to occur the contact with various areas of the project must be intensified, for example with the group occupying itself with the logistics of plantations. The results of the image analysis will first be presented in the form of thematic maps of varying scales, for example overview maps, vegetation cover maps, and maps of salt dominated areas. Area statistics for the entire region and local areas allow quantitative estimates of the plants required. Participants and project partners can analyze the results for their own purposes, for example, in regard to how these maps can be used in planning and implementation. This step is necessary to simplify result-sharing and possibly to intersect and overlay the data with further, existing data and information levels in a Geographical Information System (GIS). Therefore data will be optimally prepared for all users or adapted for their needs (Ruecker et al. 2003).

The results will be presented in the form of analogue and digital GIS maps and finally made available to other participants. Planning-relevant map products in regional and local scales are thus produced. The regional scale refers to the total area of the desiccation and will appear in 1:500,000 scale with sheet lines for the local maps. The local scale is intended for use in the study site and will be produced in 1:100,000 and, where demand exists, 1:50,000 scale for planning and planting. Further results include regional and local area statistics on the planting of the desiccated Aral Sea region. A final report will summarize the data and methods used and the results achieved.

4 CONCLUSIONS

The deflation of large soil and salt masses from the desiccating Aral Sea bed has caused tremendous economic and hygienic problems in adjacent irrigated areas of Uzbekistan, including yield losses and health problems. In order to counteract this deflation, planting the desiccated Aral Sea bottom seems to be a promising strategy. However, planning-relevant maps to locate suitable planting areas within this large desiccated zone can only be produced by innovative methods which can cover this large area and detect the different surface characteristics. In this study, satellite image remote assessment was successfully employed for this task. Using satellite data of 2000 in a semi-automated classification resulted in a desiccated Aral Sea surface-estimate of 4,270,468ha (42,704km^2). Approximately 476,347 ha (11%) of this desiccated area were identified to be priority plantation areas, because the strongest deflation is expected to be from these potentially strongly salt affected areas. The medium resolution (30m) Landsat satellite system, which has been operated and tested since the 1970s, delivers the suitable data at a comparatively low price.

Datasets and know-how at DLR-DFD facilitate the mapping and characterization work and reduce costs. Semi-automatic pre-processing with developed processing chains and rough estimates are possible in a short time. However, these data estimates must be updated with more recent satellite images to capture the significant recent desiccation dynamics. Furthermore, it is necessary to calibrate, verify, and adjust the images during a field assessment so that precise thematic map products can be gained for use in practical planning of plantations. Resulting from these maps it is possible to calculate a total verified area balance or local balance of the potential plantation area, which leads to estimates of the amount of plant material that must be acquired for plantations. More detailed map and characterization products from satellite images will show the soil and vegetation qualities and the priority areas of plantations for developing a concerted planting strategy.

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