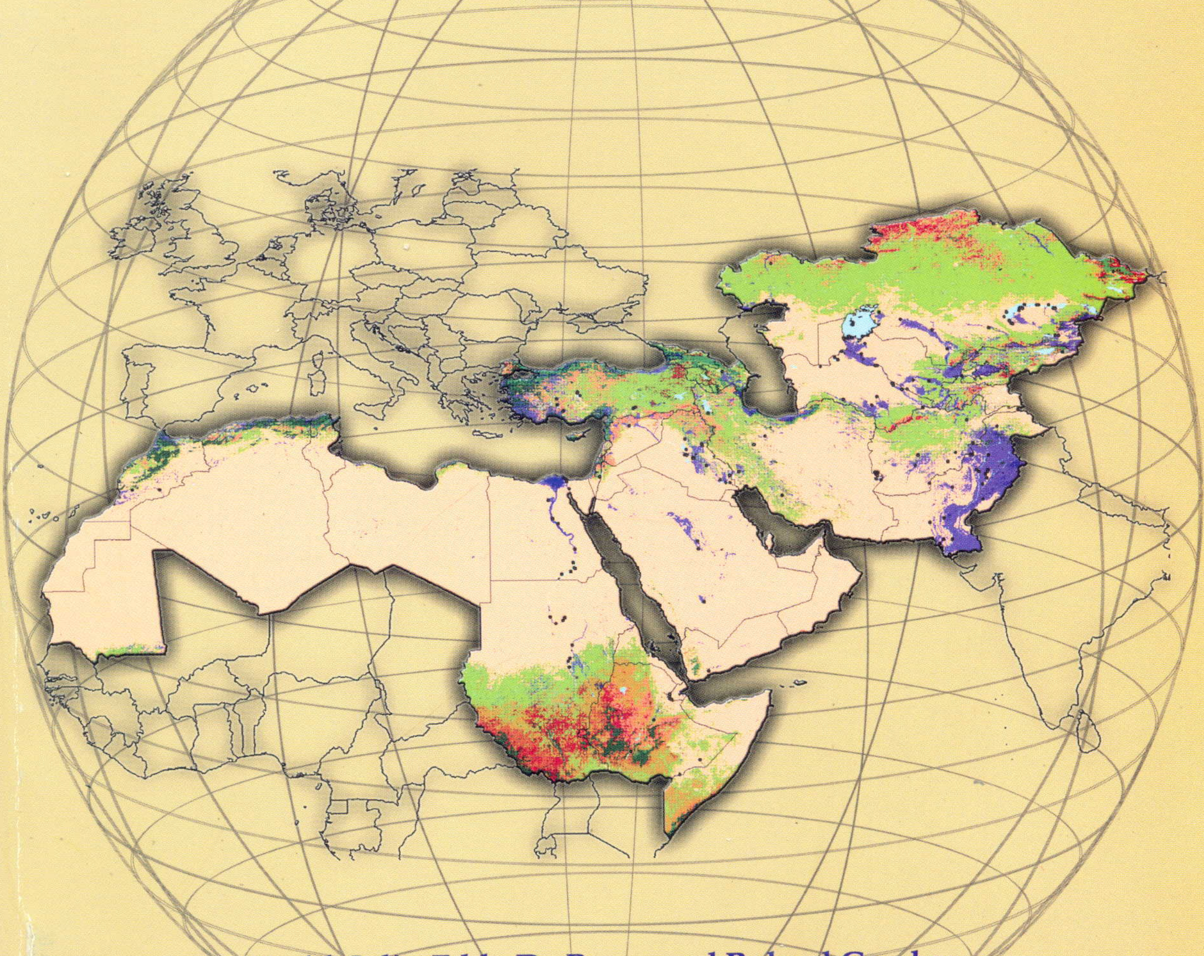
Assessment of Land Cover and Land Use in Central and West Asia and North Africa

Part 1. Land Cover/Land Use – Base Year 1993



David Celis, Eddy De Pauw, and Roland Geerken

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International Center for Agricultural Research in the Dry Areas

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Assessment of Land Cover and Land Use in Central and West Asia and North Africa

Part 1. Land Cover/Land Use – Base Year 1993

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FOREWORD

This publication is the first in a two-volume report of a regional assessment of land use and land cover in the Central and West Asia and North Africa (CWANA) region using remote sensing techniques and low-resolution satellite imagery.

It also covers the results of collaborative work from 1998 to 2002 between ICARDA and the Center for Earth Observations of Yale University in 'Remote Sensing for Natural Resource Management and Environmental Assessment', undertaken with financial support from the USAID Linkage Fund of the United States of America to the Consultative Group on International Agricultural Research (CGIAR).

It introduces a new method for identifying land use/land cover (LCLU) at a regional scale, based on analysis of the Advanced Very High Resolution Radiometer (AVHRR) imagery for the base year 1993, and provides a map of land use/land cover for the entire CWANA region at 1-km resolution.

LCLU is of paramount importance for assessing meteorological conditions (including climatic variability and change) and environmental trends. ICARDA is, therefore, a keen partner in studies to assess LCLU across its mandate region. This study offers a 1993 baseline for land management research. It is hoped the data will be updated in the near future, in order to monitor large-scale changes in land use/land cover that are indicators of land use intensification, desertification, climate change or variability.

Mahmoud Solh
Director General
ICARDA

ABSTRACT

Accurate identification of land cover/land use (LCLU) is essential for assessing the impact of meteorological conditions and environmental trends on agroecosystems. Currently available LCLU classifications for the CWANA (Central and West Asia and North Africa) region are mostly based on normalized difference vegetation index (NDVI), and calculated using spectral data obtained from the Advanced Very High Resolution Radiometer (AVHRR), which provides low spatial but high temporal resolution. These maps are not always sufficiently accurate for use at regional scale. One possible reason is that they are based on statistical analyses. Key NDVI parameters such as onset, peak, and end of greenness period are grouped into a limited number of patterns with similar NDVI phenology. The classes established statistically are then interpreted and translated into LCLU types using a limited number of ground truthing points.

This approach assumes that only the LCLU type determines the NDVI pattern. In reality, LCLU is itself adapted to different agroclimatic conditions. In a very large area such as CWANA it is therefore quite possible that in different agroclimatic zones, similar NDVI patterns could correspond to different LCLU types, but also that different NDVI patterns could represent the same LCLU type.

To overcome this problem, a new classification scheme was established that uses a hierarchical decision tree to identify LCLU types. LCLU types relevant for CWANA were selected on the basis of expert opinion, field surveys, and analysis of thematic maps and Landsat satellite imagery. Compared to the earlier methods, the new decision-tree identifies fewer LCLU classes, but with a higher degree of accuracy.

To assign a pixel to a particular LCLU type, the decision tree uses 'sliding thresholds' for the annual minimum, maximum and mean NDVI, which vary by agroclimatic zone. NDVI thresholds are then fine-tuned, based on a careful analysis of climate station data and land use maps from different agroclimatic zones. For the purpose of this study a simple climatic zoning based on the UNESCO classification of aridity regimes proved adequate.

This classification scheme was first applied to AVHRR imagery with low spatial resolution (4 arc-minute grid cell) for the year 1990; and afterwards transferred to AVHRR data of higher spatial resolution (30 arc-seconds) for the period April 1992 to March 1993.

To evaluate the accuracy of the hierarchical decision tree, we compared its results with the more detailed LCLU map of Syria, prepared from 30m resolution Landsat images and using information from extensive field surveys. For a valid comparison, the greater number of classes in the LCLU map of Syria were aggregated to match the CWANA classes. Seventy four per cent of all pixels were correctly allocated – a considerable improvement over other classification results.

1. LAND USE/LAND COVER MAPPING IN CWANA

The CWANA region covers North Africa, West and Central Asia (Figure 1). It is a region of great diversity in land and water resources, with widely varying climates, soils and landforms. A wide range of land use systems, more or less adapted to this environmental diversity, has
developed in the region.

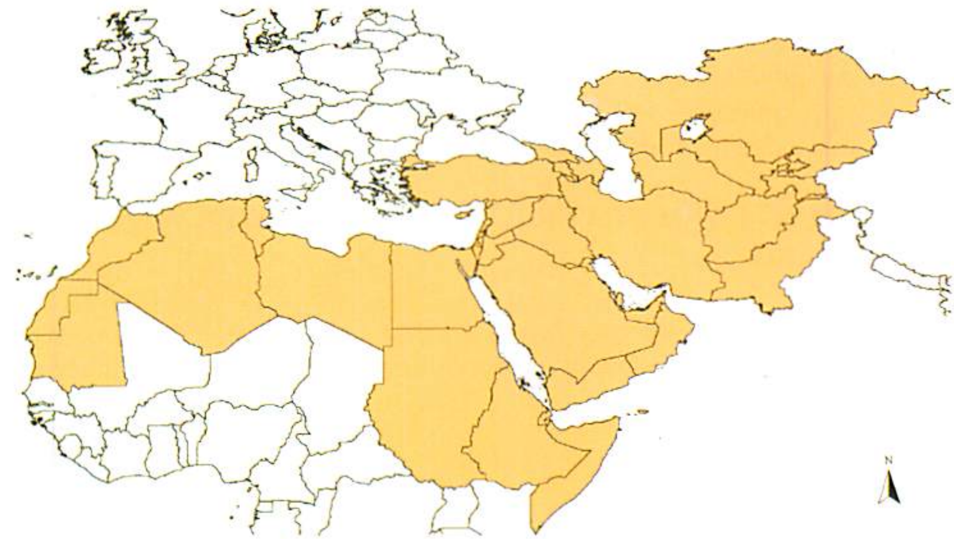

Figure 1. The CWANA region

Reliable land use information is essential for a wide range of applications. It is essential for agroecological characterization of this vast region, land use planning, assessing impacts of climate change and variability, as well as environmental trends in the agroecosystems of the CWANA region. Being able to accurately assess changes in land use is the key to detecting trends towards desertification and towards evaluating climate change impact. It is also needed to make reliable forecasts on future food supply. Land cover/land use (LCLU) maps are likewise important to supplement and improve estimates based on statistical surveys, such as those on yields and production of different agricultural products (e.g. cereals, forest products etc.).

Land cover mapping involves classification of land areas into broad categories of vegetation (natural or planted), man-made constructions, bare land or water surfaces. On the other hand, land use has been defined (de Bie et al., 1996) as *'a series of operations on land, carried out by humans, with the intention to obtain products and/or benefits through using land resources'*. In essence, land cover mapping aims to describe and locate natural or man-made resources, whereas land use mapping aims at identifying goals, products and benefits. Mapping land use requires knowledge about land user goals, operations, products and benefits from land use, which therefore cannot be determined by direct means.

Remote sensing is particularly suited to detect land cover, especially at coarse resolution for large land surfaces, such as CWANA. As the resolution increases, it is usually possible to map more components of land use. However, even at the scale of a sub-continent such as CWANA, it is possible to interpret some types of land cover in terms of use. A typical example of an overlap between land cover and use is *irrigated agriculture*, which is a use derived from a particular vegetation cover. For this reason in this report the two terms are used in conjunction as 'land cover/land use' (LCLU).

2. EXISTING LAND COVER/LAND USE CLASSIFICATIONS FOR CWANA

At the global or sub-continental level several LCLU maps exist based on data collected by the 1-km resolution Advanced Very High Resolution Radiometer (AVHRR) sensor on board the
NOAA-satellite 12.

The AVHRR sensor circles the earth in 14 polar orbits a day, capturing scenes with a swath width of 2600 km in 5 different wavelength ranges (from 0.58 to 12.5 micrometer) and at a spatial resolution of 1.1 km. Data are resampled to produce data sets of 8-km or 1-km resolution. To assure cloud-free scenes, the ground station prepares composites from 10 daily scenes. As for the 1-km composites, they only cover the periods from April 1992 to September 1993 and from February 1995 to January 1996. These composites can be easily downloaded from the USGS Eros Data website[1] .

The data from the AVHRR sensor, acquired in five spectral bands, are usually presented to the public as calibrated surface reflectance and brightness temperature plus an additional layer for the Normalized Difference Vegetation Index (NDVI). The NDVI is a contrast-stretch ratio calculated from the red band (R) and the near-infrared band (NIR) that are covered by AVHRR bands 1 and 2.

Accordingly, the NDVI is being calculated as (band2-band1)/(band2+band1). The NDVI takes advantage of typical low reflectance values of vegetation in the red wavelength range (chlorophyll absorption) and high reflectance values in the NIR range (leaf structure), by this enhancing the contrast between vegetated and un-vegetated areas.

[1] http://www.saa.noaa.gov

LCLU patterns are usually derived from vegetation indices through statistical techniques such as *unsupervised* and *supervised* classification. An unsupervised classification groups pixels automatically together in a predefined number of classes based on their spectral similarity. However, whenever ground truth is not part of the classification process the interpretation of classes becomes difficult.

Supervised classification starts with assigning well-known training regions, whose spectral information is used to calculate class means. Class membership is then attributed based on the spectral similarity with these class means.

For LCLU mapping either approach uses key NDVI parameters such as onset, peak, and end of greenness period, which are grouped into a limited number of patterns with similar NDVI phenology. The classes established statistically are then interpreted and translated into LCLU types using a limited number of ground truthing points. In principle, in addition to NDVI, other parameters can be used in these automated classifications, such as individual band reflectance values.

A different approach to land cover/land use mapping is the *decision tree*. A decision tree algorithm does not assign all classes in one step, but groups pixels together based on stepwise conditions. This way the data are split up into smaller subgroups, which allow better control of the classification process. The classes that are easier to identify, are selected first.

Post-classification refinement refers to the splitting of classes that result from unsupervised classification, in order to produce more homogeneous land cover classes. This splitting is done using secondary data (e.g. digital elevation or ecoregions) and user-defined polygons.

The characteristics of the global or regional land cover/land use maps of relevance for the CWANA region are summarized in Table 1. The differences between these maps are related to the geographical scope, the AVHRR spectral information used for classification and the method of classification.

Table 1. Existing land cover/land use maps based on AVHRR information

Land cover/land use map	Geographical scope	Derived from	Method for classification
Asian Association for Remote Sensing (AARS)	Asia	NDVI, bands 4 and 5	Unsupervised statistical + decision tree
University of Maryland (UoM)	Global	Bands 1-5	Supervised statistical + decision tree
International Global Biosphere Program (IGBP)	Global	NDVI	Unsupervised statistical + post-classification refinement

The AARS map (Tateishi, 1999) covers Asia, whereas the UoM (Hansen et al., 2000) and IGBP maps (Belward et al., 1999) have a global scope. The AARS Map is based on NDVI and AVHRR bands 4 and 5, the UoM map uses all AVHRR bands and the IGBP map uses only NDVI. In each map the classification is based on either unsupervised (automatic) classification or supervised classification. The final assignment of areas into the different classes is based on either a decision tree (AARS and UoM) or a post-classification stratification.

As mentioned earlier, these map products are available with a 1-km grid cell size. However, for the AARS map a precursor exists with 8-km resolution (Tateishi e.a., 1997), which is based on the same procedures as its 1-km version. This map product has been found useful for initial ground truthing and testing of the statistical procedures.

We evaluated the above classifications using expert opinion, LCLU maps at higher resolution, and other thematic information such as topographical maps and climatic data. The main conclusion of this evaluation was that, while useful for global level studies, the accuracy of existing classifications is inadequate for use at regional scale in CWANA. In all maps there is a considerable amount of classification errors, particularly in the recognition of irrigated land and rangelands. The reasons for this will be explained in sections 3.2.3. and 4.4., but essentially boil down to the fact that these land cover maps are based on unsupervised or supervised classification methods.

Existing unsupervised classification algorithms first classify pixels into a predefined number of classes, and assign information to the classes afterwards. The statistical approaches therefore assume that only the land-cover/land use type (LCLUT) determines the NDVI pattern. In reality LCLU is itself adapted to different agroclimatic conditions. In a very large area such as CWANA it is therefore quite possible that *in different agroclimatic zones similar NDVI patterns could correspond to different LCLUTs, but also that different NDVI patterns could represent the same LCLUT.*

To overcome the limitations of statistical approaches, an approach that incorporates expert knowledge would be appropriate.In view of the inadequacies of existing LCLU maps, it was therefore decided to produce a new LCLU map for CWANA, which applies an agroclimatic framework for the identification of LCLUTs.

3. A NEW LAND COVER/LAND USE CLASSIFICATION FOR CWANA

3.1. Principles

In order to develop a new LCLU map for CWANA, a new classification scheme was established based on the identification of LCLUTs using an empirical hierarchical decision tree.

Major land cover/land use categories were established on the basis of expert opinion, field surveys, together with thematic maps, climatic data and Landsat satellite imagery (Landsat) for Syria as a particular form of ground truth. For these categories the NDVI patterns were analyzed and empirical relationships were established with agroclimatic conditions. On the basis of these tests a final classification scheme was established which contained fewer classes than other land-cover classifications but could be identified with a higher degree of accuracy.

To assign a pixel to a particular LCLUT, the hierarchical decision tree uses "sliding thresholds" for the annual minimum, maximum and mean NDVI, which vary according to the agroclimatic zone. The fine-tuning of the NDVI thresholds was based on a careful analysis of the available CWANA climate station data and land use maps in different agroclimatic zones. For the purpose of this study a simple climatic zonation based on the UNESCO classification system of aridity regimes (UNESCO, 1979) proved adequate. The map and legend of this agroclimatic classification is presented in Annex 1.

This classification scheme was first tested out on low-resolution AVHRR imagery (4 arc-minute grid cell) for the year 1990 and afterwards transferred to higher resolution (30 arc-seconds) AVHRR imagery for the period April 1992 to March 1993.

3.2. Methodology for 4 arc-minute resolution imagery

3.2.1. Materials

To further reduce the influence of clouds and other noise that is still present in the 36 10-day interval NDVI composites, we created 12 monthly maximum value composites (MVC) from the global data covering the period from January 1, 1990 to December 31, 1990 (Tateishi and Wen, 1997). The MVC is the maximum NDVI value measured for a specific month and calculated from the three 10-day composites available for each month. The data are in Plate Carree projection with 4 minutes spatial resolution. A subset of this data set shows spatial-temporal NDVI variations in the Near East for selected months (Figure 2).

From this global dataset, an area of 1699 columns and 908 rows was cut covering the CWANA region. The location of the top left pixel is longitude 22°26' W and latitude 58°46' N. The location of the bottom right pixel is longitude 90°42' E and latitude 1°38' S. Since the resolution is 4 minutes, the height of a pixel is always 7.413 km, while the width varies from 7.413 km (equator) to 3.84 km (58.46' latitude).A sample of this dataset is shown in Figure 3 for January 1990.

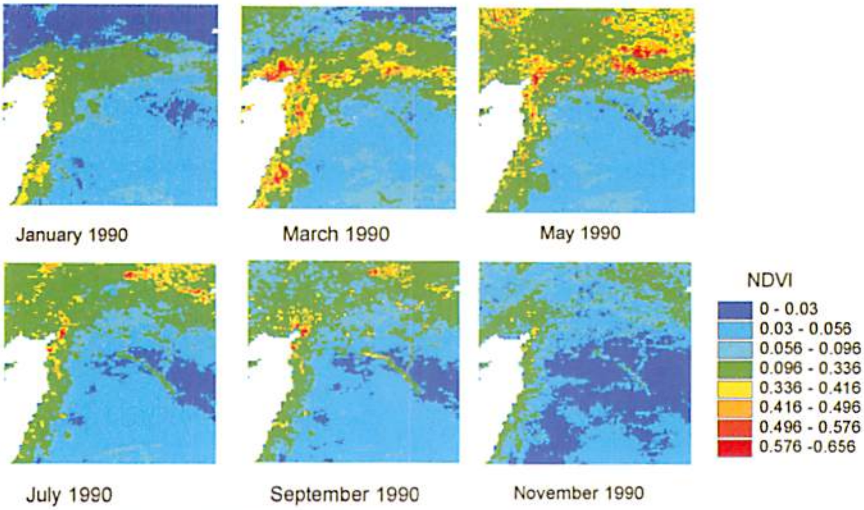

Figure 2. Monthly NDVI-composites for the Near East

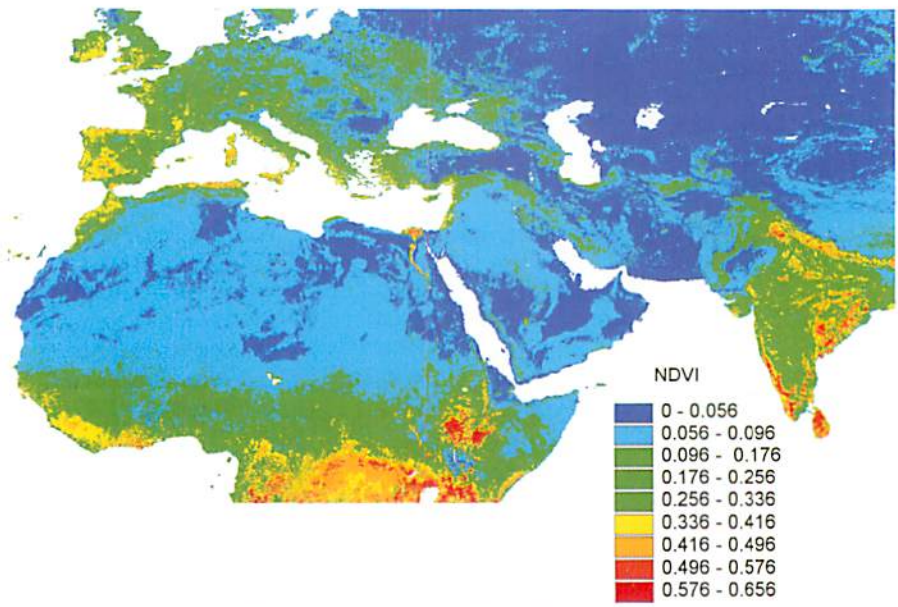

Figure 3. NDVI subset covering CWANA, dating January 1990

3.2.2. Parcel-model for radiance interpretation

The radiance received by the satellite's sensor, after correcting for atmospheric scattering and absorption, represents the average radiance of all land cover types that fall into that pixel. Where spatial resolution is high, as in Landsat TM images (30m), there is a higher probability that a great number of pixels is composed of just one class. With high spatial resolution, mixed pixels will be mainly created along class boundaries.

However, as pixel size increases e.g. to 1x1 km or 8x8 km, there is an increasing likelihood that a pixel is being composed of more than one class. The occurrence of greater numbers of pixels representing pure land cover/land use classes of a size of 1x1 km or 8x8 km is rather unlikely for most of our classes, except for classes like Barren or Grassland which tend to cover large areas.

This situation especially occurs with the very low spatial resolution AVHRR imagery (8x8-km) and may, as Figure 4 illustrates, entails considerable errors in classification, because each pixel can be assigned to one class only.

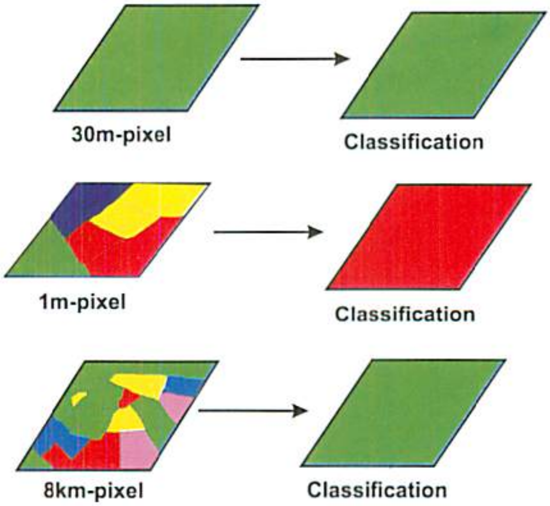

Figure 4. Relationship between resolution and classification

Theoretically, it might even occur that the combination of different LCLUTs within one pixel creates a *mixed* NDVI cycle that does not fit any of the decision tree criteria. Also, the decision tree may allocate a class that is actually not part of this pixel.

The limitations described above and imposed by pixel resolution affect any type of LCLU classification. In all classifications, the class identified is usually the LCLUT that *spectrally* dominates the annual cycle, although there may exist additional LCLUTs that are hidden by its signature.

3.2.3. Expert algorithm

The statistical algorithms used in most LCLU classifications such as IGBP-DIS (Belward et al.,1999), AARS (Tateishi et al., 1997) and CEO (Smith et al., 1997), investigate statistical similarities of NDVI-phenology *simultaneously* for all pixels. Most use three variables to characterize the NDVI-phenology in case of unimodal curves (moment of onset and peak of greenness, and amplitude of peak) and six variables for bimodal curves (one set of 3 for each peak).

This approach to land cover classification based on the NDVI-phenology is illustrated in Figure 5 and Figure 6. Both figures relate to two rainfed regions in Ethiopia, the first one with a unimodal growth pattern, the second one with a bimodal growth pattern.

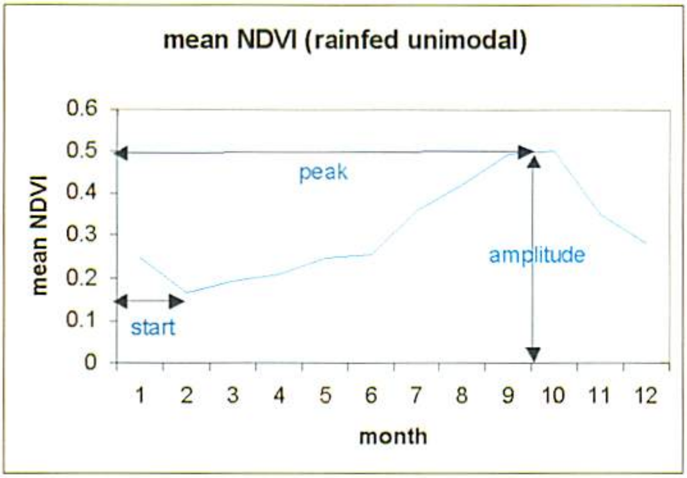

Figure 5. Unimodal NDVI-phenology

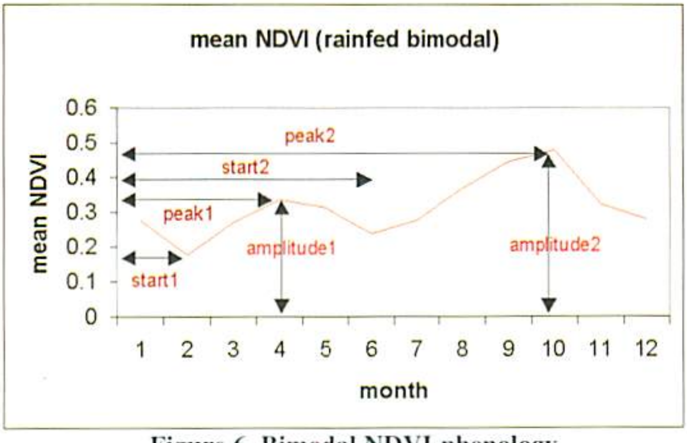

Figure 6. Bimodal NDVI-phenology

However, NDVI is not only influenced by the LCLUT but also by differences in climate, soil and topography. For example, even if the LCLUT is the same in two pixels, but there are small differences in climatic conditions between two pixels, this could result in a different value for the onset, the peak or the amplitude (Figure 7). In a statistical technique such differences could lead to a classification into different LCLUTs.

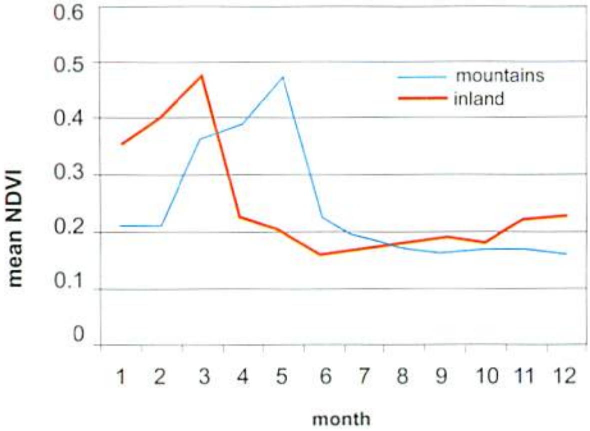

Figure 7. Mean monthly NDVI for two regions with rainfed croplands in Syria

Even if the NDVI values are sequenced from the peak value of each pixel to standardize seasonal effects (Gopal et al., 1999), it is still not possible to standardize all variables.

These limitations can be overcome by an expert algorithm, where each LCLUT is recognized independently from the non-standard NDVI phenology. The solution to the impact of regional climatic trends on LCLUTs is the identification of key characteristics for each LCLUT on the basis of a combination of statistical variables and ancillary macroclimatic variables for each LCLUT. The allocation of pixels to a particular LCLUT is then based on a decision tree in which the LCLUTs that are the easiest to identify are singled out first.

The decision tree was created in three steps:

- Selection of variables;
- Ranking the LCLUTs from the most to the least easily identifiable;
- Defining the best thresholds for the variables used to define each LCLUT.

Step 1: Selection of variables

In addition to the 12 monthly NDVI-values, the following three ancillary variables were selected to reflect the macro-climatic variation in CWANA:

- Agroclimatic Zone (UNESCO, 1979): e.g. a humid climatic zone requires NDVI-threshold settings that are different from a dry climatic zone to separate between the same LCLUTs.
- Period of dry season: this variable enables to distinguish croplands very effectively (see Decision Tree).
- Latitude Zone (3 zones): The addition of latitude as a variable enables to create different criteria to reflect the typical features of each latitudinal zone.

Step 2: Ranking the LCLUTs from the most to the least easily identified

For the NDVI variables the following abbreviations and terms were used in the Decision Tree:

Ii: a pixel's NDVI-value in month i (e.g. I8 represents the NDVI for August)
NDVImax: the annual NDVI maximum of a pixel

NDVImax = Max (I1, I2, I3, I4...... I9, I10, I11, I12)

NDVImin: the annual NDVI minimum of a pixel

NDVImin = Min (I1, I2, I3, I4....... I9, I10, I11, I12)

NDVImean: the annual NDVI mean of a pixel

NDVImean = (I1 + I2 + I3........ + I9 + I10 + I11 + I12) / 12

The following ordering sequence was used to identify major LCLUTs:

1) *Inland water* and *Barren/sparsely vegetated* can clearly be selected from the value of NDVImax.
2) On the remaining pixels, *Dry season irrigated croplands* can be distinguished because this is the only LCLUT with an NDVI-increase in the dry period.
3) On the remaining pixels, *Forests/closed shrublands* is the only remaining LCLUT with a high NDVImean.
4) On the remaining pixels, *Rainfed/supplementary irrigated croplands* can be distinguished from NDVImax in areas where no *Woodland savannas* (also with high NDVImax) occur. Secondary vegetation cover information shows that the latter LCLUT is only found south of the Tropic of Cancer. At this latitudinal zone, the LCLUT *Rainfed croplands* shows a clear increase in NDVI before (flowering) and an NDVI-decrease after harvest.
5) On the last remaining pixels, *Woodland savanna* has always a higher NDVImax than *Grasslands/open shrublands*.

Step 3: Defining the optimal thresholds for the variables used to define each LCLUT

By matching after classification the patterns of pixel distribution with the ground truth information from existing land cover and vegetation maps, the threshold with the highest differentiating power was selected for each variable and agroclimatic zone.

Differentiating *Inland water* and *Barren/sparsely vegetated*
When a pixel's NDVImax is lower than 0.14 (corresponding with 30% vegetation cover), the influence of the background soil radiance becomes overwhelming.

Reliable classification is therefore only possible above this threshold. Pixels where the NDVImax equals 0 correspond with *Inland water*. Pixels with a NDVImax lower than 0.14 are classified as *Barren/sparsely vegetated*, unless there is a distinctive vegetation change throughout the year (represented by NDVImax-NDVImean > 0.048). In this case, the class with the lowest vegetation cover, *Grasslands/open shrublands*, is assigned.

Differentiating *Dry season irrigated croplands*
For the remaining pixels with the NDVImax > 0.14 and the NDVI increases in the dry season, or when the NDVImax > 0.26 in hyper-arid regions, a pixel is classified as *Dry season irrigated cropland*. For optimal classification 'the dry season' should be sufficiently long. According to latitude the NDVI is monitored for two periods of 3 months, as follows:

- Latitude < 23°N: NDVI-increase in period Nov. to Feb. or Dec. to March.
- Latitude > 23° or < 39°N: NDVI-increase in period May to Aug.or June to Sep.
- Latitude > 39°N (North Turkey, Caucasus, Central Asia): NDVI-increase in period June -> Sep. or July -> Oct.

Differentiating *Forests/closed shrublands* For the remaining pixels when the NDVImean is higher than a threshold value, which increases with increasingly humid agroclimatic zones, the land cover class will be *Forests/closed shrublands*. Table 2 shows the threshold values of NDVImean used for different aridity regimes.

Table 2. Thresholds for annual NDVImean for differentiating 'forests/closed shrublands'

Agroclimatic zones	Threshold
All hyper-arid + arid zones	0.26
All semi-arid zones	0.34
All sub-humid zones	0.42
All humid zones	0.50

Differentiating *Rainfed/supplementary irrigated croplands* and *Grasslands/open shrublands*
For the remaining pixels at latitude < 23°N, if there is a NDVI-increase in the period August => October (before the start of the dry season: flowering) and a NDVI-decrease in the period September => November (after the start of the dry season: harvest), the pixel is classified as *Rainfed/supplementary irrigated croplands*.

For the remaining pixels with latitude > 23°, if NDVImax is higher than a threshold value, which increases with increasingly humid agroclimatic zones, the land cover class will be *Rainfed /supplementary irrigated croplands*. If NDVImax-value is lower than this threshold, the pixel is classified as *Grasslands/open shrublands*. The zone-specific thresholds for NDVImax are shown in Table 3.

Table 3. Thresholds for annual NDVImax for differentiating 'rainfed croplands'

Agroclimatic zone	Threshold
Semi-arid	0.26
Semi-arid, cold winter, very warm summer	0.34
Sub-humid	0.42
Humid	0.5

Differentiating *Woodland savannah*

For the remaining pixels with latitude < 23°, if NDVImax is higher than a threshold value, which increases with increasingly humid agroclimatic zones, the pixel is classified as *Woodland savannah*. If the NDVImax-value is lower than this threshold, the pixel is classified as *Grasslands/open shrublands*.

The zone-specific thresholds for NDVImax are shown in Table 4. Following this scheme seven basic LCLUTs could be established. These classes are illustrated in Figure 8 for the Horn of Africa and parts of the Arabian Peninsula.

Table 4. Thresholds for annual NDVImax for differentiating 'woodland/savannah'

Agroclimatic zone	Threshold
Arid	0.26
Semi-arid	0.34
Sub-humid	0.42
Humid	0.50

By making use of the parcel model described in section 3.2., croplands and natural vegetation could be further differentiated in subclasses based on density, resulting finally in 11 classes. The procedure is described below.

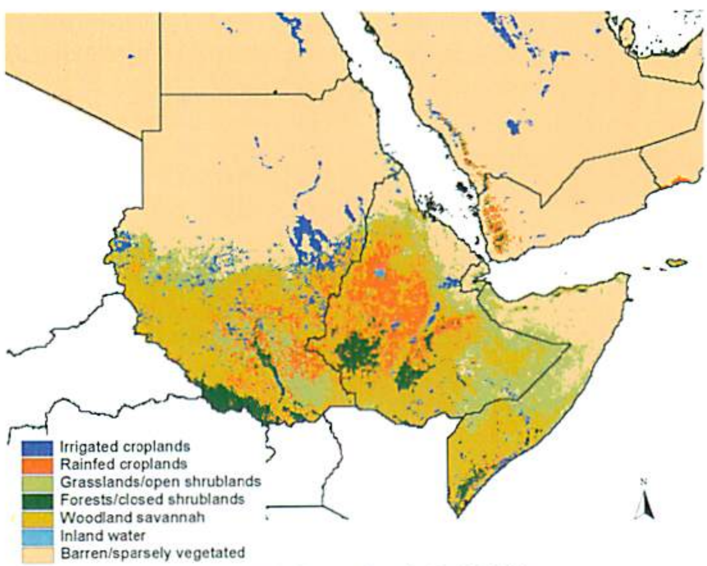

Figure 8. Seven basic LCLUTs

The differentiation of natural vegetation covers is based on a NDVImin-threshold. Whenever this threshold is exceeded it could point to the difference between 'evergreen' and 'deciduous' vegetation. However, it could also simply mean that the density of vegetation within the same class is higher. Owing to the fact that a 'dominant' LCLUT may mask the presence of others, as explained in the parcel model approach to radiance interpretation, it is not possible to separate consistently greenness from density characteristics.

Forests/closed shrublands and Woodland savannah are therefore differentiated in a separate class if the following NDVImin criterion is met:
If NDVImin I> 0.14:

High density/evergreen forests/closed shrublands
High density, evergreen woodland savannah.

Similarly the differentiation of croplands is possible on the basis of an NDVImax-threshold. Following the same reasoning as above, it is not possible to determine whether a high NDVImax for croplands corresponds with a high yield or a high proportion of croplands within the pixel. Croplands are therefore differentiated in a separate class if the following NDVImax criterion is met:
If NDVImax > 0.5

High density, high yielding dry season irrigated croplands
High density, high yielding rainfed/ supplementary irrigated croplands.

On this basis 11 final LCLUTs could be established. These classes are illustrated in Figure 9 for the Horn of Africa and parts of the Arabian Peninsula.

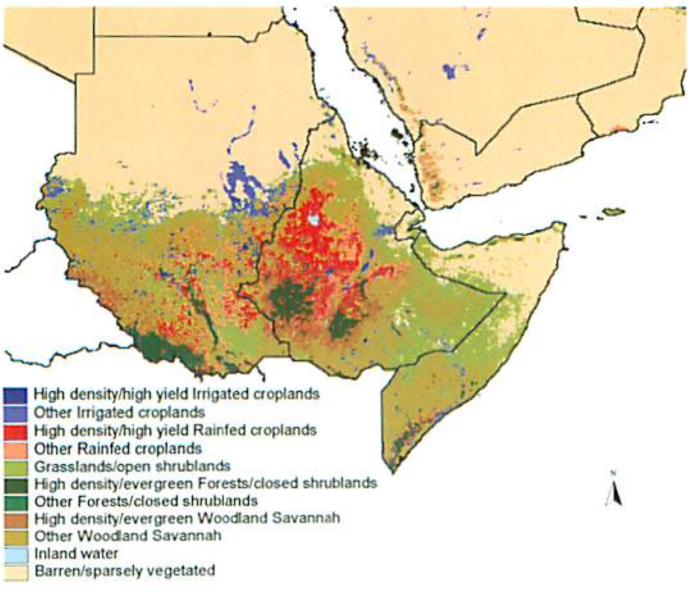

Figure 9. Eleven final LCLUTs

3.3. Methodology for 30 arc-second resolution imagery

3.3.1. Materials

Thirty six 10-day composites of AVHRR-NDVI data with 1-km resolution were downloaded from the USGS Eros Data Center's website[2]. They cover a 1-year period from 1 April 1992 until 31 March 1993. The selected area spans latitudes –2° to 59° and longitudes –23° to 91°, covering the entire CWANA-region. Radiometric calibrations and atmospheric corrections were already done by the EROS Data Center. As with the 4 arc-minute resolution imagery, data inherent noise was reduced by creating 12 monthly MVCs after noisy pixels had been flagged. These images were reprojected from the Goode's Homolosine projection into the Plate-Carree latitude/longitude projection with 30'' resolution using the software ERMapper. Using a 30''-grid slope-map (Annex 2), derived from the DEM GTOPO30 (Gesch and Larson, 1996), a slope correction could be made by multiplying each pixel's NDVI-value with the cosine of its slope angle.

3.3.2. Land cover classes

Even with 30" resolution it was not possible to distinguish between tree crops and forests/closed shrublands on the basis of NDVI-values, since they have an identical phenology. For this reason forests/closed shrublands and tree crops were put into one category and the following three classes were differentiated:

- *Forests/tree crops/closed shrublands*
- *Dry season irrigated field crops*
- *Rainfed/supplementary irrigated field crops*

The class *Urban/built up areas* was obtained from the Digital Chart of the World (Danko, 1992) and converted into a 30''-grid.

The four other classes established in the 4' resolution classification were retained:

- *Open shrubland/grassland*
- *Woodland savannah*
- *Barren, sparsely vegetated*
- *Inland water*

3.3.3. Expert algorithm

The following modifications were made in building the expert algorithm for the 30'' dataset:

[2] URL: http://edcdaac.usgs.gov/1km/comp10d.html

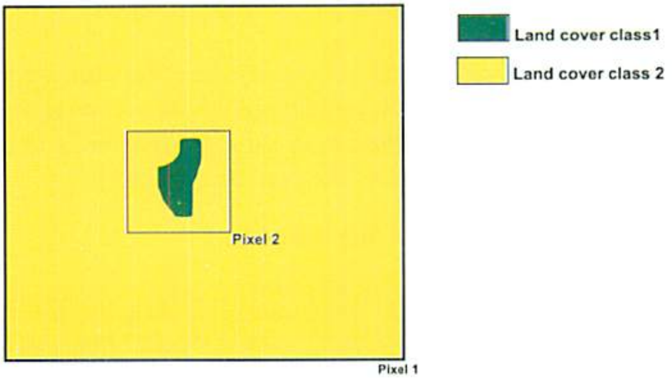

Figure 10. Effect of pixel size on threshold value

1) In comparison to the 4'-resolution dataset, threshold values needed some modification to correctly identify certain LCLUTs in the 30'' dataset. The reason is the tremendous difference in pixel size, with the 30'' dataset offering a 64-times higher spatial resolution. While lower threshold values remain the same, this has considerable impact on maximum NDVIs. The likelihood of a single class of certain LCLU classes (e.g. crop classes) to occupy an entire 1x1-km pixel is much higher than it is for a 8x8-km pixel (Fig.10). The average annual maximum NDVI for this class will therefore be much higher than in 8x8-km resolution data. This typically happens in areas with small textured land use and land cover but has less impact on classes describing extended homogeneous land covers.

2) The thresholds to select 'Forests/tree crops/ closed shrublands' are lower in comparison to the 4'-dataset because the land cover class was redefined, as explained in section 3.3.2.

3) The definition of 'dry season' was changed from 2 possible periods of 3 months into 2 possible periods of 2 months.

4) Instead of separating all pixels into those with and without distinctive influence of the soil background color (with NDVImax – threshold), this constraint was only kept to select pixels with irrigation, forests and the rainfed areas south of the Tropic of Cancer (23°N). For all other classes, the constraint was omitted because bare soil pixels can also have NDVImax values higher than 0.25 and rainfed pixels can also have NDVImax values lower than 0.25.

These modifications result in the following new algorithm:

A) If NDVImax > 0.25 (influence of soil background color is not distinctive):

1) If the NDVI increases in the dry season or when NDVImax > 0.25 in hyper-arid regions, a pixel is classified as *Dry-season irrigated field crops.* Optimal classification is achieved when 'the dry season' is defined, according to latitude, as two possible periods (Table 5).

Table 5. Definition of 'dry-season'

Geographical domain	NDVI pattern
Latitude < 23°N (Tropic of Cancer)	NDVI -increase in period Dec-Feb or Jan-March
Latitude > 23° or < 39°N	NDVI-increase in period June-Aug or July-Sep
Latitude > 39°N (Northern Turkey, Caucasus, Central Asia)	NDVI -increase in period July-Sep or Aug-Oct

2) For the remaining pixels, if NDVImean is higher than a threshold value, which increases with the humidity of the agroclimatic zone (Table 6), the land cover class will be *Forests/tree crops/closed shrublands.*

Table 6. Thresholds for NDVImean to differentiate 'forest/closed shrublands' (1-km)

Agroclimatic zone	Threshold
All arid zones	0.20
All semi-arid zones	0.25
Sub-humid zones with mild summer and mild winter	0.35
Other sub-humid zones	0.30
All humid zones	0.40

3) For the remaining pixels with latitude < 23°N, if a NDVI-increase occurs in the period August => October (before the start of the dry season: flowering) and a NDVI-decrease in the period October => December (after the start of the dry season: harvest), and the NDVImax > 0.5, the land cover class is *Rainfed/supple mentary irrigated field crops.*

B) All remaining pixels:

4) For pixels with latitude > 23°N, if NDVImax is higher than a threshold value, which increases with the humidity of the agroclimatic zone (Table 7), the land cover class will be *Rainfed/supplementary irrigated field crops.*

Table 7. Thresholds for NDVImax to differentiate 'rainfed field crops' (1-km)

Agroclimatic zone	Threshold
All arid zones	0.22
All semi-arid zones except with cold winter	0.35
All sub-humid zones except with cold winter, semi-arid zones with cold winter	0.40
All humid zones, sub-humid zones with cold winter	0.50

5) For pixels with latitude < 23°N, if NDVImax is higher than a threshold value, which increases with the humidity of the agroclimatic zone (Table 8), the land cover class will be *Woodland savannah*.

Table 8. Thresholds for NDVImax to differentiate 'woodland savannah' (1-km)

Agroclimatic zone	Threshold
All arid zones	0.25
All semi-arid zones	0.35
Al l sub-humid zones	0.40
All humid zones	0.50

6) For the remaining pixels, if the difference (NDVImax – NDVImean) > 0.07 (reflecting a distinctive vegetation change throughout the year), the land cover class will be *Open shrublands/grasslands*. All remaining pixels are classified as *Barren/sparsely vegetated.*

7) As in the approach that uses 4 arc-minute resolution imagery, the classes *Forests/tree crops/closed shrublands* and *Woodland savannah* can be further differentiated on the basis of greenness or density characteristics. As explained in section 3.2.3., it is not possible to consistently separate greenness from density characteristics.

   If NDVImin > 0.2, these classes get the specification of 'High density, evergreen', which results into the following LCLUTs: *High density & evergreen Forests/tree crops/closed shrub lands* or *High density & evergreen Woodland savannah*

Similarly field crops can be differentiated on the basis of the same greenness /density characteristics. The criterion for subdivision is the NDVImax.If NDVImax > 0.6, the following LCLUTs are differentiated: *High density & high yield dry season irrigated field crops* or *High density & high yield rainfed/ supplementary irrigated field crops.*

3.3.4 Decision tree

The expert algorithm, explained in section 3.3.3, allows differentiation of land cover and land use into 12 final classes. The decision tree is shown in Figure 11. A sample output for Ethiopia is shown in Figure 12. The LCLU map for CWANA, developed according to the rules of the decision tree, is shown in Annex 4.

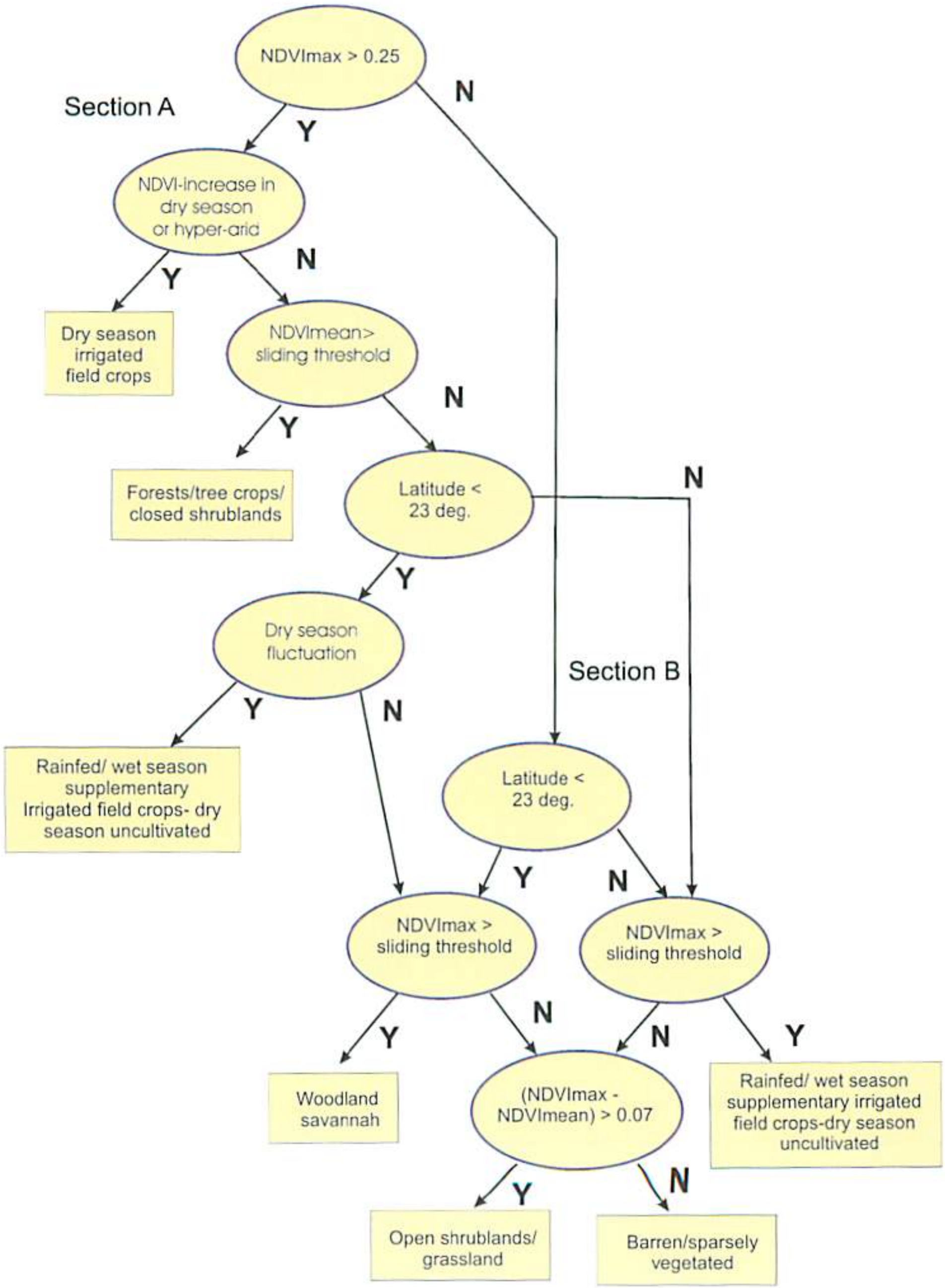

Figure 11. Decision tree for land cover/land use classification in CWANA

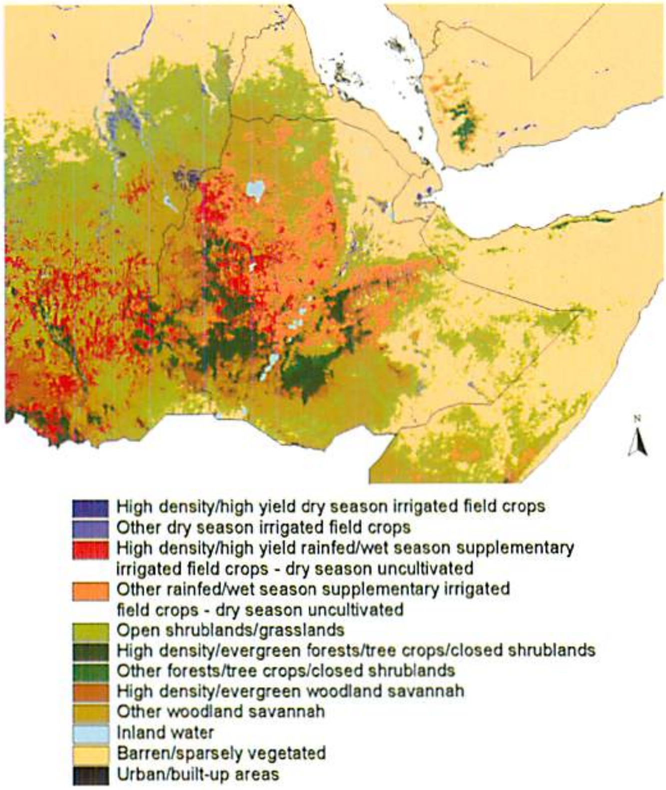

Figure 12. LCLU map for part of the Horn of Africa

4. EVALUATION

This chapter explains how the different land use/land cover maps were compared by means of standard accuracy tests.

4.1. Accuracy testing of 4 arc-minute Land Cover/Land Use Map

For accuracy testing the digital LCLU map of Syria for 1990 was used (De Pauw et al., 2004). This map (Annex 3) was obtained from field work, visual interpretation of 1:200.000 false color-print-outs of Landsat 5-scenes and subsequent digitizing and integration in a GIS. Since it represents the land cover/land use situation in the same period and is based on a much larger resolution, it is an ideal tool for accuracy testing of the land cover/land use maps derived from low-resolution imagery.

The first step was to cut an area of 4175 pixels, corresponding with the area of Syria, fromin Syria the CWANA land cover/land use map (Fig. 13). The second step was to aggregate the LCLU map of Syria to an 8-km grid using a simplified legend. This 'reference' map is shown in Figure 14.

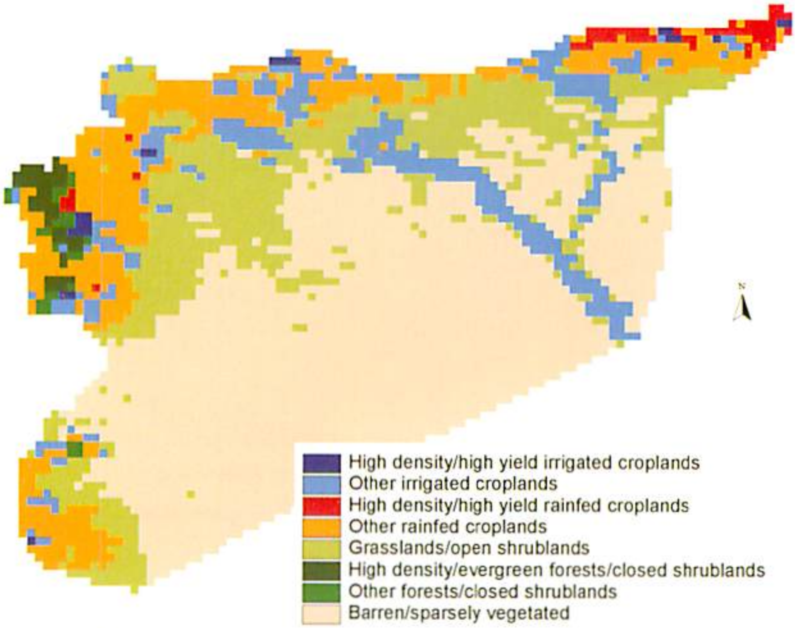

Figure 13. Land cover/land use classes for Syria derived from 8-km CWANA LCLU map

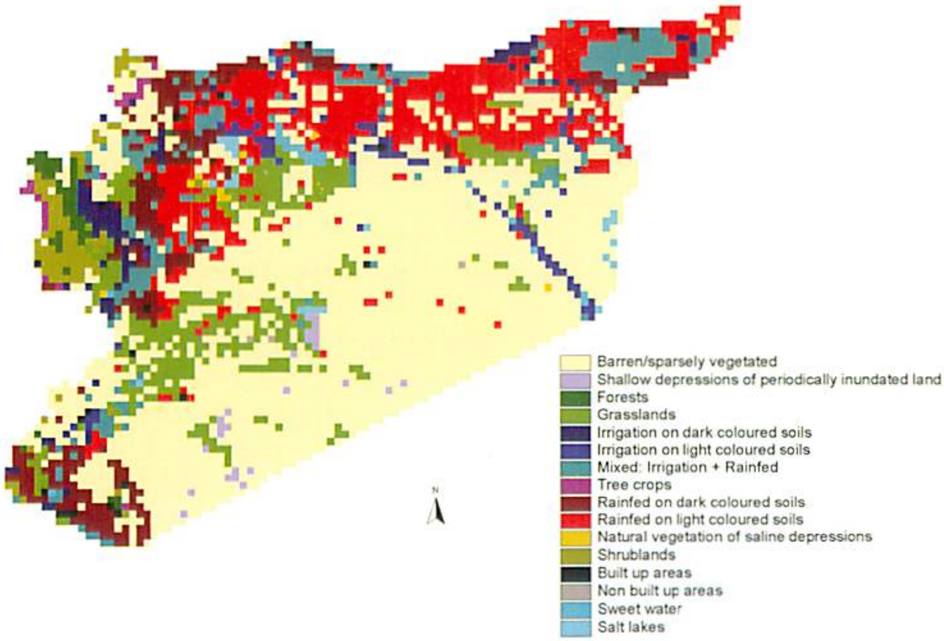

Figure 14. Reference map of land cover/land use in Syria at 8-km resolution

The third step was to aggregate the legends of the two maps, which are very different in scale, into a common legend of 5 LCLUTs:

- Irrigated croplands
- Rainfed croplands
- Forests
- Grasslands
- Barren soil.

The aggregation was achieved by retaining on each pixel only the dominant Land Cover Type, being the one with the highest areal extent in each pixel.

The fourth step was to overlay the two reclassified maps and count the number of correctly assigned pixels. The results are shown in Table 16 of Annex 5, and are summarized in Table 9. An overall accuracy of 56% of corresponding pixels was found.

Table 9. Results of the accuracy test in Syria for the 8-km resolution LCLU map

LCLUT	No. pixels	Accuracy
Irrigation	433	0.26
Rainfed	669	0.65
Grasslands	868	0.08
Forests	85	0.67
Barren	2120	0.79
Inland water	0	0
Overall accuracy		**0.56**
KHAT		**0.34**

To ensure that each LCLUT has the same weight in the calculation of an accuracy indicator, a different calculation method can be followed, using the KHAT accuracy index (Lillesand and Kiefer, 1994):

$$KHAT = \frac{N * \sum xi. * x.i}{N^2 - \sum xi. * x.i}$$

in which N refers to the total number of pixels, $xi.$ to the column totals and $x.i$ to the row totals of Table 16.

The advantage of the KHAT accuracy index is that the accuracy results are evenly applied to different classes and are not dominated by the accuracy for a particular class.

4.2. Accuracy testing of 30 arc-second Land Cover/Land Use maps

The first step in testing existing LCLU maps was to transform the LCLU map for Syria (De Pauw et al, 2004) into a 30'' grid, and to reduce the legend into a 7-class legend. This step is shown in Table 17 of Annex 6 and in Figure 15. In this way a *reference map* with a very high amount of samples (267,279) was obtained from high-resolution data (Landsat) to evaluate new classifications at lower resolution (AVHRR).

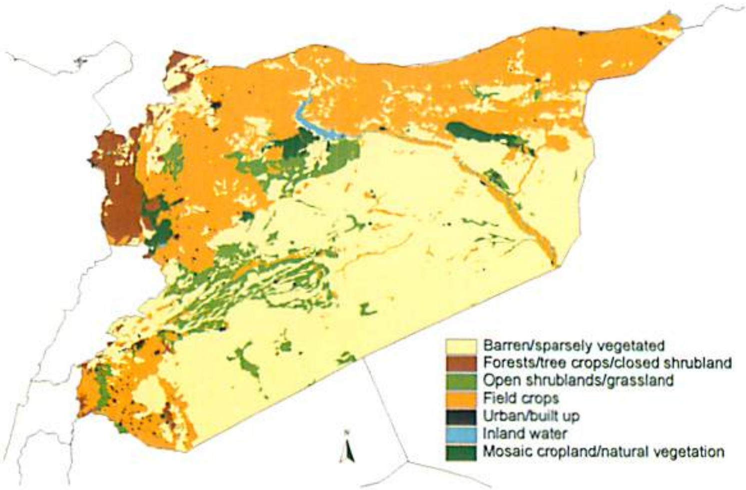

Figure 15. Reference map of land cover/land use in Syria at 1-km resolution

The four 30'' land cover maps to be evaluated were the IGBP-DIS land-cover map (Belward e.a., 1999), the AARS land-cover map (Tateishi, 1999), the University of Maryland (Umd) land-cover map (Hansen et al.., 2000) and the ICARDA map described in section 3.2. They are all based on the same 1-km AVHRR 12-month time series from 1 April 1992 until 31 March 1993, which makes a comparison possible. Their legends were correlated to the 7-class legend of the reference map, and their classes merged as shown in Tables 18-21 of Annex 6. In this way they could be compared at the same level of distinction, in this case without further separation of croplands into rainfed or irrigated croplands.

As in the case of the 4 arc-minute LCLU map, accuracy was tested by overlaying each map of merged classes with the reference map, and counting the number of correctly assigned pixels. In addition the weighted accuracy index KHAT was used to ensure the test was not biased by the dominance of one or another LCLUT.

4.2.1. Land Cover/Land Use Map of IGBP-DIS

The reclassified LCLU map of IGBP-DIS is shown in Figure 16. The results of the accuracy tests are summarized in Table 10. Figure 17 shows in color the areas where the various LCLUTs were correctly classified. Comparison with the original LCLU map of Syria (Table 10) shows that the IGBP-DIS map overestimates the area of *Open shrublands*, where in fact *Barren areas* and *Field crops* occur. Also the class *Mosaic cropland/natural vegetation was* allocated, where in reality *Field crops* and *Forests* occur. The classes *Savannah* and *Wetlands* do not exist in Syria.

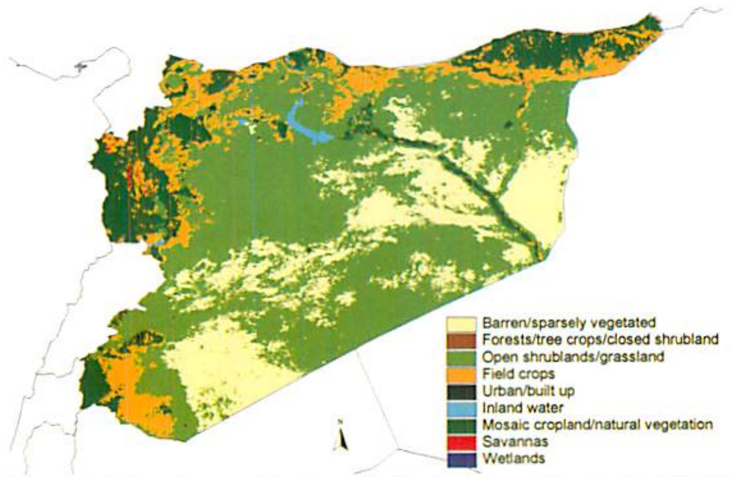

Figure 16. Land cover/land use in Syria according to the IGBP-DIS map (merged classes).

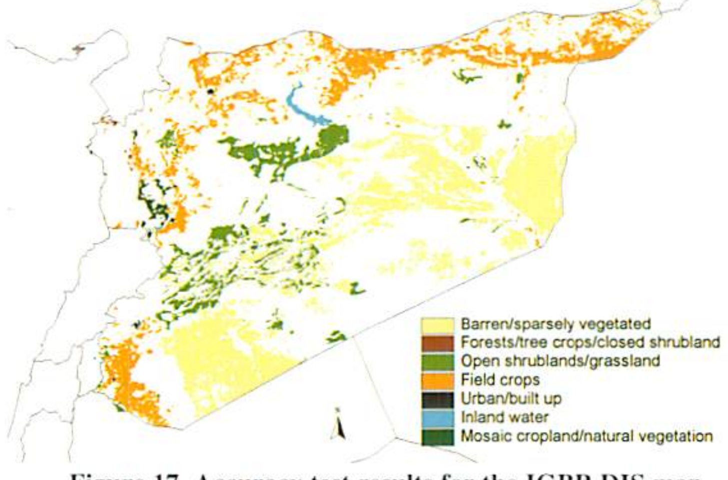

Figure 17. Accuracy test results for the IGBP-DIS map

Table 10. Number of corresponding pixels for 1GBP-DIS LCLU

Assigned classes	Reference classes							
	Forests	Open Shrubs	Field Crops	Urban	Mosaic	Barren	Inland Wate	*Total*
Forests	**173**	6	173	6	14	0	0	*372*
Open Shrubs	376	**13068**	43860	360	3564	82835	38	*144101*
Savannas	132	18	14	0	0	14	0	*178*
Wetlands	0	0	0	0	0	14	10	*24*
Croplands	1311	821	**22420**	418	460	4524	58	*30012*
Urban	0	0	72	**202**	0	14	20	*308*
Mosaic	7814	504	20225	313	**922**	3170	317	*33265*
Barren	14	5821	2758	126	130	**48602**	99	*57550*
Inland Water	58	14	274	25	28	220	**850**	*1469*
Total	*9878*	*20252*	*89796*	*1450*	*5118*	*139393*	*1392*	*267279*
Total percent correct		***32.30***						
KHAT		***0.1976***						

4.2.2. Land cover/Land Use Map of AARS

The map of merged LCLU classes for AARS is shown in Figure 18.
The results of the accuracy tests are summarized in Table 11. Figure 19 shows in color the areas where the various LCLUTs were correctly classified.

Comparison with the original LCLU map of Syria (Table 11) shows that a big overestimation occurred for the class *Mosaic cropland/natural vegetation*, where in reality there are *Field crops* and *Forests*. In addition, the class *Swamps* was proposed instead of *Field crops*. A small overestimation occurred for *Barren/sparsely vegetated*, which should have been *Open shrublands* and *Field crops*. The class *Tundra* does not occur in Syria.

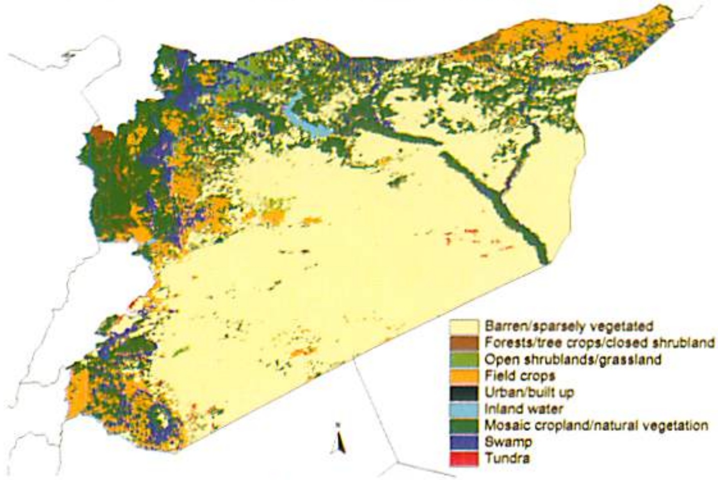

Figure 18. Land cover/land use in Syria according to the AARS map (merged classes)

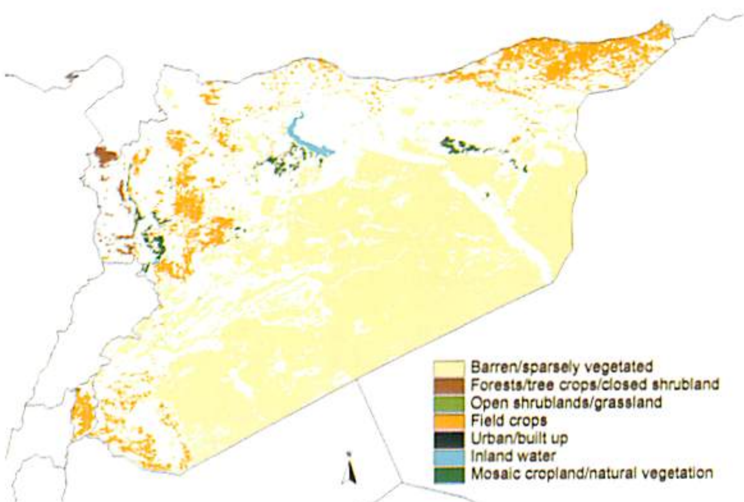

Figure 19. Accuracy test results for the AARS map

Table 11. Number of corresponding pixels for AARS LCLU map

Assigned classes	Reference classes							
	Field crops	Forests	Open Shrubs	Mosaic	Barren	Urban	Inland Water	*Total*
Field crops	**19071**	630	749	691	5085	215	21	*26462*
Forests	693	**1124**	0	5	251	25	0	*2098*
Open Shrubs	3385	14	**173**	14	1167	29	52	*4834*
Mosaic	36572	7678	1958	**1873**	13050	677	425	*62233*
Barren	21908	173	16507	2204	**115663**	288	58	*156801*
Inland water	216	0	16	29	288	0	**807**	*1356*
Swamp	7937	259	835	302	3399	216	29	*12977*
Tundra	14	0	14	0	490	0	0	*518*
Total	*89796*	*9878*	*20252*	*5118*	*139393*	*1450*	*1392*	*267279*
Total percent correct		***51.9***						
KHAT		***0.2667***						

4.2.3. Land cover/Land Use Map of UoM

The map of merged LCLU classes for UoM is shown in Figure 20. The results of the accuracy tests are summarized in Table 12. Figure 21 shows in color the areas where the various LCLUTs were correctly classified.

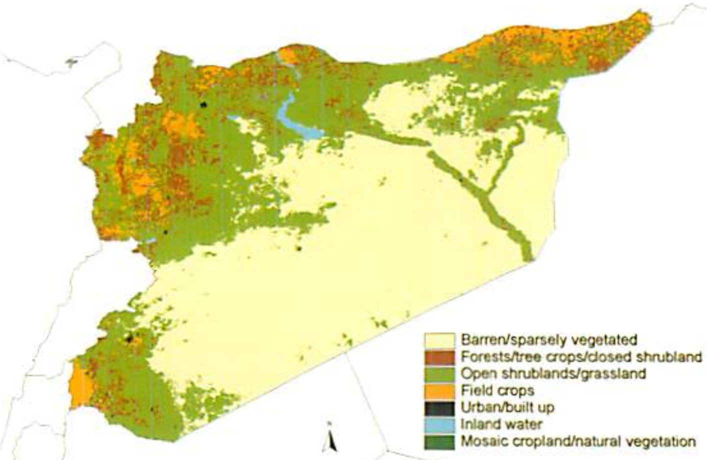

Figure 20. Land cover/land use in Syria according to the UoM map (merged classes)

Table 12. Number of corresponding pixels for UoM LCLU map

Assigned classes	Reference classes							
	Field crops	Forests	Open Shrubs	Mosaic	Barren	Urban	Inland Water	*Total*
Field crops	**8585**	1210	216	202	360	58	14	*10645*
Forests	18768	**3126**	576	619	3212	274	86	*26661*
Open Shrubs	51980	5485	**4595**	3298	26933	730	457	*93478*
Barren	10103	43	14850	983	**108629**	187	14	*134809*
Urban	101	14	15	0	14	**187**	0	*331*
Inland water	259	0	0	16	245	14	**821**	*1355*
Total	*89796*	*9878*	*20252*	*5118*	*139393*	*1450*	*1392*	*267279*
Total percent correct		***47.12***						
KHAT		***0.2373***						

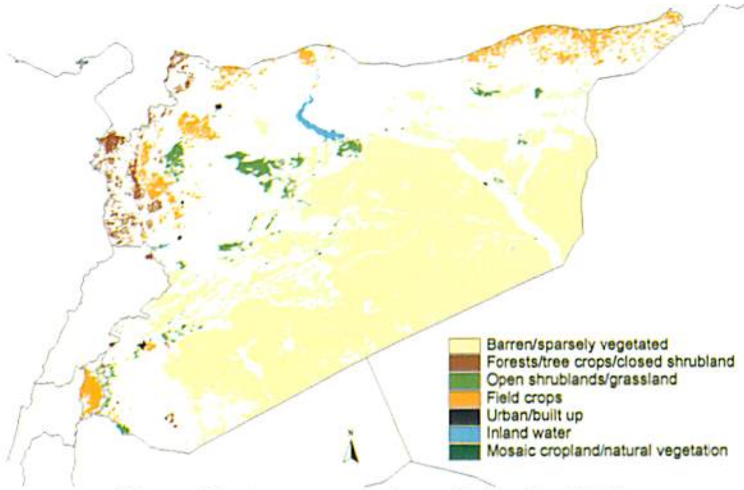

Figure 21. Accuracy test results for the UoM map

Comparison with the original LCLU map of Syria (Table 12) shows a big over-estimation of the class *Open shrublands*, which was in reality a mosaic of *Barren* areas and *Field crops*. Also the class *Forests* was assigned instead of *Field crops*.

4.2.4. Land Cover/Land Use Map of ICARDA

The LCLU map of ICARDA is shown in Figure 22. The results of the accuracy tests are summarized in Table 13.

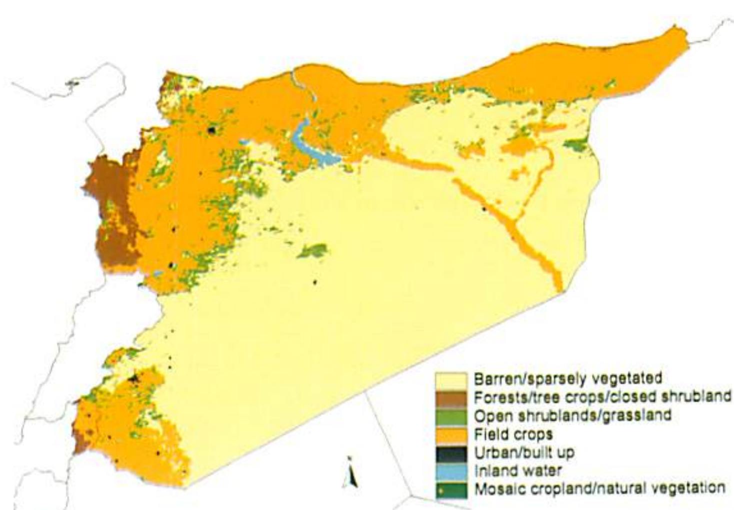

Figure 22. Land cover/land use in Syria according to the ICARDA map

Table 13. Number of corresponding pixels for ICARDA LCLU map

Assigned classes	Reference classes							
	Forests	Field Crops	Open Shrubs	Barren	Inland Water	Urban	Mosaic	*Total*
Forests	**6655**	663	0	752	14	43	74	*8127*
Croplands	2074	**62167**	1991	9737	490	792	0	*77251*
Open Shrubs	703	7636	**823**	4033	0	144	0	*13339*
Barren	432	19042	17410	**124565**	60	302	1959	*161811*
Inland Water	0	216	14	288	**807**	0	29	*1325*
Urban	14	72	14	18	21	**169**	0	*308*
Mosaic	0	0	0	0	0	0	**3056**	*0*
Total	*9878*	*89796*	*20252*	*139393*	*1392*	*1450*	*5118*	*267279*
Total percent correct		***74.17***						
	KHAT	***0.5533***						

In order to evaluate the ICARDA-map at the most detailed level of comparison between the classified legend and the reference legend, a second legend was created in which the distinction between rainfed and irrigated croplands was preserved (Fig. 23). The reference legend was adapted in the same way to make this distinction (Fig. 24).

The results of the accuracy tests are summarized in Table 14. Figure 25 shows in color the areas where the various LCLUTs were correctly classified. This map has a very acceptable accuracy for *Field crops*, *Forests* and *Barren/sparsely vegetated* areas. Its main weakness is its inability to correctly identify the transition zone between the cultivated areas and the desert.

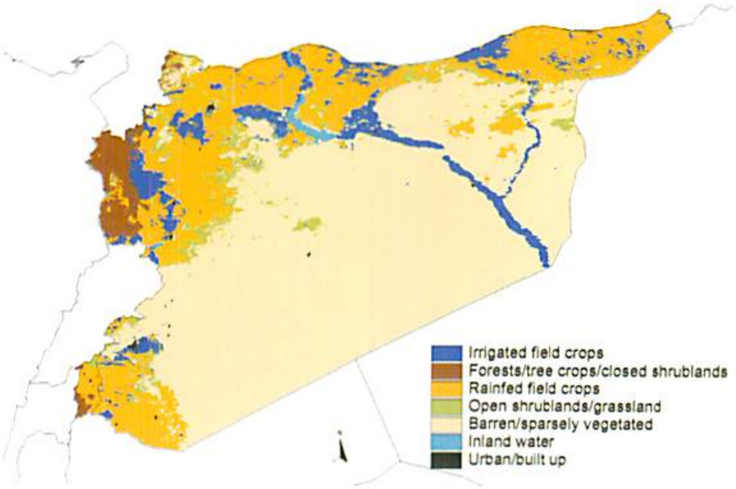

Figure 23. Land cover/land use in Syria, with differentiation between irrigated and rainfed crops

Table 14. Number of corresponding pixels for ICARDA LCLU map (with irrigated areas)

Assigned classes	Reference classes						
	Irrigated	Forests	Rainfed	Open Shrubs	Barren	Urban	*Total*
Irrigated	**8873**	432	6957	130	2377	216	*18985*
Forests	130	**6655**	607	19	735	43	*8189*
Rainfed	1541	1641	**47389**	1850	7360	576	*60357*
Open Shrubs	331	706	7317	**1272**	4033	144	*13803*
Barren	692	430	20295	17414	**124565**	302	*163698*
Inland Water	144	0	101	14	288	0	*547*
Urban	43	14	33	14	35	**169**	*308*
Total	*11754*	*9878*	*82699*	*20713*	*139393*	*1450*	*265887*
Total percent correct		***70.98***					
	KHAT	***0.5573***					

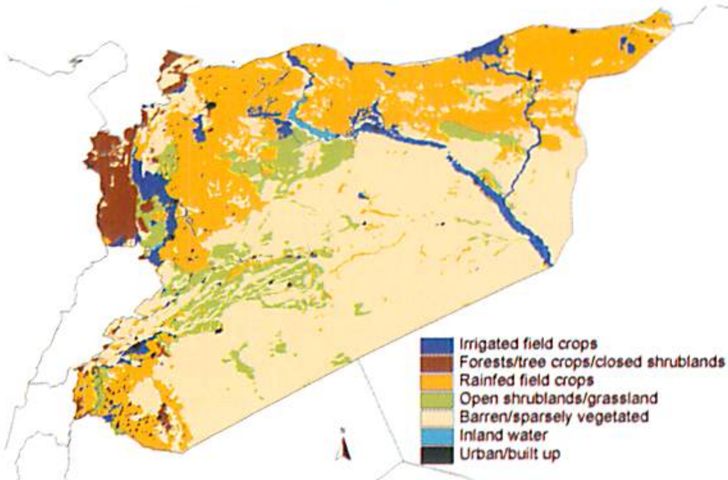

Figure 24. Reference map, with differentiation between irrigated and rainfed crops

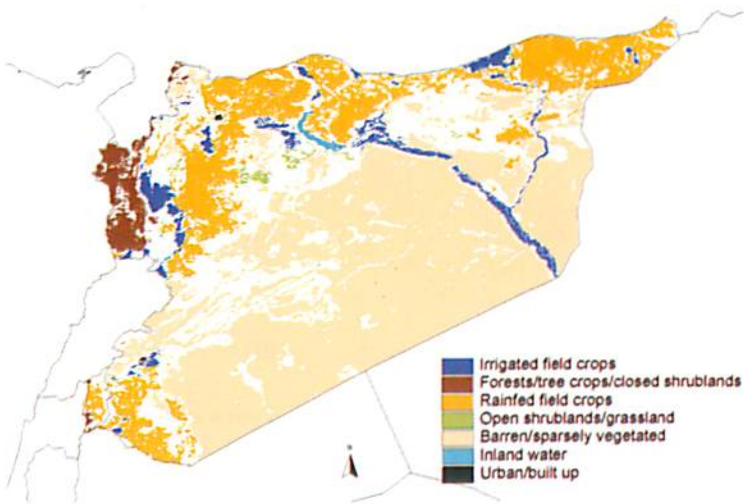

Figure 25. Accuracy test results for the ICARDA map

4.3. Additional accuracy tests of the ICARDA Land Cover/Land Use Map in Central Asia and Pakistan

During the summer of 1996 and 1997 and the spring of 1998, the Institute of Botany and Phytointroduction of Kazakhstan and CEReS, and the Center for Environmental Remote Sensing of the Chiba University in Japan, undertook a joint ground truth collection trip in Central Asia (Tateishi e.a., 1999). Information from 29 ground truth samples (see Figure 26 and Table 22 in Annex 6) made it possible to test the accuracy of the ICARDA 1-km Land Cover Map for this area, which resulted in 72% of correct pixels.

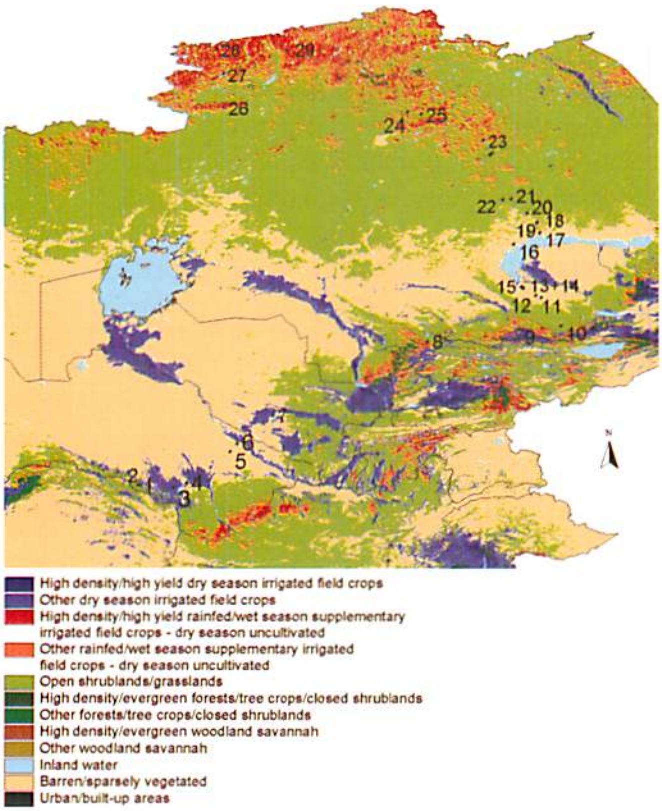

Figure 26. Location of sample points in Central Asia

4.4. Conclusions from accuracy testing

From tests with LCLU maps at higher resolution in a region representative for many areas in CWANA, the accuracy of existing classifications was found to be of limited use at a regional scale for CWANA. One of the reasons appears to be that these land cover maps are all based on unsupervised or supervised classification methods, which do not work well in a large region with major agro-climatic differences.

The accuracy tests indicate that the new classification system based on an empirical hierarchical decision tree with sliding thresholds according to agroclimatic conditions, works better. In comparison to global classifications that require a greater number of classes to cover the most diverse climatic zones, limiting the classification to a smaller region with a typical dryland climate allows to reduce the total number of relevant classes and makes a consistent distinction more easy.

In the new classification the LCLUTs were established on the basis of ground truthing, using field surveys, together with thematic maps and Landsat satellite imagery (Landsat) as a special form of ground truth. By applying the new decision-tree applied to a specific region, a smaller number of land use/cover classes was obtained than in other land-cover classifications, but they could be identified with a higher degree of accuracy. The validity of the new approach is demonstrated by an accuracy of the 4 arc-minute resolution map that is higher than the accuracy for the previous 1-km resolution maps.

4.5. Evaluation of the 'sliding threshold' approach

4.5.1. NDVI statistics for land cover types in Syria

The availability of a high-resolution LCLU reference map for Syria (De Pauw et al., 2004) allowed calculating different NDVI-statistics for the 24 basic land cover types[3]. The mean NDVI and standard deviation of NDVI was calculated for each land cover type and the results are summarized in Figures 27-32.

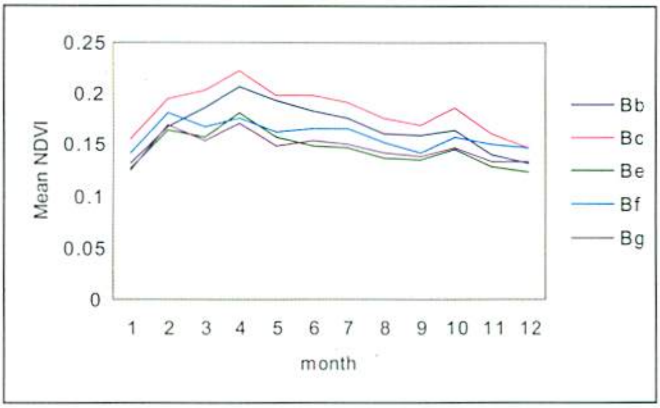

Figure 27. Mean NDVI for bare soil classes Bb, Bc, Be, Bf and Bg

[3] The classes differentiated are shown in Annex 4.

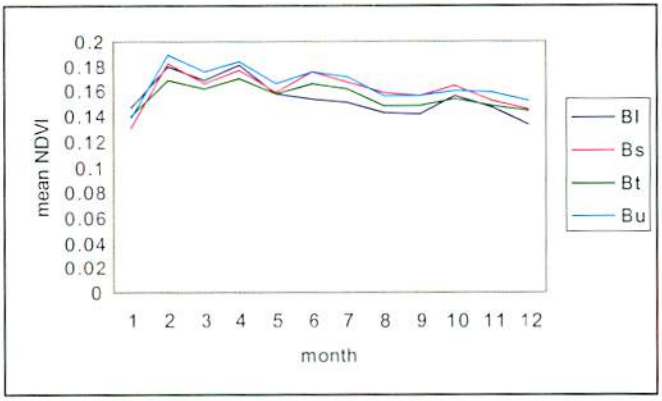

Figure 28. Mean NDVI for bare soil classes Bl, Bs, Bt and Bu

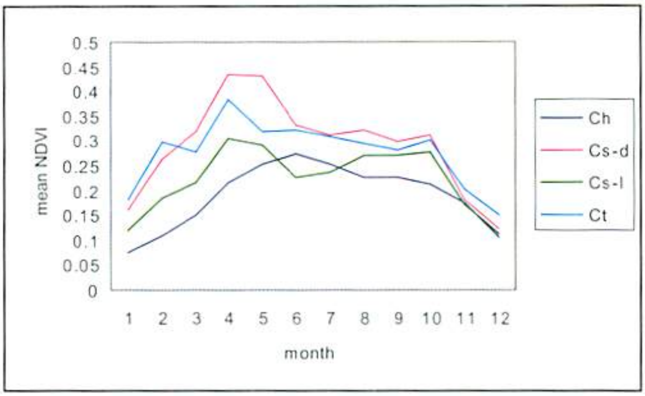

Figure 29. Mean NDVI for cropland classes Ch, Cs-d, Cs-l and Ct

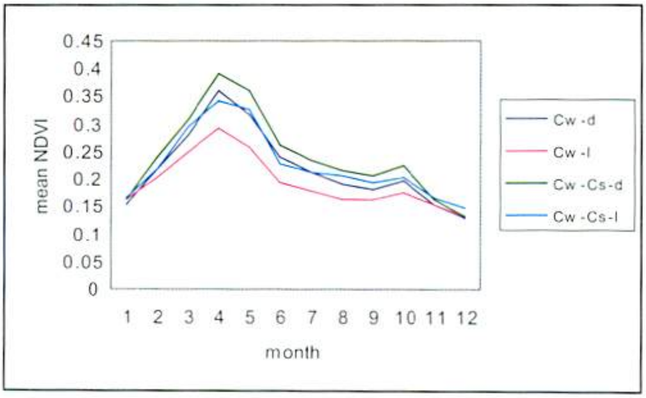

Figure 30. Mean NDVI for cropland classes Cw-d, Cw-l, Cw-Cs-d and Cw-Cs-l

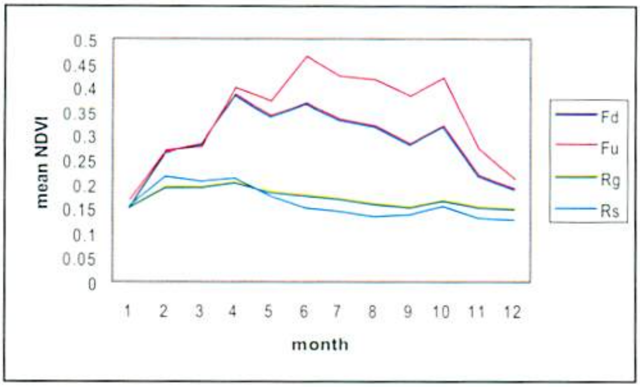

Figure 31. Mean NDVI for forest and rangeland classes

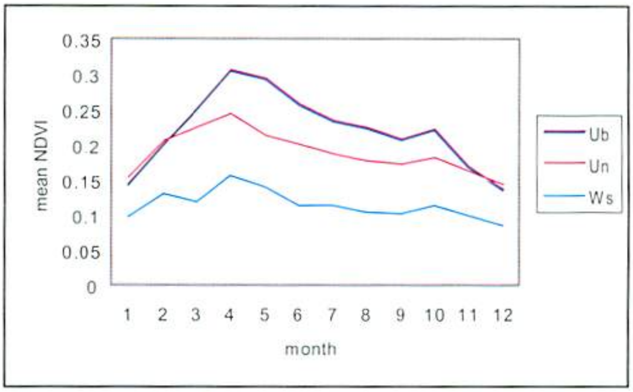

Figure 32. Mean NDVI for urban and water classes

4.5.2. NDVI and agroclimatic conditions

Combined with macro-scale climatic information, these statistics allow assessing the relationship between LCLU and NDVI.The Agroclimatic map for CWANA (UNESCO, 1979) shows three major agroclimatic zones for Syria (Fig. 33). With the exception of water bodies and urbanized areas, which are not relevant for NDVI-analysis, the basic classes of the LCLU map of Syria were correlated to a legend with 5 major classes, corresponding to the legend used for accuracy assessment (section 4.2):

- Barren/sparsely vegetated
- Open shrublands/grasslands
- Rainfed field crops
- Irrigated field crops
- Forests/tree crops/closed shrublands

The distribution of these major classes over the climatic zones is represented in Table 15. This distribution is important for weighing the importance of further statistical results.

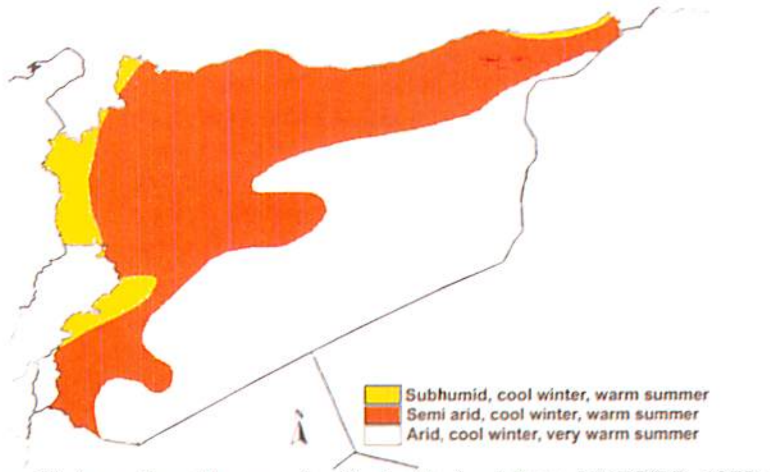

Figure 33. Agroclimatic zones for Syria (derived from UNESCO, 1979).

Table 15. Distribution of major LCLUTs in relation to agroclimatic zones

LCLUT	Agroclimatic zone		
	Arid	Semi-arid	Sub-humid
Barren	70	26	4
Open shrubland	40	56	4
Rainfed cropland	13	84	3
Irrigated cropland	23	72	5
Forest	0	18	82

For each of the 24 basic LCLUTs the mean values and standard deviations were calculated for the NDVI variables NDVImax, NDVImean and (NDVImax – NDVImean). Given the wide range in values for these parameters, the data distribution was modeled using the ArcView Spatial Analyst extension (see example in Figure 34), removing 10% of the data at both tail ends of the histogram, resulting in 80-percent data intervals.

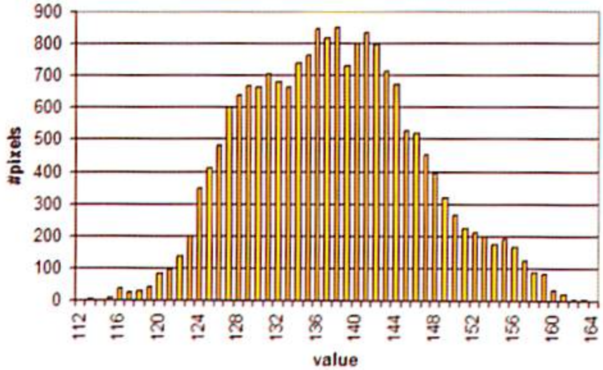

Figure 34. Histogram of NDVImax-values[4] for rainfed winter field crops on dark-coloured soils

[4] Scaled as (NDVImax*100+100)

In addition, the 80-percent data intervals were calculated for the 5 major classes mentioned in section 4.5.1and disaggregated according to major climatic zones.

The indicated thresholds are those applied by the decision tree of the ICARDA 1-km- land cover classification algorithm. NDVImax is used to differentiate rainfed field crops. Figures 35-37 indicate that the thresholds used in the different agroclimatic zones adequately separate classes in which soil reflectance dominates (*Bare soil* and *Open grassland*) from the classes in which the spectral characteristics are primarily determined by vegetation. However, in the semi-arid and sub-humid areas somewhat lower thresholds (e.g. 0.30 for semi-arid and 0.35 for sub-humid areas) would have been more appropriate to avoid that some rainfed croplands are classified as either *Barren* or *Open shrubland/grasslands*.

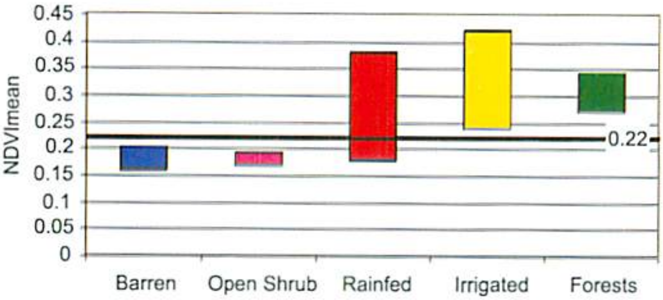

Figure 35. 80-percent data intervals for NDVI-max: Arid region

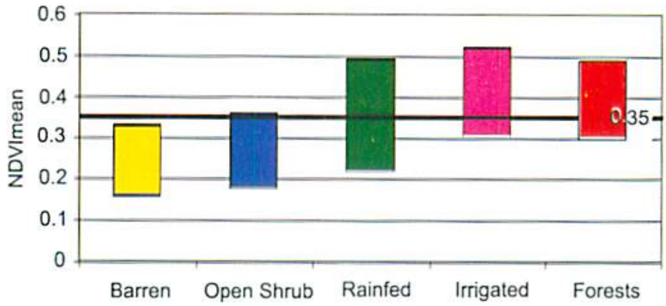

Figure 36. 80-percent data intervals for NDVImax: Semi-arid region

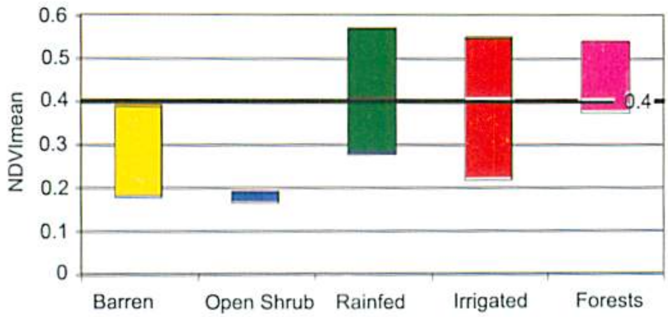

Figure 37. 80-percent data intervals for NDVImax: Sub-humid region

The NDVImean threshold is used to differentiate *Forests/tree crops/closed shrubland*. Figures 38-40 show that, while the values used are in the right range, in all agroclimatic zones somewhat lower thresholds would have been optimal to separate tree-dominated land cover.

The parameter [NDVImax-NDVImean] is used as a threshold to separate *Open shrublands/grasslands*. Figure 41 indicates that this threshold has been well set.

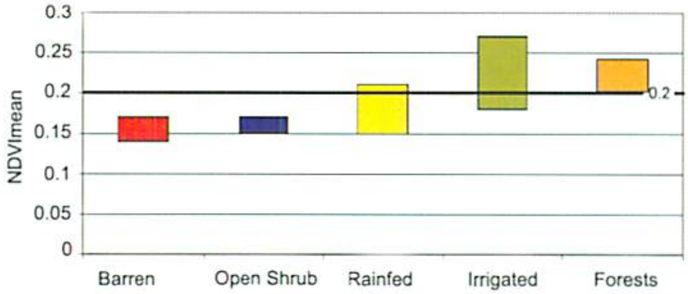

Figure 38. 80 percent data intervals for NDVI-mean: Arid region

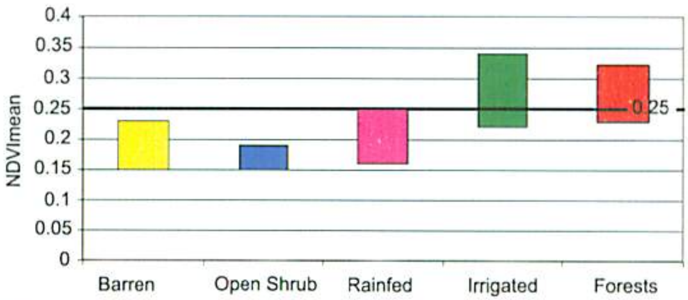

Figure 39. 80-percent data intervals for NDVI-mean: Semi-arid region

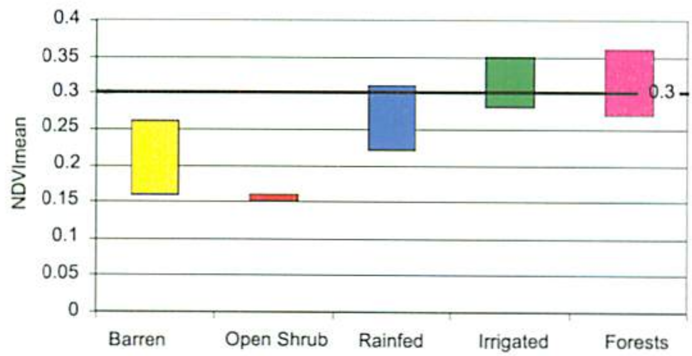

Figure 40. 80-percent data intervals for NDVI-mean: Sub-humid region

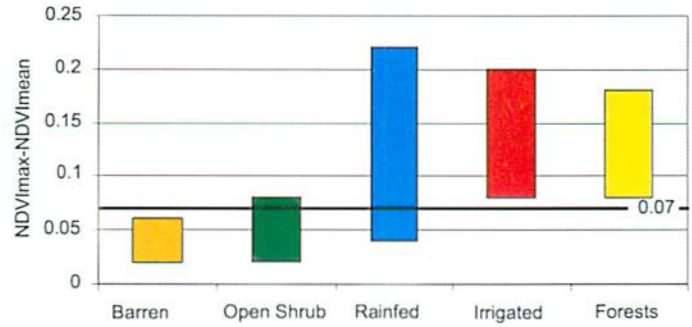

Figure 41. 80-percent data-intervals of [NDVImax – NDVImean]

4.5.3. Conclusions

All 80-percent data intervals for NDVImax and NDVImean for basic and major land cover classes show the same trend: *the NDVI-values within the same land cover class are higher in more humid climatic regions*. This proves that the use of increasing thresholds for more humid climatic regions will improve the accuracy of the classification.

This pattern can be explained by the occurrence of different species, each adapted to its individual climatic regime. Species typically found in more moist climates will exploit the available moisture resulting in more vigorous growth and higher leaf area. Species adapted to dry conditions try to reduce their photosynthetic activity in order to limit water losses through transpiration, typically achieved by reducing leaf area but also resulting in less greenness. The same trend applies to pixels of the *Bare soil* class; therefore, the influence of climate (soil moisture, soil temperature) on soil reflectance also needs to be considered.

The influence of climate is clearly shown by the correspondence of the annual rainfall patterns in Syria and the annual NDVImax for both rainfed crops and barren areas in Figures 42-44.

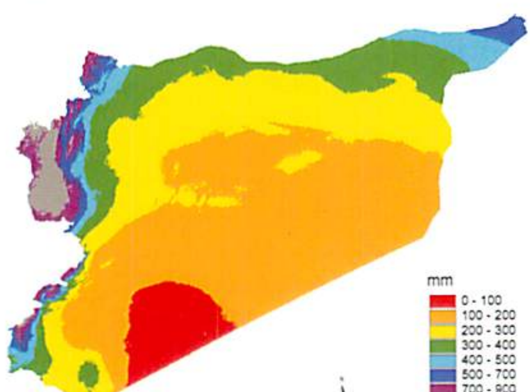

Figure 42. Mean annual rainfall distribution in Syria (period 1979 to 1996) (Source: ICARDA GIS Unit)

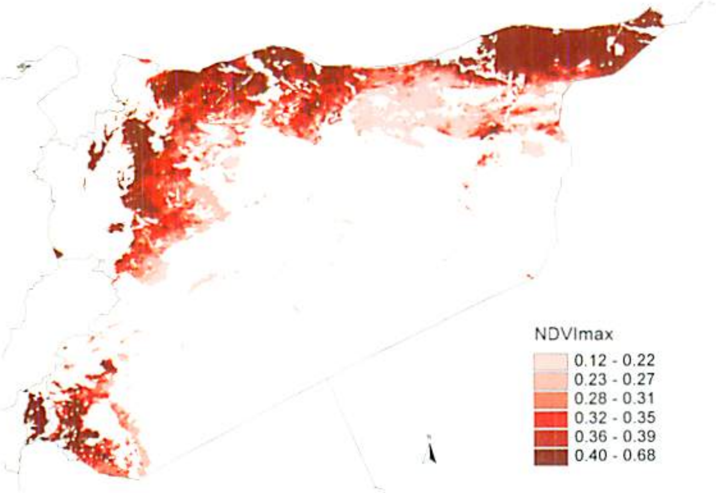

Figure 43. NDVImax for rainfed croplands

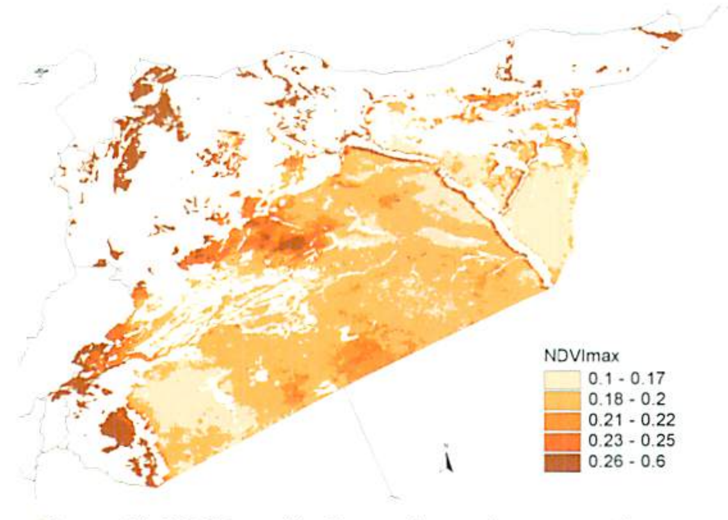

Figure 44. NDVImax for Barren/sparsely vegetated areas

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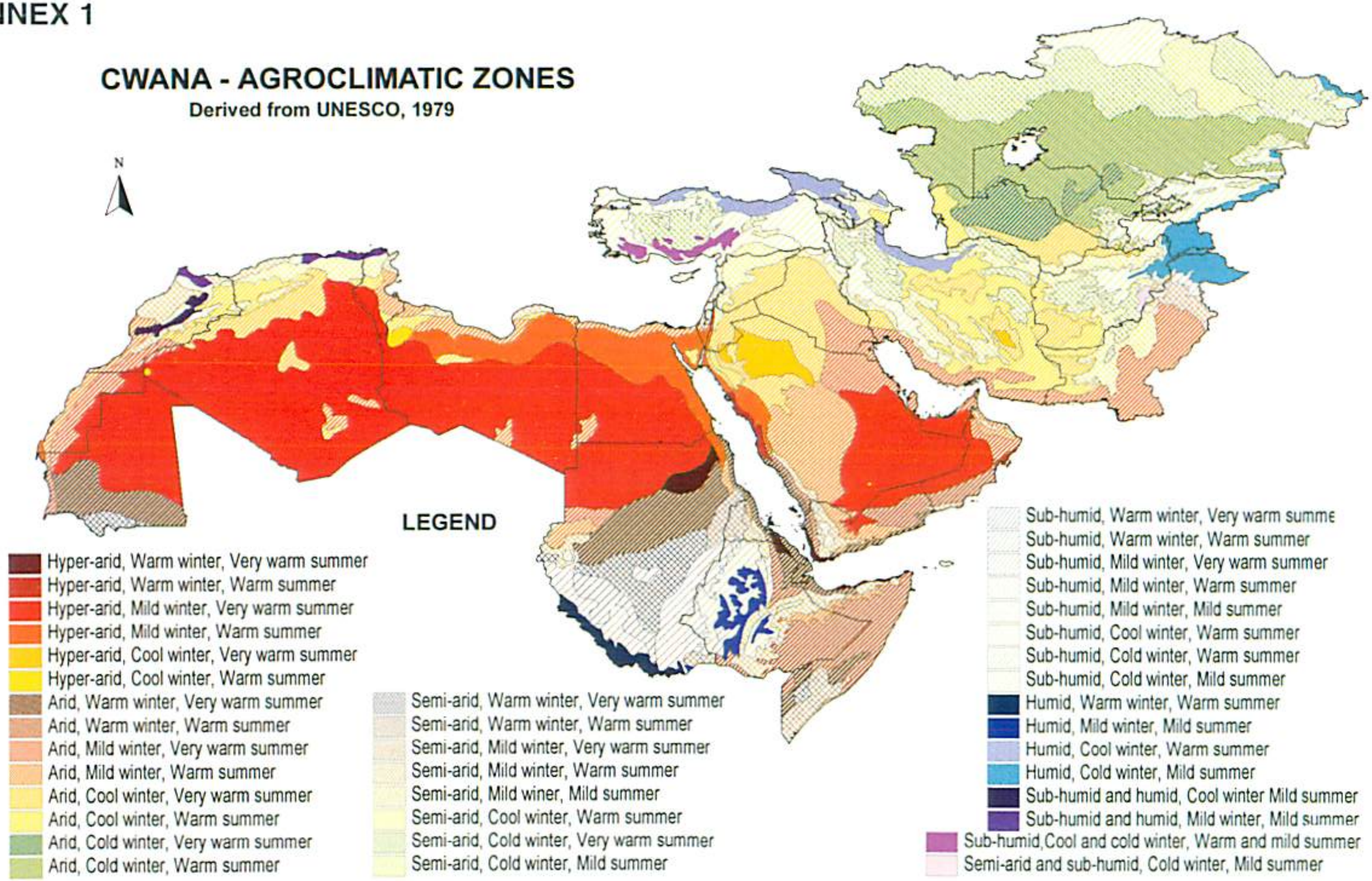
ANNEX 1

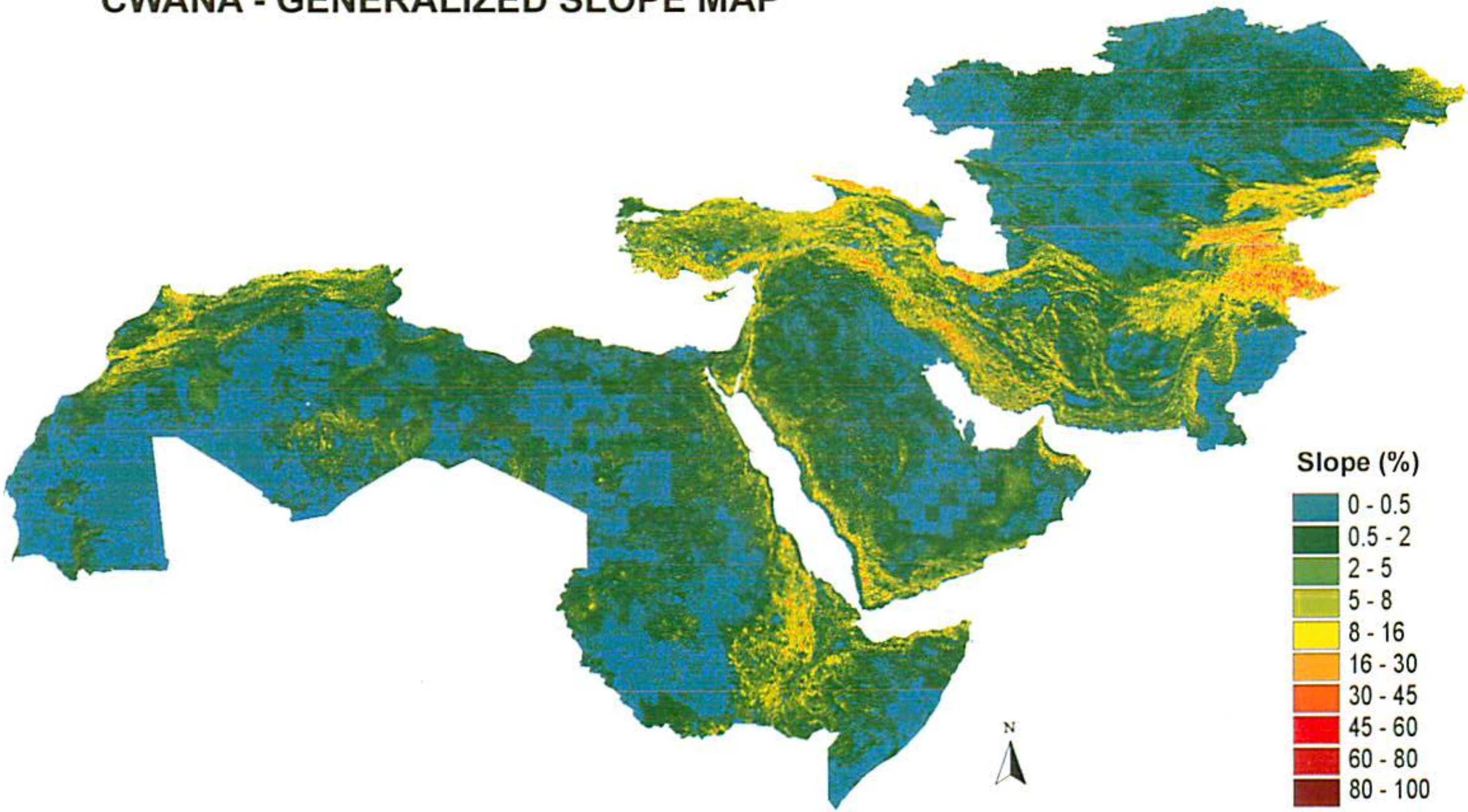
CWANA - AGROCLIMATIC ZONES

Derived from UNESCO, 1979



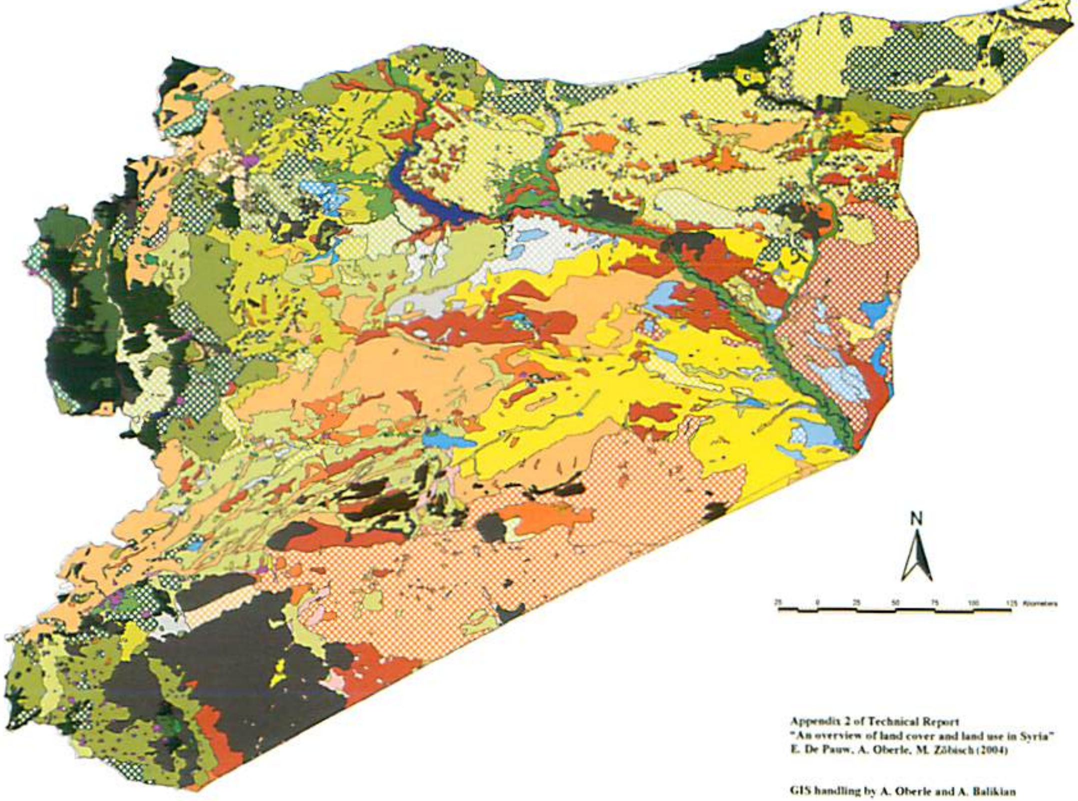
ANNEX 2

CWANA - GENERALIZED SLOPE MAP



ANNEX 3

LAND COVER AND LAND USE IN SYRIA. BASE YEAR 1989/1990



Appendix 2 of Technical Report
"An overview of land cover and land use in Syria"
E. De Pauw, A. Oberle, M. Zöbisch (2004)

GIS handling by A. Oberle and A. Balikian

LEGEND

- Bb
- Bb/Cw-d
- Bb/Fd
- Bc
- Bc/Bs
- Bc/Ct
- Bc/Rg
- Be
- Be/Bs
- Be/Cw-1
- Be/Rg
- Be/Rg/Bg
- Be/Rs
- Be/Ws
- Bf
- Bg
- Bg/Bs
- Bg/Bt/Bs
- Bg/Rg
- Bl
- Bl/Cw-1
- Bs
- Bs/Bg
- Bs/Bg/Rg
- Bt
- Bu
- Bu/Be
- Bu/Bs
- Ch
- Cs-d
- Cs-l
- Cs-l/Bs
- Ct
- Ct/Ch
- Ct/Cw-d
- Ct/Cw/Cs-d
- Cw-d
- Cw-d/Bb
- Cw-d/Bl
- Cw-l
- Cw-l/Be
- Cw-l/Bg
- Cw-l/Bl
- Cw-l/Bu
- Cw-l/Rg
- Cw-ld
- Cw/Cs-d
- Cw/Cs-d/Be
- Cw/Cs-d/Bg
- Cw/Cs-d/Ct
- Cw/Cs-l
- Cw/Cs-l/Bl
- Cw/Cs-l/Rs
- Cw/Cs-ld
- Fd
- Fu
- Fu/Fd
- Rg
- Rg/Bu
- Rg/Cw-l
- Rg/Cw-d
- Rs
- Ub
- Un
- Wl
- Ws
- Ws/Be

CLASSES OF THE LAND COVER/LAND USE MAP*

1) Homogeneous Units

Water bodies
Wl: Fresh water lakes and reservoirs, rivers
Ws: Salt lakes, periodically inundated salt flats

Bare areas with or without sparse cover
Bb: Basaltic rock outcrops and slope detritus
Bc: Carbonate-type rock outcrops and slope detritus
Be: Undifferentiated highly dissected and eroded land
Bf: Plains with bare soil surface covered with flint-stones
Bg: Plains with bare gypsum-enriched soil surface or gypsum out crops
Bl:Plains with bare lime-enriched soil surface covering calcareous sediments
Bs: Plains with bare soil surface partially covered with sand sheets
Bt: Shallow depressions of periodically inundated land (takyrs)
Bu: Plains with undifferentiated bare soil surface

Rangelands
Rs: Natural vegetation of saline depressions
Rg: Sparse grasslands and shrublands of rocky hills and arid lands

Forests and other wooded areas
Fu: undifferentiated coniferous & broadleaf, deciduous & evergreen, forest areas
Fd: scrubland and other types of degenerate forest, often with interspersed tree crops

Cultivated areas
Ch: Horticultural crops
Ct: Tree crops

Mostly irrigated summer field crops, on dark-coloured soils (Cs-d) or on light-coloured soils (Cs-l)

Mostly rainfed winter/spring field crops, on dark-coloured soils (Cw-d) or on light-coloured soils (Cw-l)

Urbanized areas
Ub: Built-up areas and settlements (cities, villages)
Un: Non-built-up areas

* For more details see De Pauw et al. 2004

2) Mixed Units

Predominantly water bodies
Ws/Bc
Dominant: salt lake or periodically inundated salt flats
Associated: carbonate-type rock outcrops and rubble slopes

Predominantly bare or sparsely covered land
Bb/Cw-d/Cs-d
Dominant: basaltic rock outcrops and rubble slopes
Associated: rainfed winter/spring field crops
Inclusions: irrigated crops on dark-colored soils

Bb/Fd
Dominant: basaltic rock outcrops and rubble slopes
Associated: scrubland and other types of degenerate forest

Bc/Bs
Dominant: carbonate-type rock outcrops and rubble slopes
Associated: bare soil surface partially covered with sand sheets

Bc/Ct
Dominant: carbonate-type rock outcrops and rubble slopes
Associated: tree crops

Bc/Rg
Dominant: carbonate-type rock outcrops and rubble slopes
Associated: sparse grasslands and shrublands of rocky hills and arid lands

Be/Bs
Dominant: highly dissected and eroded land
Associated: bare soil surface, partially covered by sand sheets

Be/Cw-l/Cs-l
Dominant: highly dissected and eroded land
Associated: rainfed winter/spring field crops
Inclusions: irrigated crops on light-colored soils

Be/Rg
Dominant: highly dissected and eroded land
Associated: sparse grasslands and shrublands

Be/Rg/Bg
Dominant: highly dissected and eroded land

Associated: sparse grasslands and shrublands
Inclusions: bare gypsum-enriched soil surface or gypsum outcrops

Be/Rs
Dominant: highly dissected and eroded land
Associated: natural vegetation in saline depressions

Be/Ws
Dominant: highly dissected and eroded land
Associated: periodically inundated salt flats

Bg/Bs
Dominant: plains with predominantly bare gypsum-enriched soil surface or gypsum outcrops
Associated: sand sheets

Bg/Bt/Bs
Dominant: bare gypsum-enriched soil surface or gypsum outcrops
Associated: shallow depressions of periodically inundated land
Inclusions: scarce grassland and scrubland, and bare soil surface covered with sand sheets

Bg/Rg
Dominant: plains with bare gypsum-enriched soil surface or gypsum outcrops
Associated: sparse grasslands and shrublands of arid lands

Bl/Cw-l/Cs-l
Dominant: plains with bare lime-enriched soil surface covering calcareous sediments
Associated: rainfed winter/spring field crops
Inclusions: irrigated crops on light-colored soils

Bs/Bg
Dominant: plains with bare soil surface, partially covered with sand sheets
Associated: gypsum-enriched plains, or with gypsum outcrops

Bs/Bg/Rg
Dominant: plains with bare soil surface, partially covered with sand sheets
Associated: gypsum-enriched plains, or with gypsum outcrops
Inclusions: some sparse grasslands or scrublands

Bu/Be
Dominant: plains with undifferentiated bare soil surface
Associated: highly dissected and eroded land

Bu/Bs
Dominant: plains with bare soil surface
Associated: sand sheets

Predominantly rangelands
Within this category three mixed mapping units can be differentiated:

Rg/Bu
Dominant: sparse grass and shrub plains
Associated: undifferentiated bare soil

Rg/Cw-d
Dominant: sparse grasslands and shrublands of rocky hills and arid lands
Associated: rainfed winter/spring field crops
Inclusions: irrigated crops on dark-colored soils

Rg/Cw-l
Dominant: sparse grasslands and shrublands of rocky hills and arid lands
Associated: abandoned rainfed cropland, on light-colored soils

Predominantly forests and other wooded areas

Fu/Fd
Dominant: undifferentiated coniferous and broadleaf, deciduous and evergreen, forest areas
Associated: scrubland and other types of degenerate forest, often with interspersed tree crops

Predominantly cultivated areas
Within this category 20 mixed mapping units have been differentiated:

Cs-l/Bs
Dominant: irrigated summer field crops, on light-colored soils
Associated: natural vegetation in saline depressions

Ct/Ch
Dominant: tree crops
Associated: horticultural crops

Ct/Cw/Cs-d
Dominant: tree crops
Associated: rainfed winter/spring and summer-irrigated field crops, on dark-colored soils

Ct/Cw-d
Dominant: tree crops
Associated: rainfed winter/spring field crops
Inclusions: irrigated crops, on dark-colored soils

Cw/Cs-d
Dominant: rainfed winter/spring field crops
Associated: summer-irrigated crops, on dark-colored soils

Cw/Bc/Cs-d
Dominant: rainfed winter/spring field crops
Associated: carbonate-type rock outcrops and rubble slopes
Inclusions: irrigated crops, on dark-colored soils

Cw/Bg/Cs-d/
Dominant: rainfed winter/spring field crops
Associated: bare gypsum-enriched soil surface or gypsum outcrops
Inclusions: irrigated crops, on dark-colored soils

Cw/Cs-d/Ct
Dominant: rainfed winter/spring field crops
Associated: irrigated summer crops on dark-colored soils
Inclusions: tree crops

Cw/Cs-l
Dominant: rainfed winter/spring field crops
Associated: summer-irrigated crops, on light-colored soils

Cw/Cs-l/Bl
Dominant: rainfed winter/spring field crops
Associated: summer-irrigated crops, on light-colored soils, and bare, lime-enriched soil surface covering calcareous sediments

Cw/Cs-l/Rs
Dominant: rainfed winter/spring field crops
Associated: summer-irrigated crops, on light-colored soils, and natural vegetation in saline depressions

Cw/Cs-ld
Dominant: rainfed winter/spring field crops
Associated: summer-irrigated crops, mainly on light-colored but also dark-colored soils

Cw-d/Bb
Dominant: rainfed winter/spring field crops, with inclusions of irrigated crops, on dark-colored soils
Associated: basaltic rock outcrops and rubble slopes

Cw-d/Bl
Dominant: rainfed winter/spring field crops, with inclusions of irrigated crops, on dark-colored soils
Associated: bare lime-enriched soil surface covering calcareous sediments

Cw-l/Be/Cs-l
Dominant: rainfed winter/spring field crops
Associated: highly dissected and eroded land
Inclusions: irrigated crops, on light-colored soils

Cw-l/Bg
Dominant: plains with predominantly rainfed winter/spring field crops
Associated: bare gypsum-enriched soil surface or gypsum outcrops
Inclusions: irrigated crops, on light-colored soils

Cw-l/Bl
Dominant: plains with predominantly rainfed winter/spring field crops
Associated: bare, lime-enriched soil surface covering calcareous sediments
Inclusions: irrigated crops, on light-colored soils

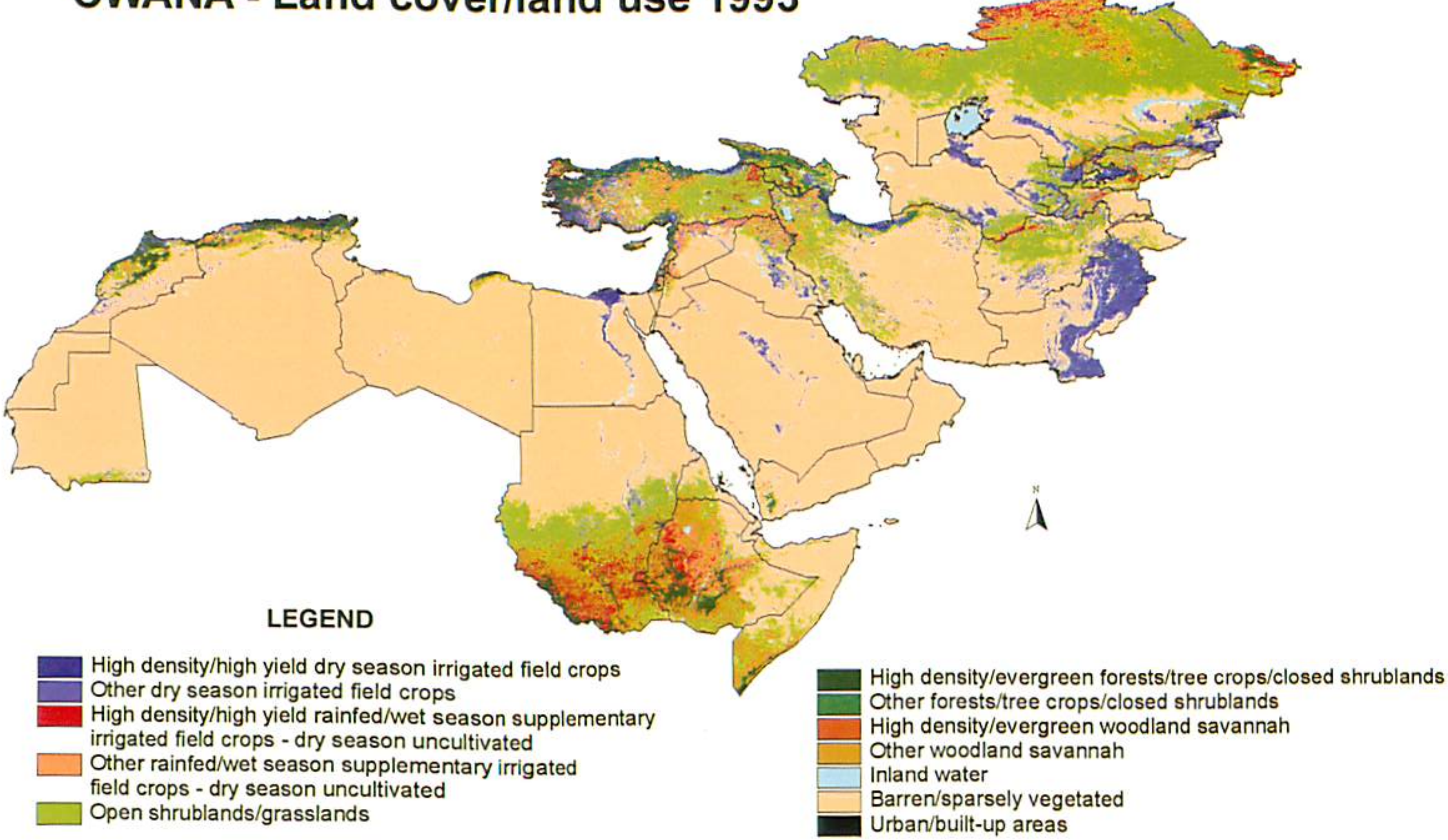
Cw-l/Bu
Dominant: plains with rainfed winter/spring field crops
Associated: bare soil surface
Inclusions: irrigated crops

Cw-l/Rg
Dominant: rainfed winter/spring field crops
Associated: sparse grasslands and shrublands
Inclusions: irrigated crops, on light-colored soils

Cw-ld
Dominant: rainfed winter/spring field crops mainly on light-colored, but also dark-colored soils
Inclusions: irrigated crops

ANNEX 4

CWANA - Land cover/land use 1993



ANNEX 5. ACCURACY TEST RESULTS FOR 4 ARC-MINUTE LAND COVER/LAND USE MAP

Table 16. Corresponding pixels between reference and evaluated maps

Assigned classes	Reference classes						Total
	Irrigation	Rainfed	Grasslands	Forests	Barren	Inland water	
Irrigation	**111**	167	12	9	125	9	*433*
Rainfed	33	**432**	42	57	105	0	*669*
Grasslands	26	469	**70**	9	276	18	*868*
Forests	7	10	4	**57**	7	0	*85*
Barren	6	144	259	6	**1682**	23	*2120*
Inland water	0	0	0	0	0	**0**	*0*

ANNEX 6. ACCURACY TEST RESULTS FOR 30 ARC-SECOND LAND COVER/LAND USE MAP

Table 17. Building a 7-class reference legend from the Land Cover/Land Use Map of Syria

LCLUT	Reference classes							#Pixels
	Field Crops	Forests	Open Shrubs	Mosaic	Barren	Urban	Inland Water	
Bb					*			18877
Bc					*			30021
Be					*			24891
Bf					*			2038
Bg					*			3360
Bl					*			4516
Bs					*			21413
Bt					*			1430
Bu					*			31081
Ch	*							80
Cs-d	*							5519
Cs-l	*							6235
Ct		*						1330
Cw-d	*							19085
Cw-l	*							42090
Cw-l/Rg				*				307
Cw-Csd	*							7815
Cw-Csl	*							8972
Cw-Csl/Rs				*				29
Fd		*						5461
Fu		*						3087
Rg			*					19664
Rg/Cwd				*				1705
Rg/Cwl				*				3077
Rs			*					588
Ub						*		1326
Un						*		124
Wl							*	1392
Ws					*			1766

Table 18. Correlating the IGBP-DIS legend to the 7-class legend

Classes IGBP-DIS Map	Forests	Open Shrubs	Field Crops	Urban	No match	# Pixels
Evergreen needleleaf forest	*					14
Deciduous needleleaf forest	*					4
Deciduous broadleaf forest	*					6
Mixed forest	*					337
Closed shrublands	*					11
Open shrublands		*				140781
Woody savannas					*	61
Savannas					*	117
Grasslands		*				3320
Permanent wetlands					*	24
Croplands			*			30012
Urban/Built-Up				*		308

Classes IGBP-DIS Map	Mosaic	Barren	Inland Water	# Pixels
Cropland/Natural vegetation mosaic	*			33265
Barren or sparsely vegetated		*		57550
Water bodies			*	1469

Table 19. Correlating the ICARDA map legend to the 7-class legen

Classes ICARDA Map	Field Crops	Forests	Open Shrubs	Barren	# Pixels
Irrigated field crops	*				77251
Rainfed field crops	*				8017
Forests/Tree crops/Closed shrublands		*			13523
Open Shrublands/Grasslands			*		3056
Barren/Sparsely vegetated				*	163770

Classes ICARDA Map	Urban	Inland Water	#Pixels
Urban/Built up	*		308
Inland water		*	1354

Table 20. Correlating the AARS-legend to the 7-class legend

Classes AARS Map	Mosaic	Forests	Open Shrub	Field crops	#Pixels
Vegetation	*				18449
Evergreen forest or Shrubland		*			447
Evergreen Forest		*			1484
Evergreen needle-leaf forest		*			144
Deciduous forest or Shrubland		*			10
Deciduous broad-leaf forest		*			12
Natural deciduous broad-leaf forest		*			45
Deciduous needle-leaf forest		*			24
Grassland	*				24826
Natural Grassland/Pasture			*		4766
Grass Crops				*	26292
Paddy				*	128
Wheat				*	13

Classes AARS Map	Mosaic	Open Shrub	No match	Barren	Inland Water	#Pixels
Mixed Vegetation	*					18955
Swamp			*			12965
Tundra			*			513
Other Little Vegetation		*				78728
Bare Ground				*		39581
Rock				*		38435
Stones or gravel				*		20
Water					*	1352

Levels of distinction:

First
Second
Third
Fourth
Fifth
Sixth

Table 21. Correlating the Umd-legend to the 7-class legend

Classes Umd Map	Forests	Open shrubs	Field crops	Barren	Urban	Inland water
Water						*
Evergreen needleleaf forest	*					
Deciduous broadleaf forest	*					
Mixed forest	*					
Woodland	*					
Wooded grassland	*					
Closed shrubland	*					
Open shrubland		*				
Grassland		*				
Cropland			*			
Bare ground				*		
Urban & Built-up					*	

Table 22. Accuracy testing for point-data in Central Asia (italics: wrongly classified

Nr.	Latitude	Longitude	Description	Classification
1	37.32333	59.765	Yellow grassland	*Irrigated field crops*
2	37.335	59.69833	Grassland	Open Shrubland/grassland
3	37.23	60.99167	Irrigated wheat	Irrigated field crops
4	37.405	61.52667	Open shrubs	Barren/sparsely vegetated
5	38.57667	63.17167	Karakoum Desert	Barren/sparsely vegetated
6	38.88167	63.43	Karakoum Desert	Barren/sparsely vegetated
7	39.95167	64.78667	Little vegetation	Barren/sparsely vegetated
8	42.73167	70.67333	Wheat	Rainfed field crops
9	43.21667	74.135	Fallow	*Forest*
10	43.325	75.695	Wheat	*Open Shrubland/grassland*
11	44.41167	74.94667	Little vegetation	*Open Shrubland/grassland*
12	44.47833	74.76	Bare ground	Barren/sparsely vegetated
13	44.75833	74.295	Solonchak	Barren/sparsely vegetated
14	44.76	74.295	Solonchak	Barren/sparsely vegetated
15	44.81	74.20833	Little vegetation	Barren/sparsely vegetated
16	46.41833	73.92	Little vegetation	Barren/sparsely vegetated
17	46.86333	74.90167	Little vegetation	Barren/sparsely vegetated
18	47.255	74.79667	Little vegetation	Barren/sparsely vegetated
19	47.21833	74.80833	Grassland	Open Shrubland/grassland
20	47.58333	74.44333	Little vegetation	*Open Shrubland/grassland*
21	48.12333	73.84667	Grassland	Open Shrubland/grassland
22	48.09333	73.52167	Little vegetation	*Open Shrubland/grassland*
23	50.33667	72.78333	Wheat	Rainfed field crops
24	51.39333	69.94667	Wheat	*Open Shrubland/grassland*
25	51.32333	70.455	Wheat	*Open Shrubland/grassland*
26	51.60667	62.95333	Wheat	Rainfed field crops
27	52.87667	62.945	Grassland	Rainfed field crops
28	53.83667	62.695	Cultivated ground	Rainfed field crops
29	53.76167	65.38333	Sunflower	Rainfed field crops

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ICARDA-05/500/July 2007